CMS at CERN
Higgs Boson Analysis, Part II

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Final Presentation
Higgs Analysis Goals

• Find the best way to find the Higgs
  – Making the $H \rightarrow ZZ^{(*)} \rightarrow 4\mu$ decay channel effective

• This work is to ensure that when the LHC gets real data it is understood correctly and conclusively

• Find properties of the Higgs

• Present results to the scientific community
Tracker Muons, Phase II

- New cuts on more and multiple variables
- Understanding detector geometry
  - Implement different muon sorting
  - Lee’s event reconstruction
  - Finding viable cuts from interesting variables
- Current level of improvement ~1% additional significance increase
  - Hopefully we can still improve upon this
Reconstructed events for Higgs mass = 150 GeV/c^2
2D cut plots

- $\Delta \eta$: difference in pseudorapidity between the two muons from $Z(*)$.
  - Pseudorapidity is calculated from the angle between the y and z axes
    - y is vertical
    - z is along the beam
- Transverse momentum is taken from lower-momentum muon from $Z(*)$. 
Interesting: $\Delta \eta$ vs. $\mu_4p_T$

Higgs mass = 150 GeV/c$^2$
ZZ(*) Background Alone
Effectiveness varies with mass

130 GeV/c²

150 GeV/c²

180 GeV/c²

205 GeV/c²
Detector geometry cuts

- $\Delta \eta$ vs. $\mu_4 p_T$ may be a good high-mass cut against $ZZ^{(*)}$ background
- $\Delta \phi$ between muons from a $Z$-decay
  - $\phi$ refers to the angle in the $xy$ plane
    - Perpendicular to the beam
- $\Delta \phi$ is also mass-dependent
  - High mass cut possible for $Z1$
  - Center cut possible for $Z^{(*)}$
These peaks can be cut
$\Delta \phi$ from $Z^{(*)}$: angle between 3rd and 4th muons

This peak can be cut
Tracker Muons, Phase II

• Revamping our previous strategy currently results in \(~1\%\) increase in significance

• What are our other options?
  – $2\epsilon2\mu$, a similar decay channel
  – Calorimeter muon inclusion
  – MET: Missing Transverse Energy
2e2µ Analysis

- H \rightarrow ZZ(*) \rightarrow 2e2µ decay analysis
- Expanding and adapting current framework to include 2e2µ channel
  - Has been put on hold
  - 4µ analysis has better selection efficiency
- Improve 4µ analysis before analyzing this decay
Current and Ongoing Work

- **Calorimeter muon inclusion**
  - 4 lepton workshop: adds efficiency for low $p_T$ muons
  - High $p_T$ muons may deposit extra energy here, too
- **Conquering software problems**
  - Progress is happening

These are muons detected in here
Current and Ongoing Work

- **Missing transverse energy**
  - Energy associated with missing transverse momentum, such as neutrinos

- **Should be highly discriminating for tt background**

- **May be effective on other backgrounds**

- **Possible use of this variable on other Higgs decays, such as H -> ZZ(*) -> 2\mu2\nu**

- **Progress is happening despite more software issues and coding challenges**
Future Development

- **HiggsToZZ4Leptons analysis**
  - Common to several channels, reproducible
- **FeynRules**
  - Calculates Feynman rules for physics models to simulate new physics
- **Genetic Algorithm for Rectangular Cuts Optimization**
  - Cuts “compete” based on performance power and after “generations,” the “living” are optimized cuts
  - \(~10^{50}\) permutations in a couple of hours
Thank you to

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• Images were produced by Roberto, Lee, and/or myself.
Pseudorapidity

- Difference in vertical orientation
- Calculation for $\eta$:
  $$\eta = -\ln(\tan[\theta/2])$$
Particles in the Standard Model

- Six quarks
- Six leptons
- Force carriers: photons for E&M, gluons for strong force, and W and Z bosons for weak force
- W and Z bosons are observed to have mass
The Science of the Search

• This analysis concerns the Higgs boson in the $H \rightarrow ZZ^{(*)} \rightarrow 4$ lepton decay
  – Ongoing work on the four muon channel
  – Broadening to work on the two electron, two muon channel

• The Higgs mass is unknown, thus the search goes over a range of masses from 115 to 600 GeV/$c^2$, focusing on the 115-205 range

• Actual collider data is fairly complex, so signal needs to be separated from background
  – ZZ, Zb-bbar, t-tbar backgrounds
  – These decay into leptons as well and must be cut out from the Higgs signal
Image References

• Images:
  – Standard Model, http://www2.warwick.ac.uk/fac/sci/physics/teach/module_home/px147/images/standardmodel.jpg
  – All other images produced by Roberto Casagrande, Lee Coates, and/or Amelia Uecker at Purdue University
Tracker Muon Inclusion

- Started with a basic set of cut variables and cut values
- Applied to global muons
- Implemented the inclusion of additional tracker muon events
  - These are events with data from only the tracker portion of the detector
- Some early optimization of cuts