# CMS at CERN
# Higgs Boson Analysis, Part II

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July 30, 2009

Final Presentation

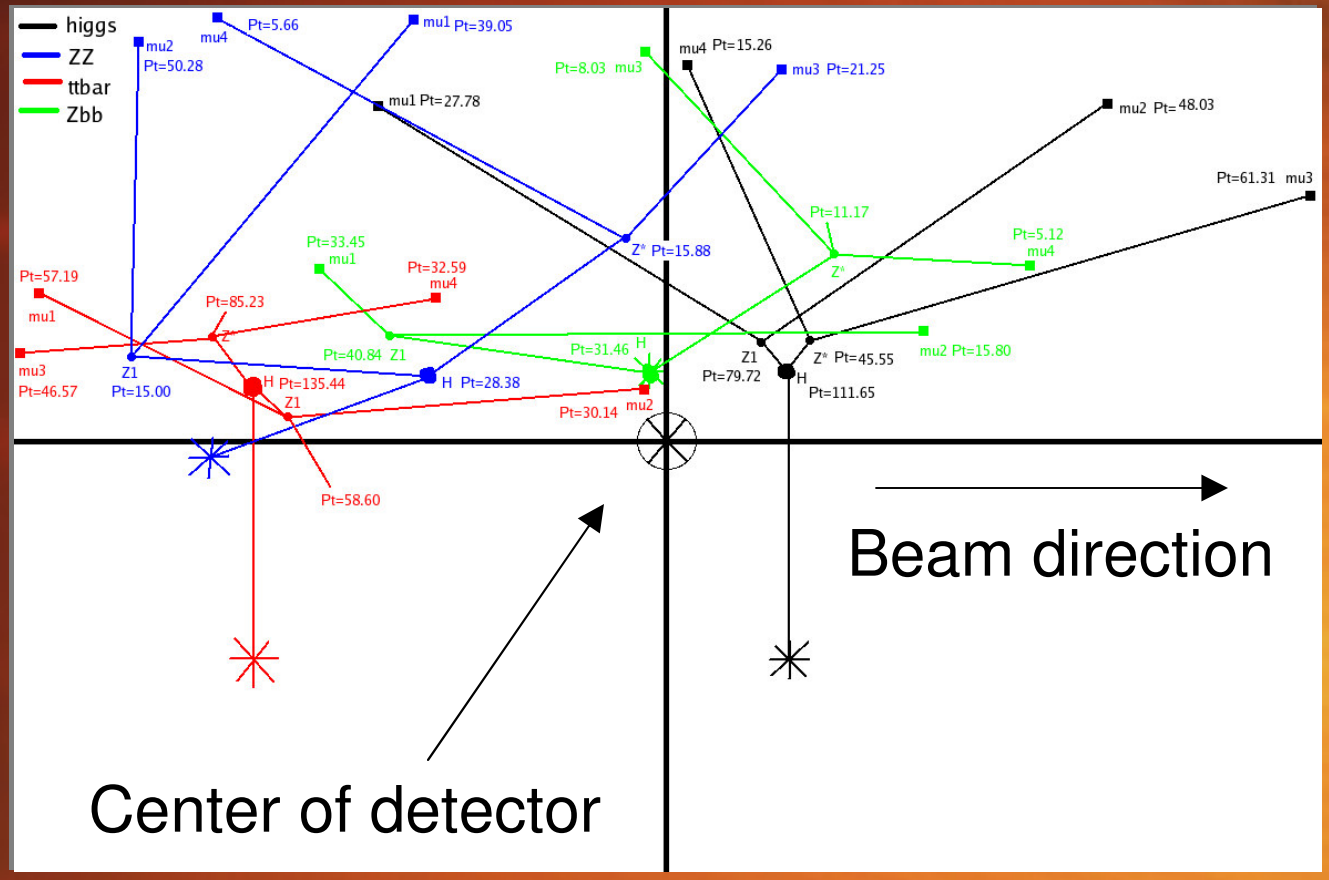
# Higgs Analysis Goals

- 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

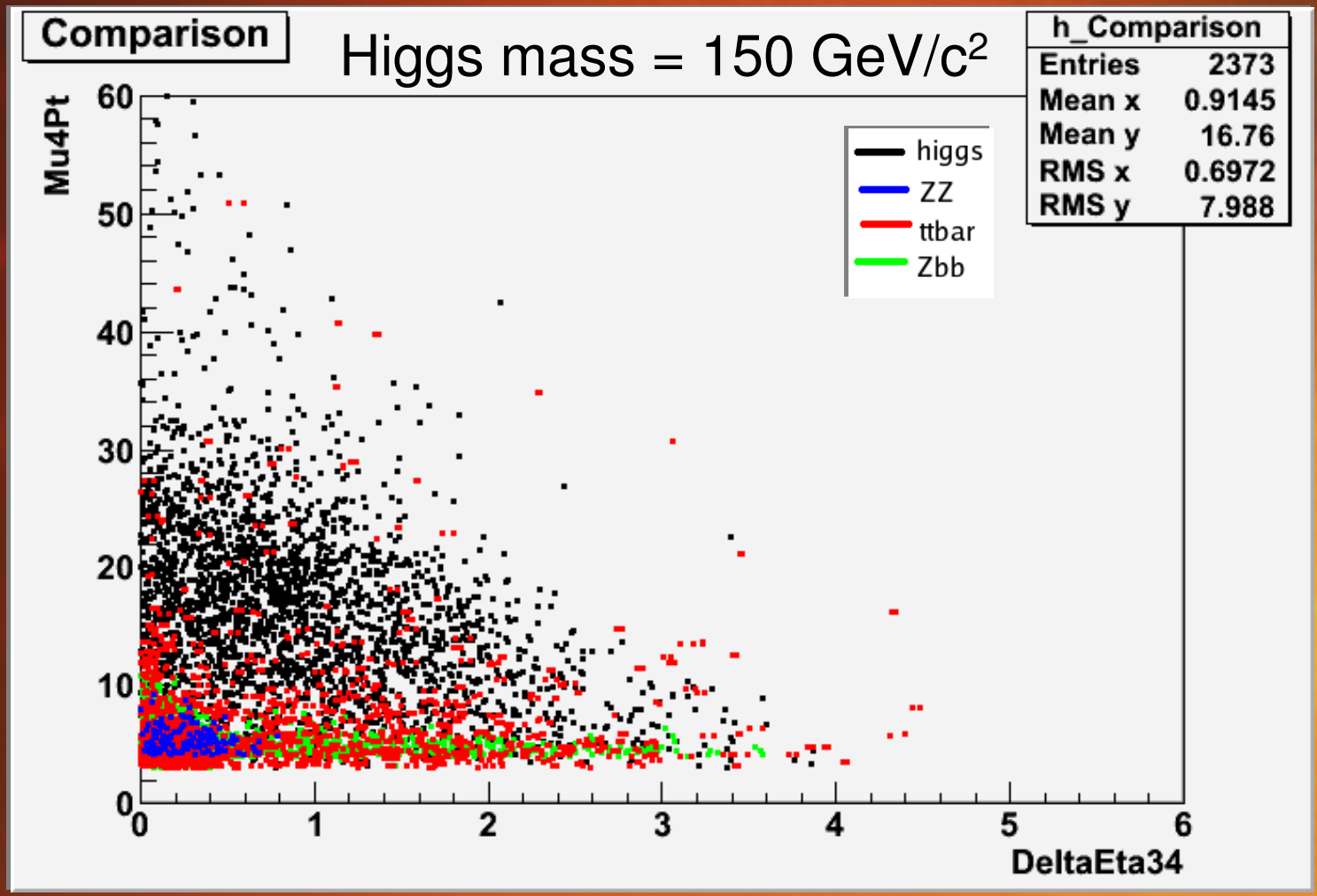
# Reconstructed events for Higgs mass = 150 GeV/$c^2$



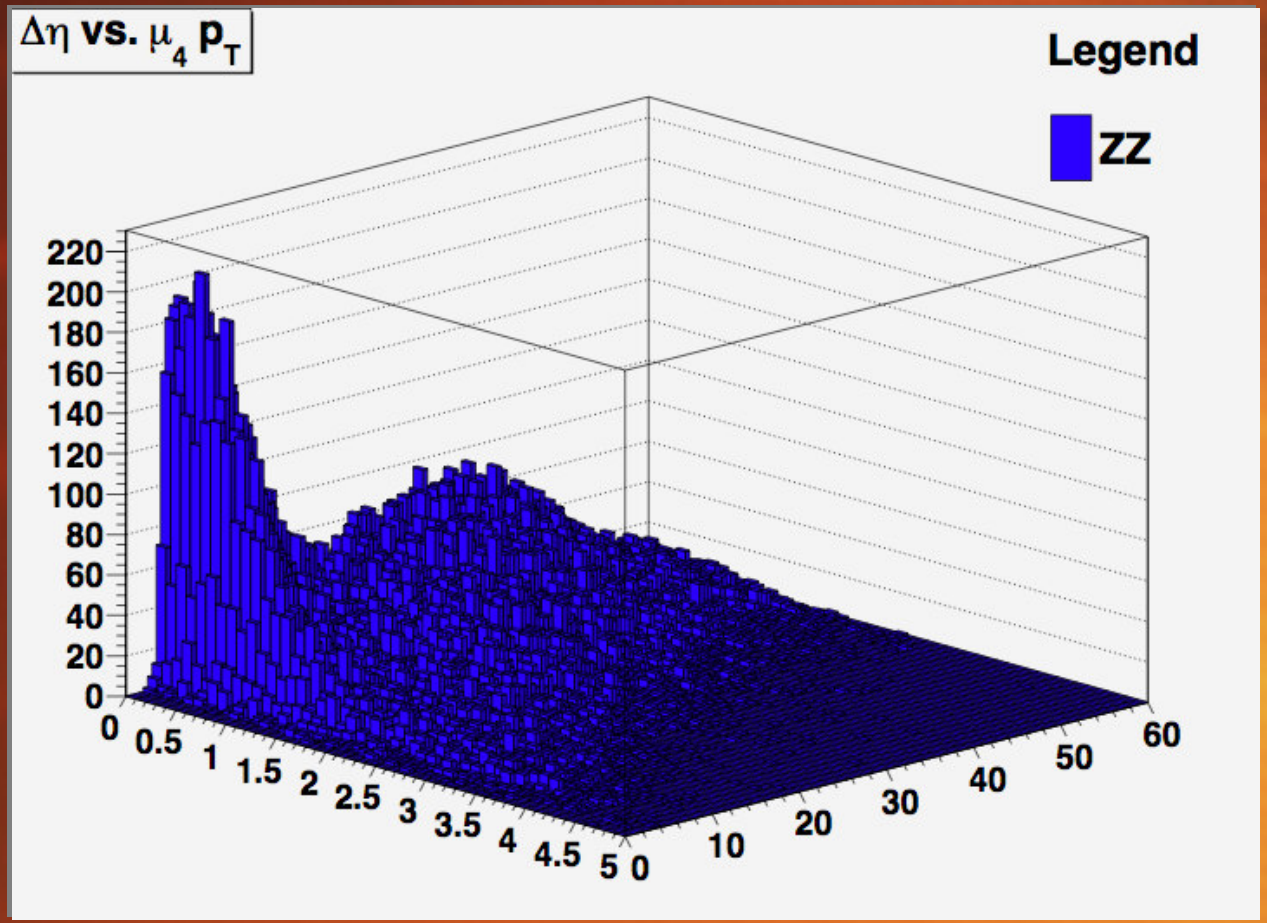
# 2D cut plots

- $\Delta\eta$: 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. $\mu_4 p_T$

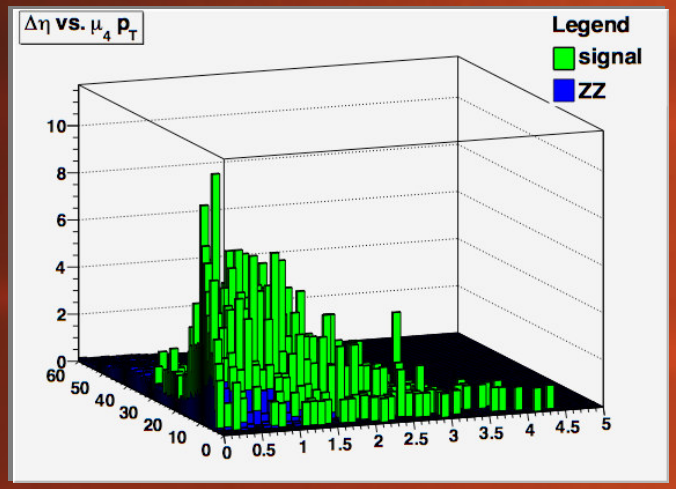


# $ZZ^{(*)}$ Background Alone

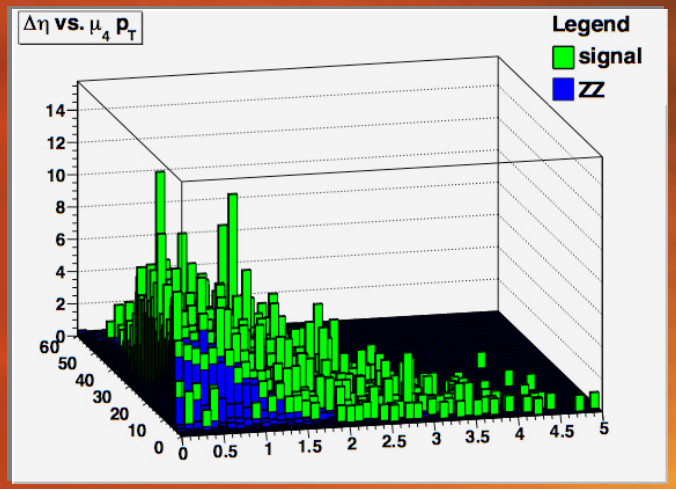


# Effectiveness varies with mass

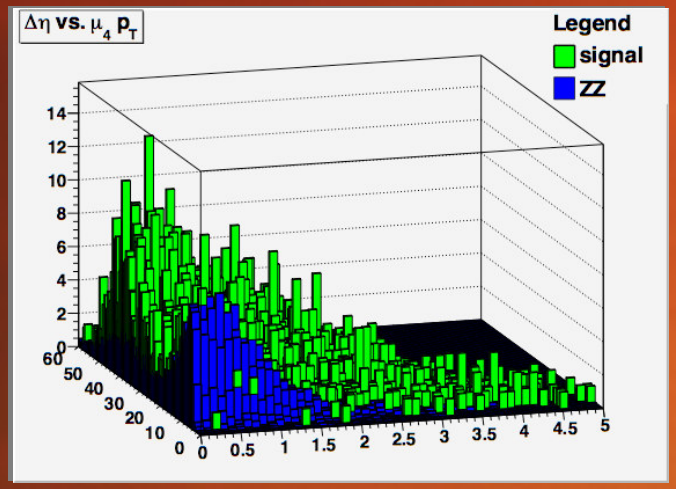
130 GeV/$c^2$



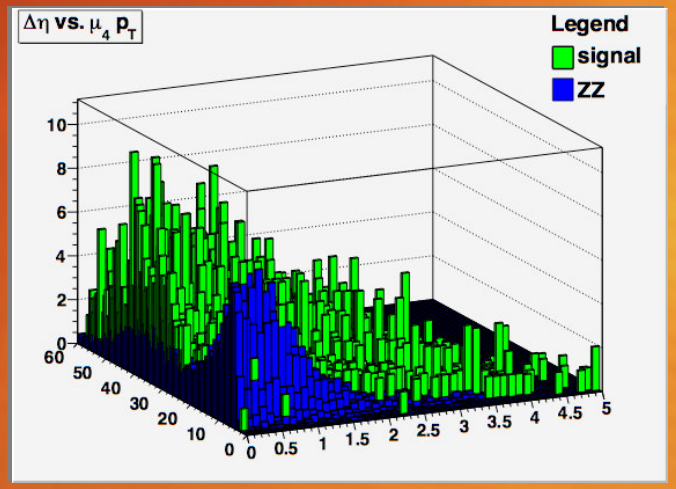

150 GeV/$c^2$




180 GeV/$c^2$




205 GeV/$c^2$

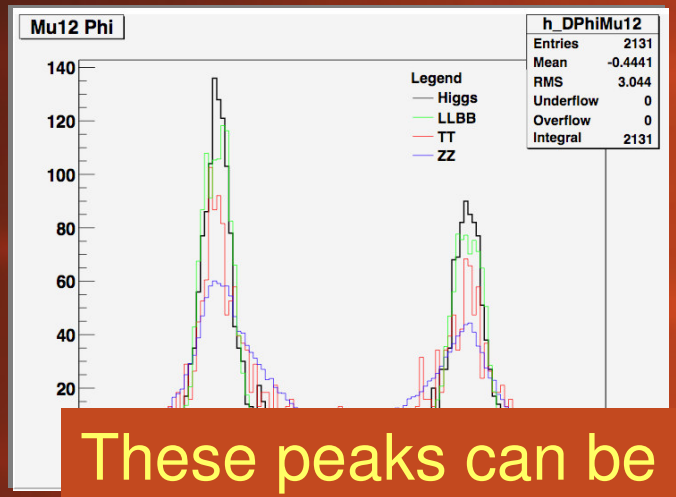


# Detector geometry cuts

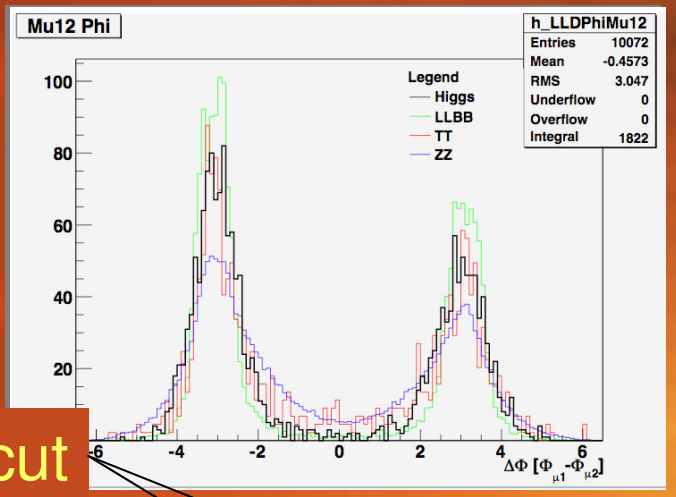
- $\Delta\eta$ vs. $\mu_4 p_T$ may be a good high-mass cut against $ZZ^{(*)}$ background
- $\Delta\phi$ between muons from a Z-decay
  - $\phi$ refers to the angle in the xy plane
    - Perpendicular to the beam
- $\Delta\phi$ is also mass-dependent
  - High mass cut possible for Z1
  - Center cut possible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

# Δϕ from Z1: angle between 1st and 2nd muon paths

115 GeV/c²

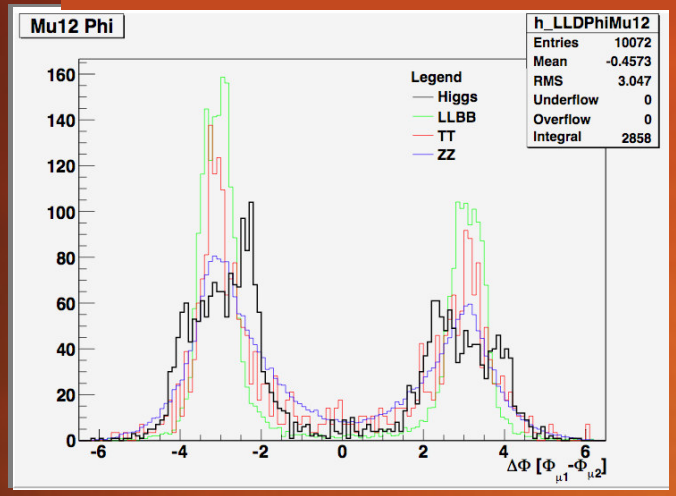



175 GeV/c²

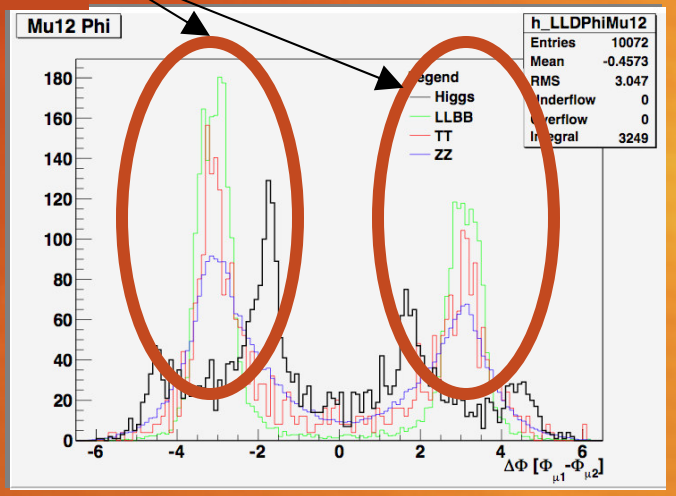



These peaks can be cut

205 GeV/c²

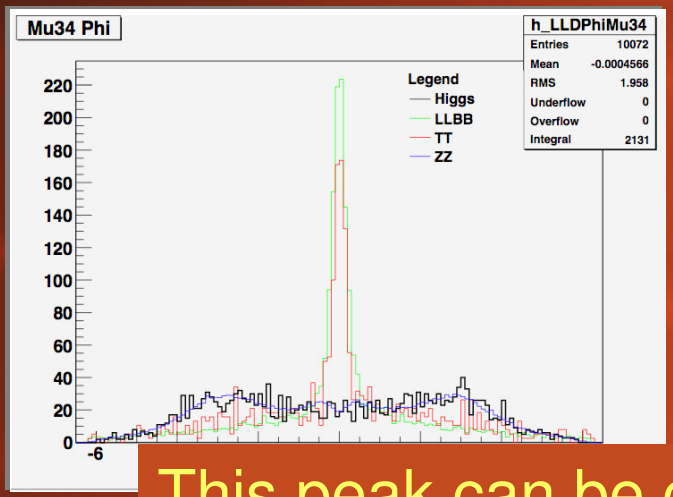



250 GeV/c²

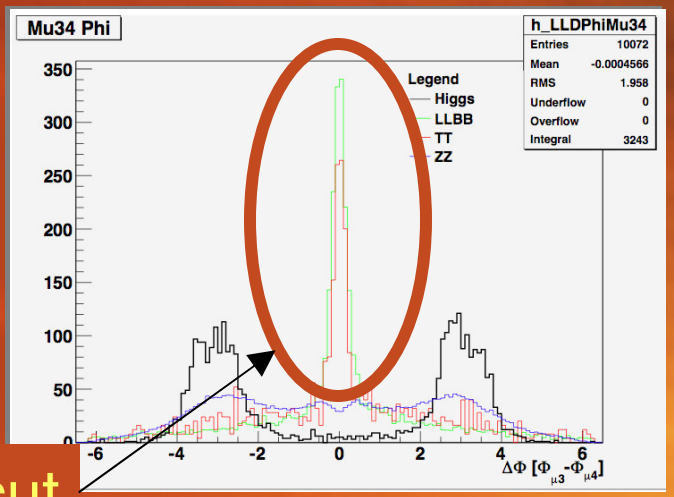


# Δϕ from Z(*): angle between 3rd and 4th muons

115 GeV/c²

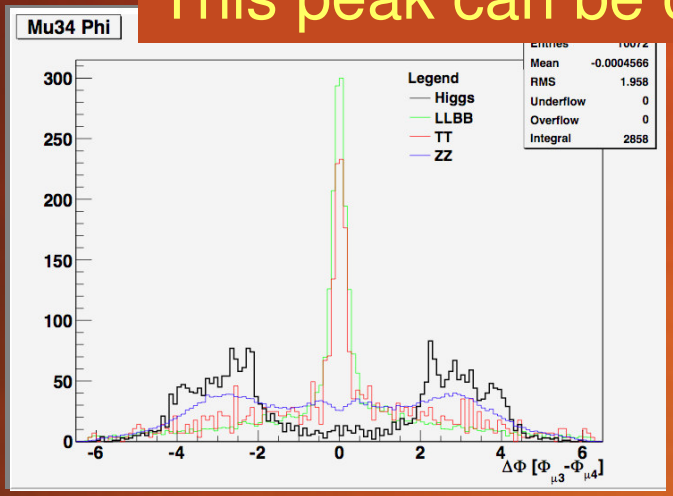



190 GeV/c²

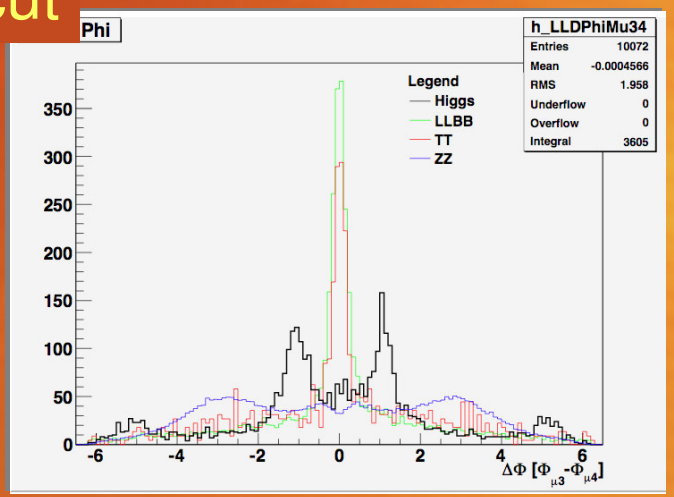



This peak can be cut

205 GeV/c²




350 GeV/c²



# Tracker Muons, Phase II

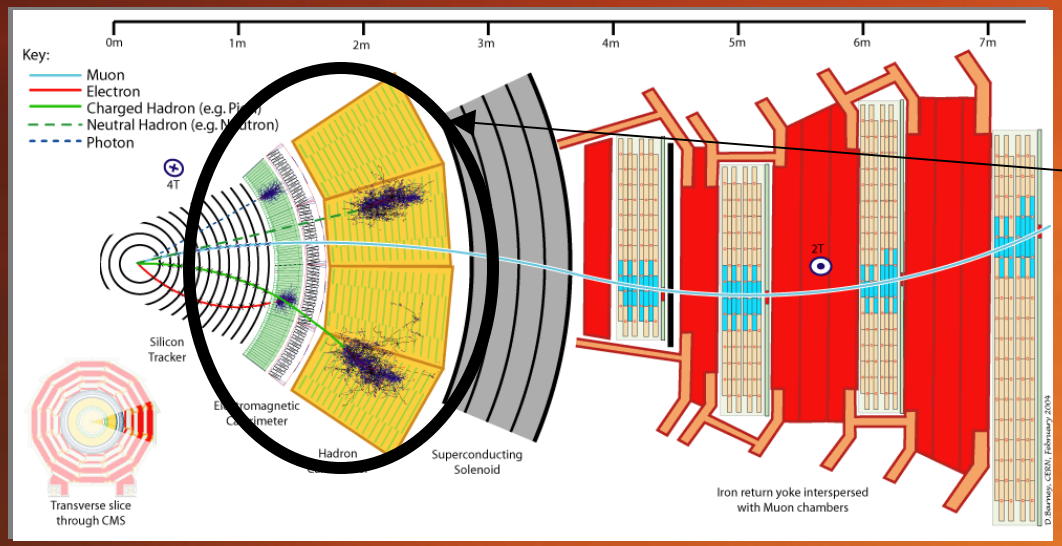
- Revamping our previous strategy currently results in ~1% increase in significance
- What are our other options?
  - 2e2μ, a similar decay channel
  - Calorimeter muon inclusion
  - MET: Missing Transverse Energy

# 2e2μ Analysis

- H -> $ZZ^{(*)}$ -> 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(*) -> 2μ2ν
- Progress is happening despite more software issues and coding challenges

# Future Development

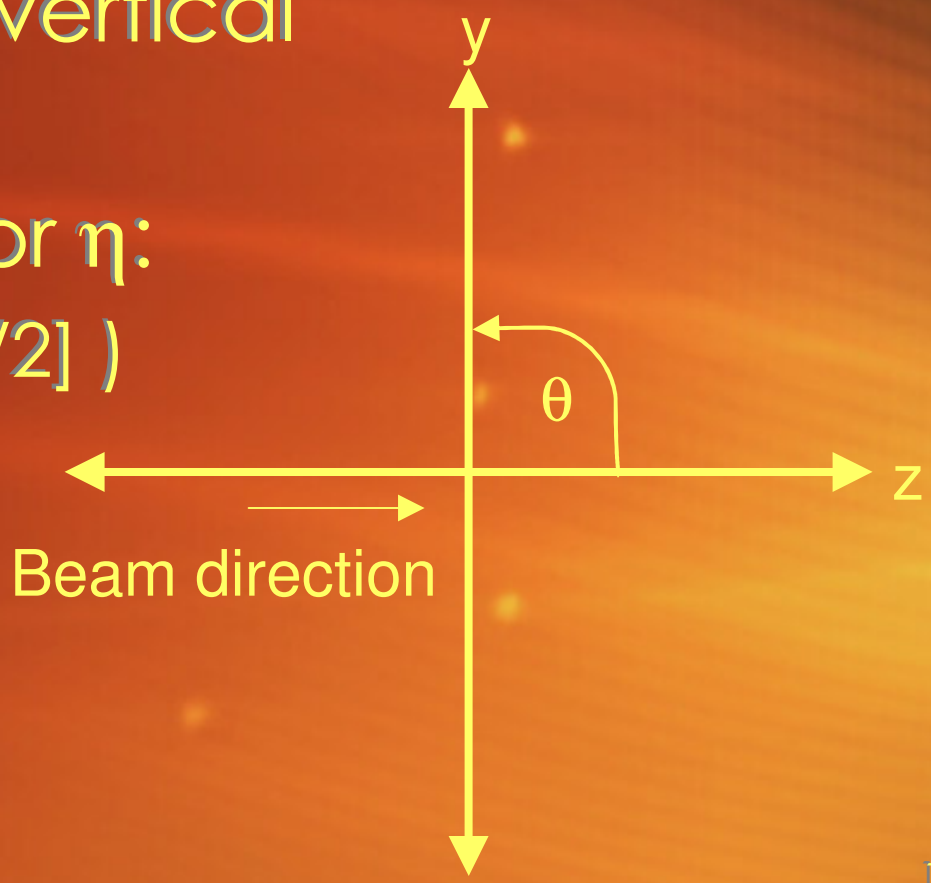
- HiggsToZZ4Leptons analysis
  - Common to several channels, reproducible
- FeynRules
  - Calculates Feynman rules for physics models to simulate new physics
- Genetic Algorithm for Rectangular Cuts OptimizatioN
  - Cuts "compete" based on performance power and after "generations," the "living" are optimized cuts
  - ~$10^{50}$ permutations in a couple of hours

# Thank you to

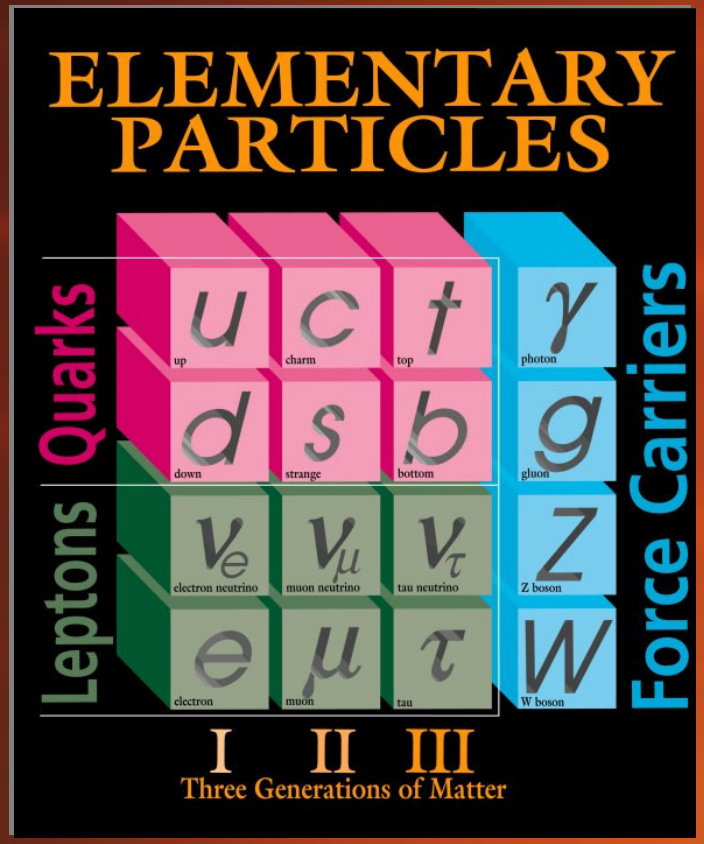
- Everybody I work with:
- Dr. Daniela Bortoletto, Roberto Casagrande, and Lee Coates, plus Petra Merkel and Jakob Zablocki from CERN
- Images were produced by Roberto, Lee, and/or myself.

# 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 -> $ZZ^{(*)}$ -> 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