Higgs Search In $ZH \rightarrow llbb$ at CDF

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on behalf of the CDF Collaboration

Fermilab -- New Perspectives
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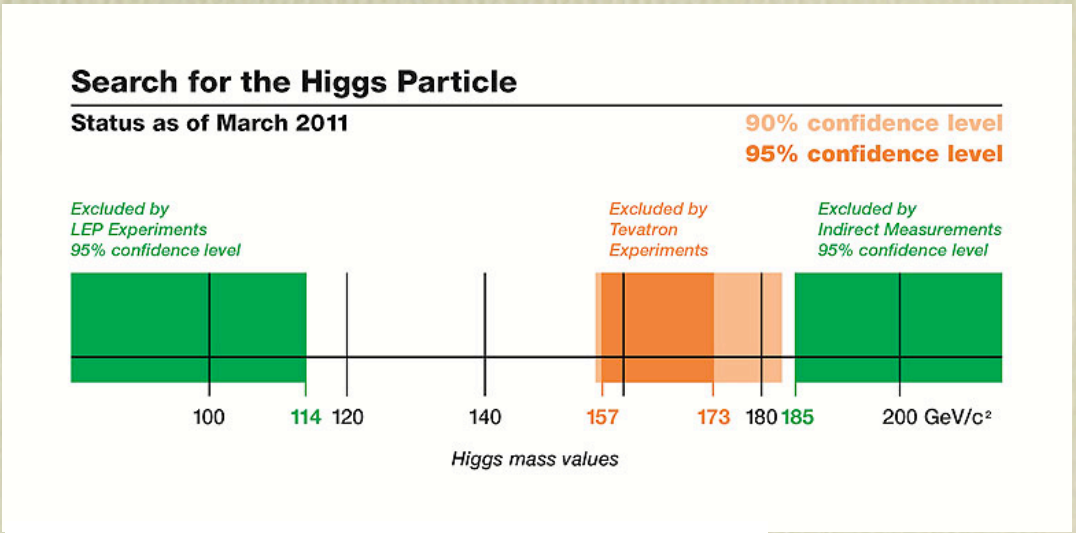
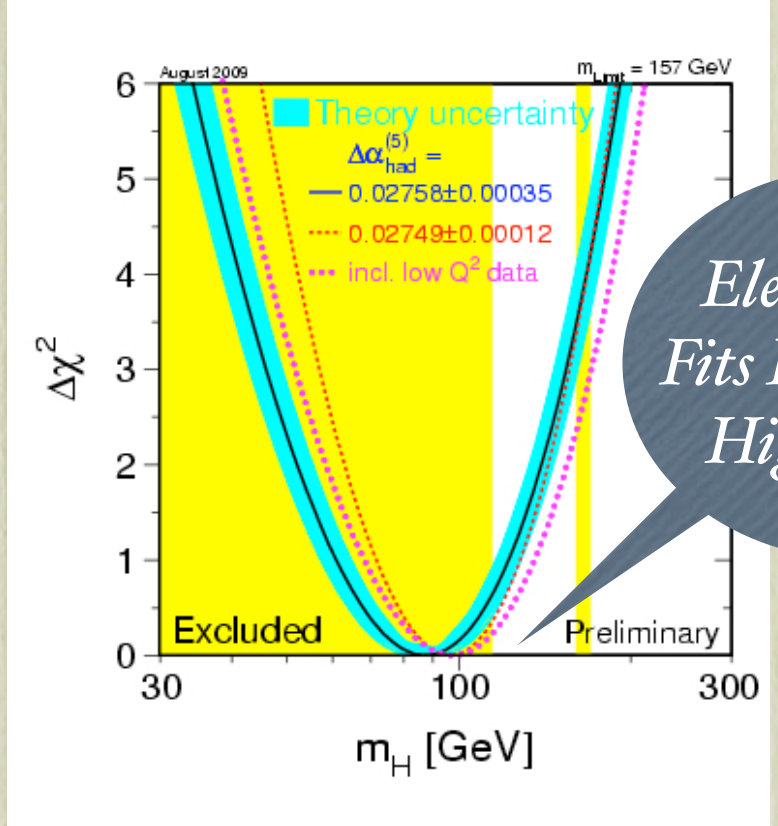
Introduction

- Higgs boson is the last remaining undiscovered particle in the Standard Model
  - Postulated by Peter Higgs, 1964, to provide an explanation for particle masses

- Several experiments have placed limits on the Higgs mass
  - LEP excludes **$M_H < 114.4$ GeV/c²** at 95% C.L.
  - Tevatron excludes **$157 < M_H < 173$ GeV/c²** at 95% C.L.

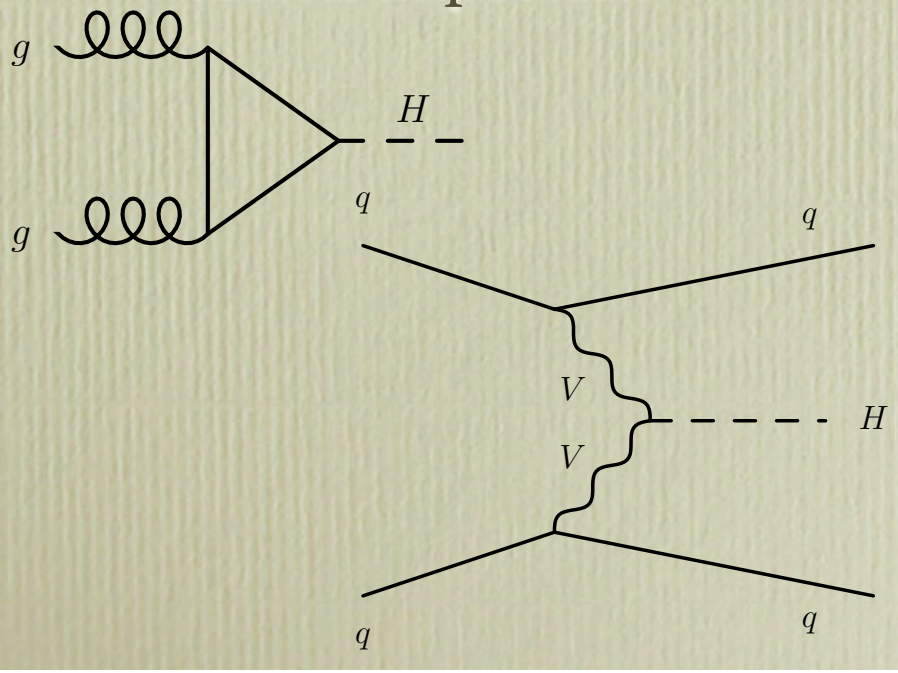


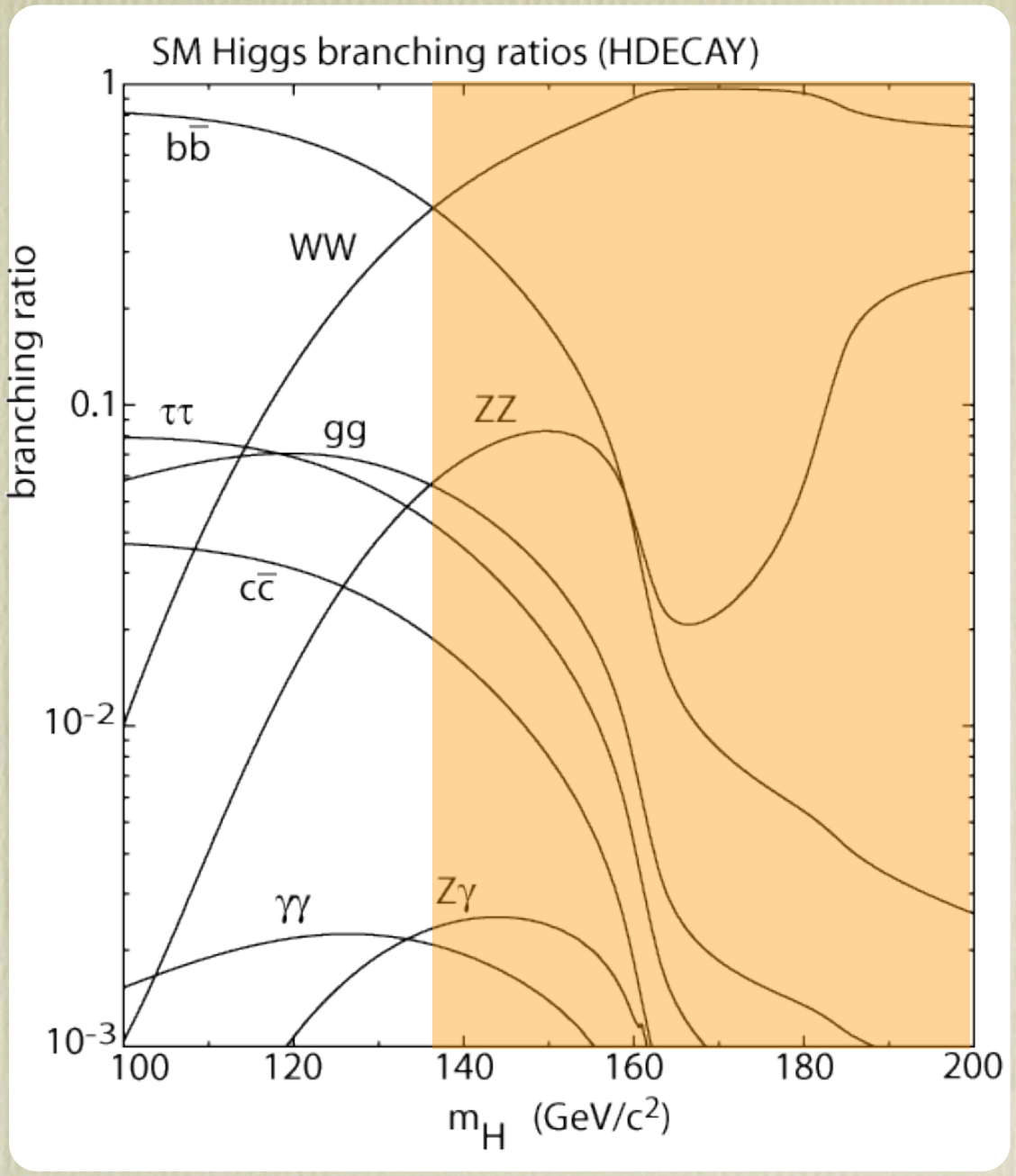


Higgs Properties

- Higgs analyses divided into two general regimes

- **HIGH MASS**
  - M_H > ~135 GeV/c²
  - Main channels use $H \to WW$, $H \to ZZ$ decays
  - Gluon fusion, vector boson fusion important

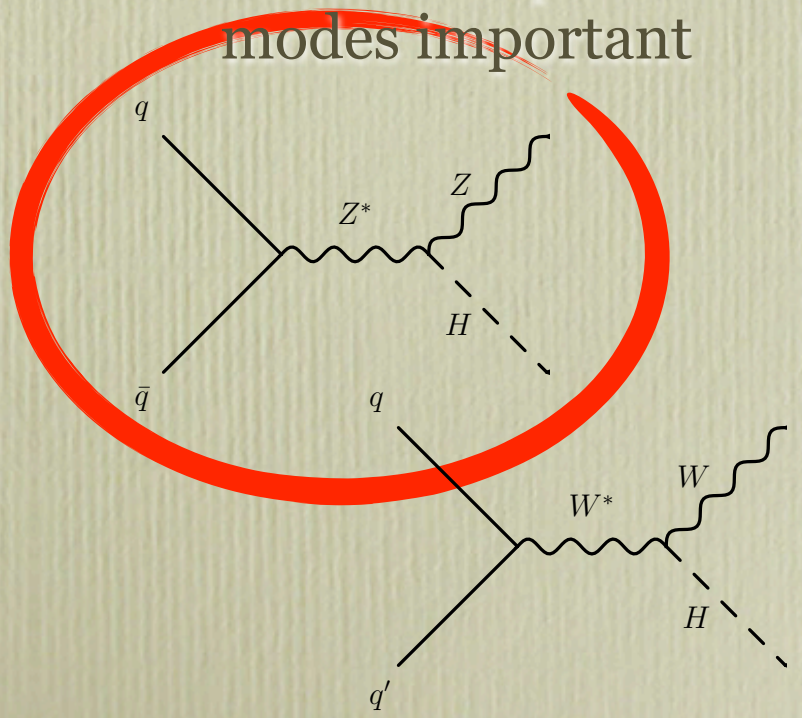


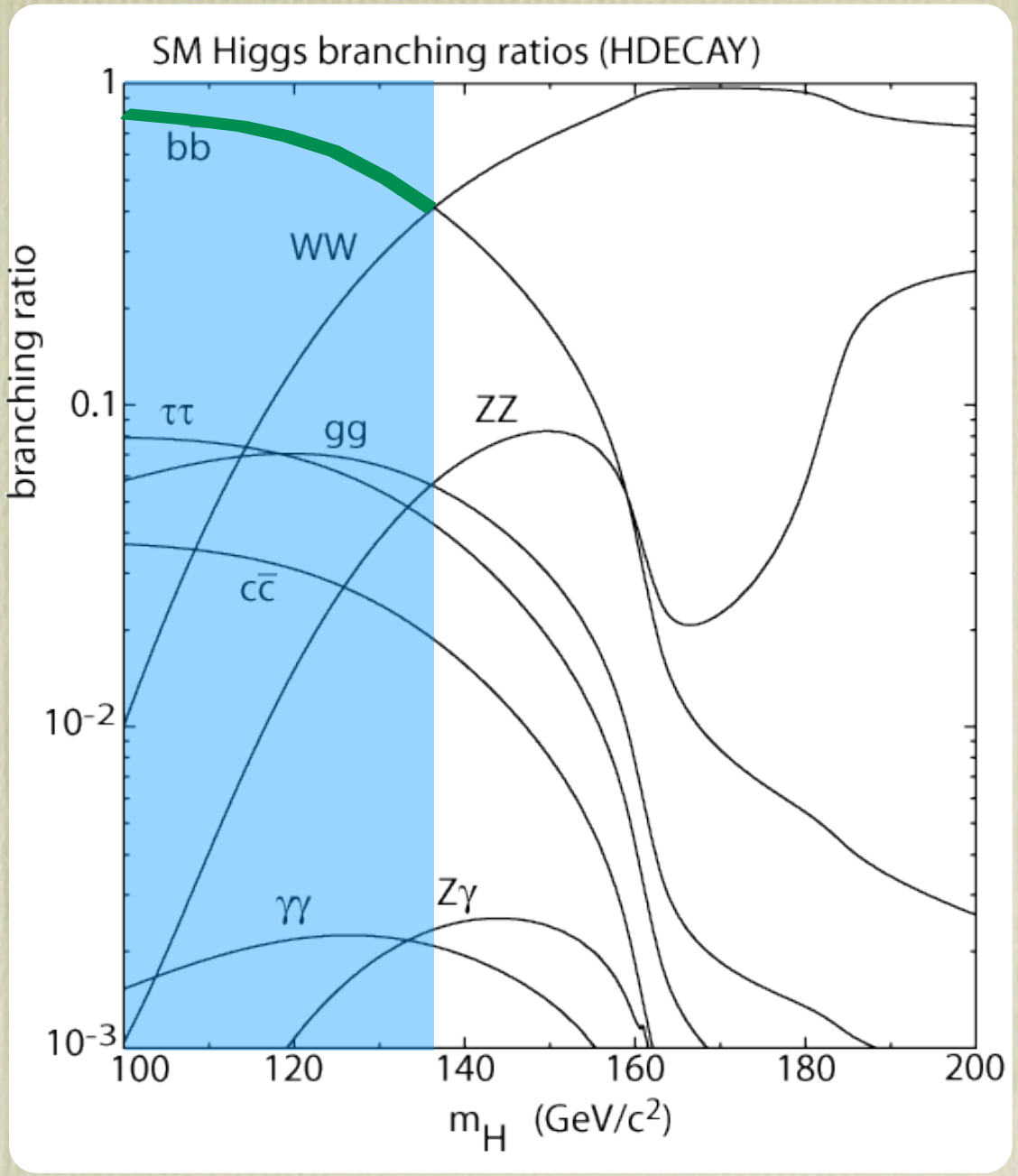


Higgs Properties

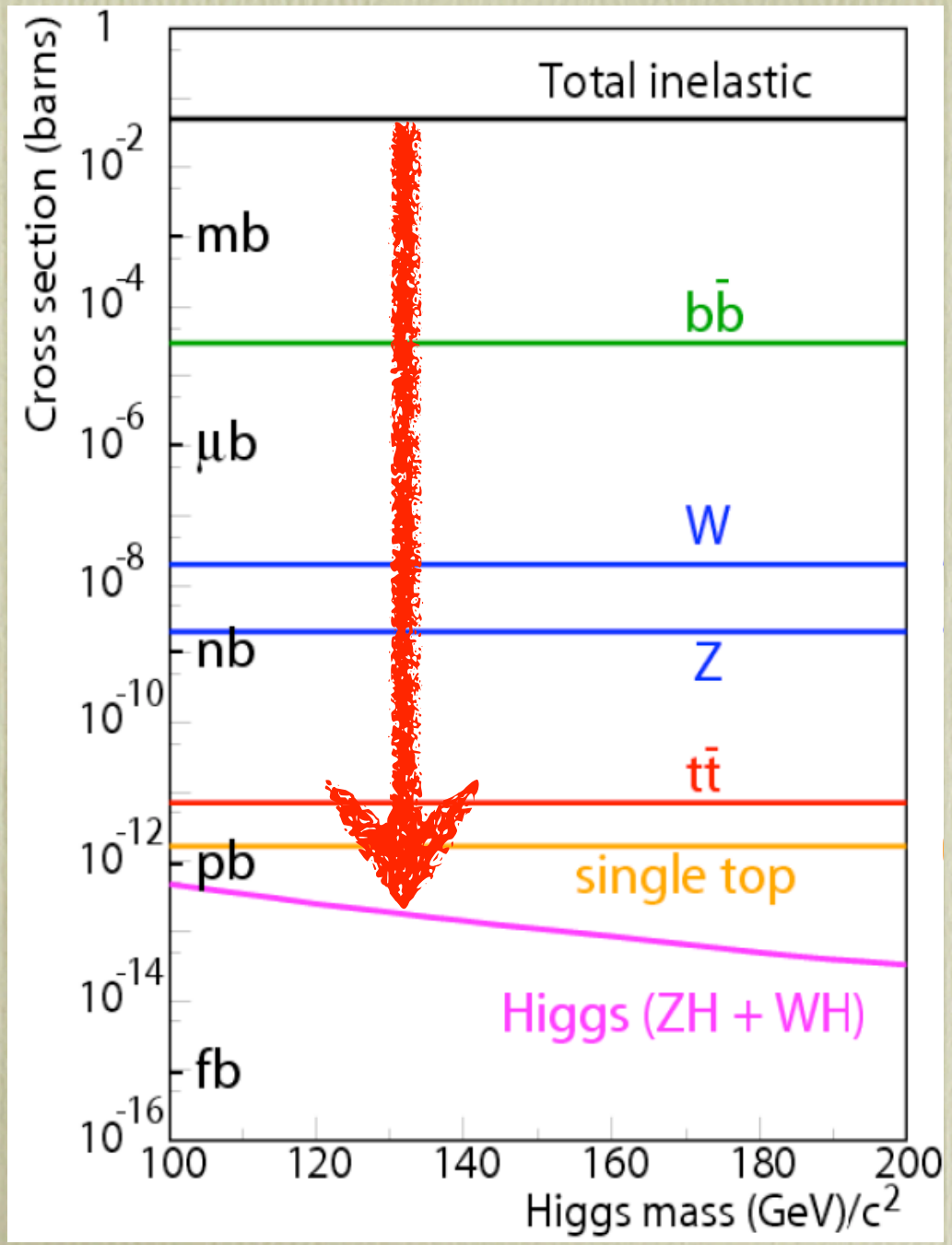
- Higgs analyses divided into two general regimes

- **LOW MASS**
  - M_H < ~135 GeV/c²
  - Main channels use $H \rightarrow bb$ decay
  - Associated production modes important





Cross Section Comparison



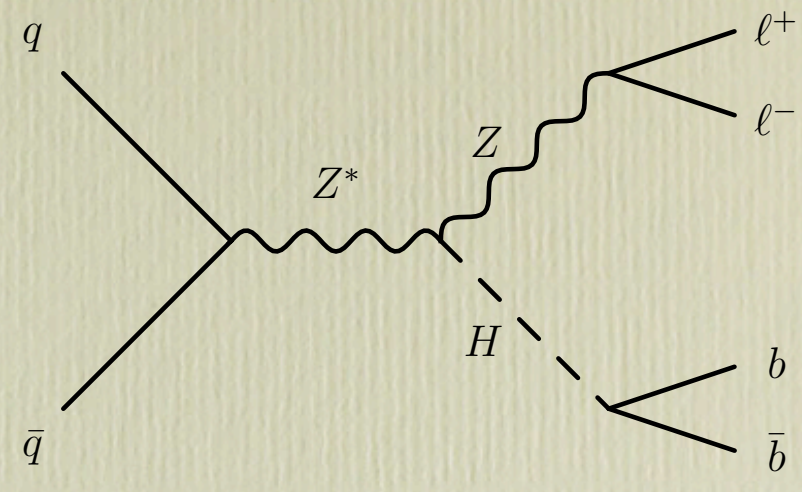
- Higgs production cross section is ~10 - 100 fb over the mass range of interest
- Swamped by Standard Model backgrounds
  - *bb* production 10^8 x Higgs
  - *W, Z* production 10^5 x Higgs
- Challenge to discriminate the small number of expected Higgs events
- Before doing anything, S:B is ~ $1:10^{12}$!

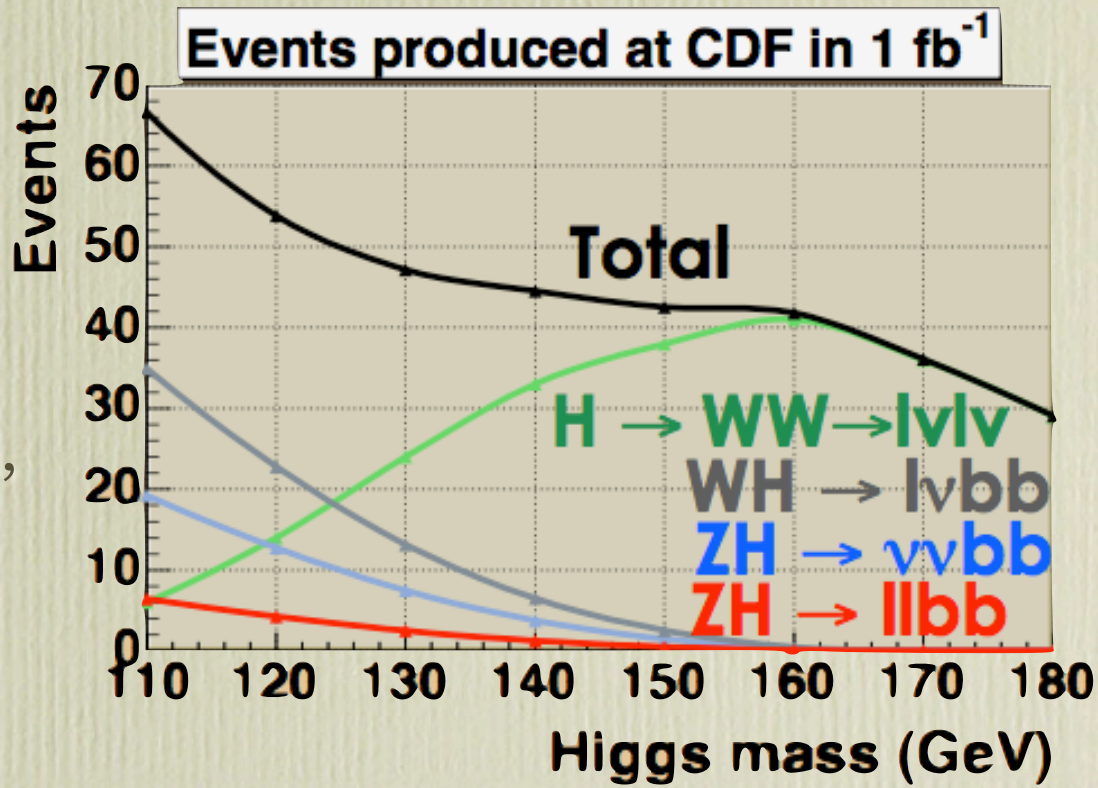
The $ZH \rightarrow llbb$ Channel

- Search for two oppositely-charged leptons (e or μ) that reconstruct to a Z boson ($76 < M_Z < 106$ GeV/c²)

- Require 2 or more jets
  - Jet 1 $E_T > 25$ GeV
  - Jet 2+ $E_T > 15$ GeV

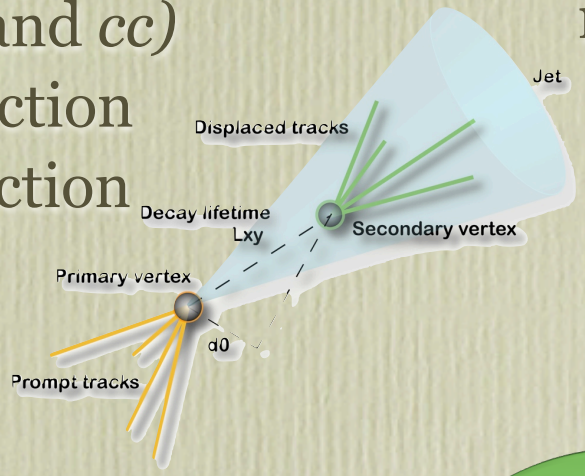
- This channel has the lowest number of produced events of all associated prod. channels
  - Benefits from a clean signal, reducing backgrounds significantly
  - All final state particles are detected and reconstructed



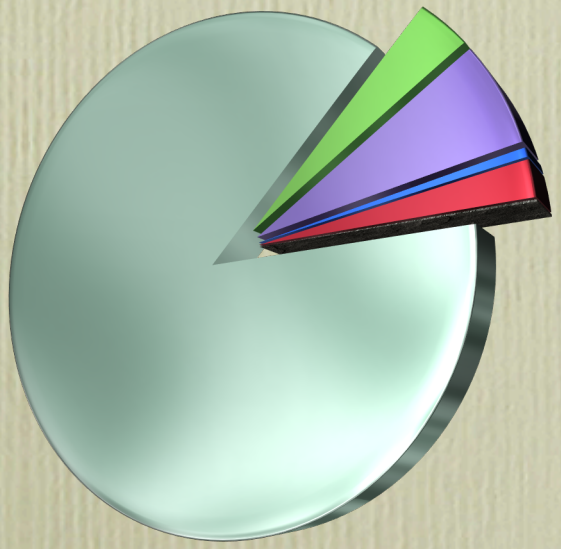


The $ZH \rightarrow llbb$ Channel

- The main background processes which contribute are:
  - Z+jets (qq, bb and cc)
  - Top pair production
  - Diboson production

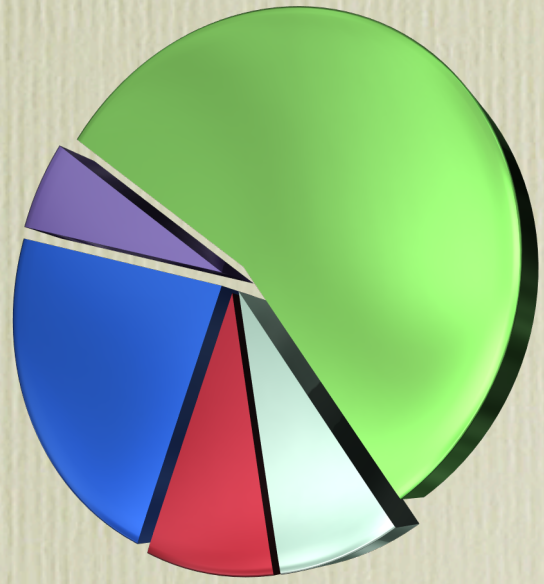


- To improve the signal purity, and to reject background, we require the jets to be '*b*-tagged'
  - Separate events into categories with 1 tagged jet and 2 tagged jets



Before *b*-tagging

Z*+*bb
Z*+*cc
Top
Diboson
Z*+*LF

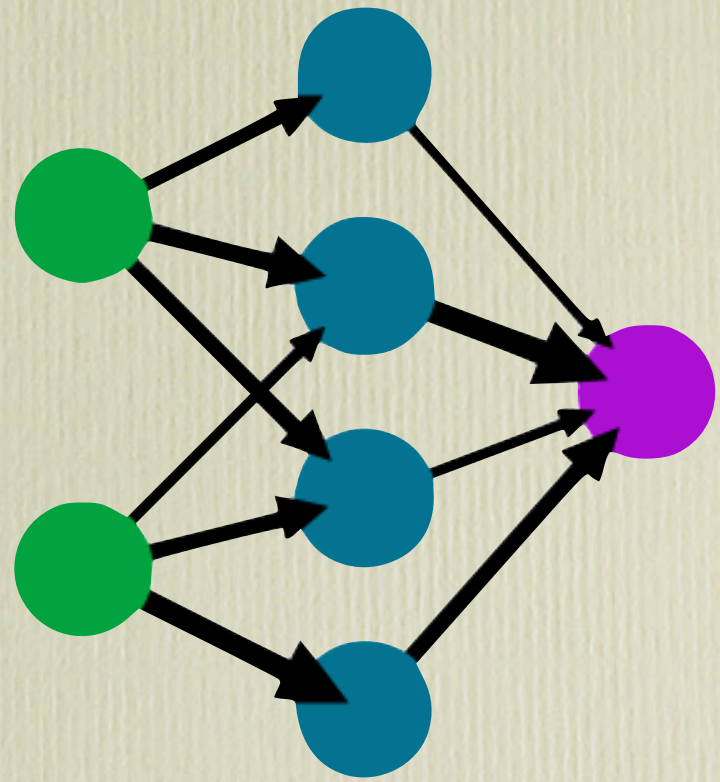


After *b*-tagging

TAGS	*S* : *B*
0	$3 : 10^4$
1	1 : 500
2	1 : 50

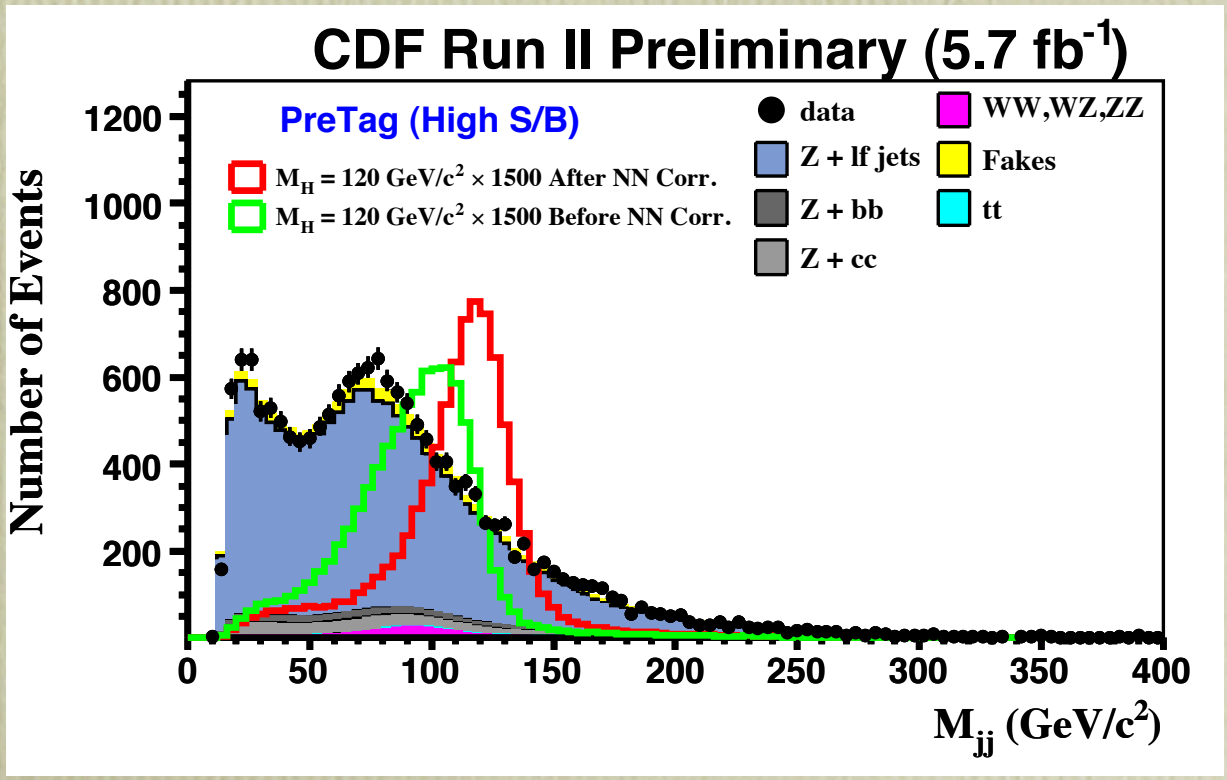
Analysis Techniques

- We can do even better than a *S:B* of 1 : 50 !
- The *ZH→llbb* channel uses many advanced analysis techniques to further improve the signal discrimination, as well as signal acceptance in general
- These methods are based on multivariate approaches
  - Artificial Neural Networks
- Three specific examples:
  - Jet energy corrections
  - Multivariate lepton ID
  - Expert discriminants



Improving Sensitivity

- Multivariate techniques can be used to improve the dijet mass resolution
  - This is one of the most sensitive variables to Higgs discrimination
- Since we expect missing transverse energy only from jet mis-measurement, we can use this to correct the jet energies
  - Projections on individual jets

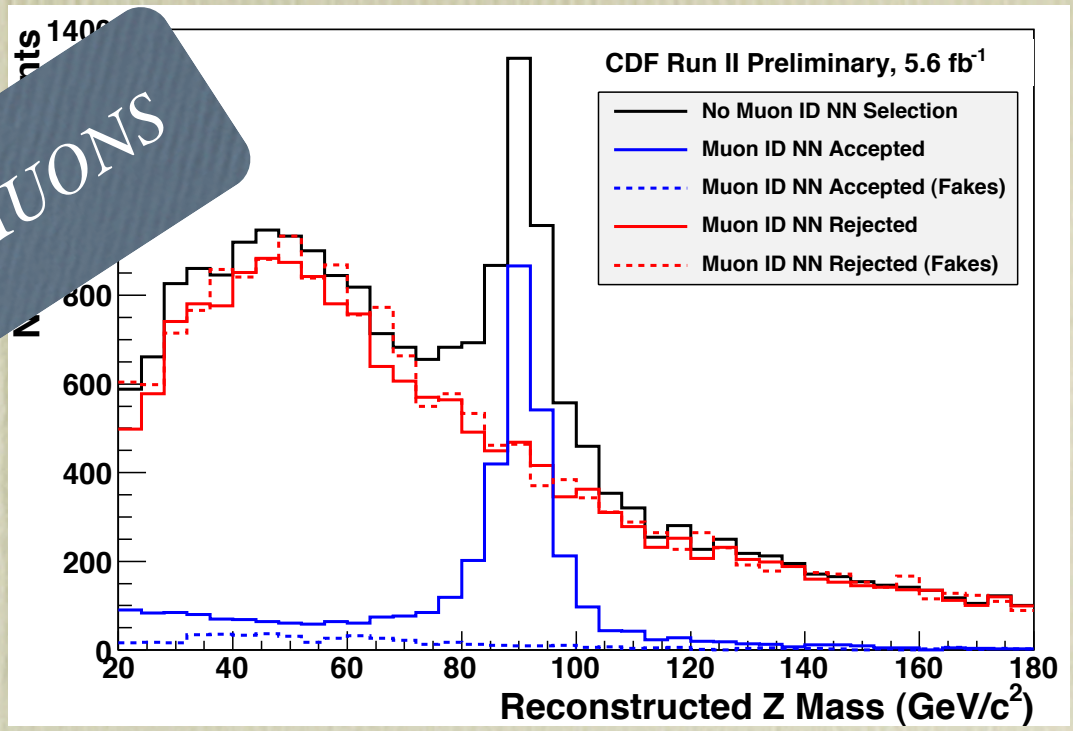


M_H (GeV/c^2)	*Dijet Mass Resolution*	
	No Correction	*With Correction*
110	17.2%	10.8%
120	17.7	10.5
150	16.8	9.5

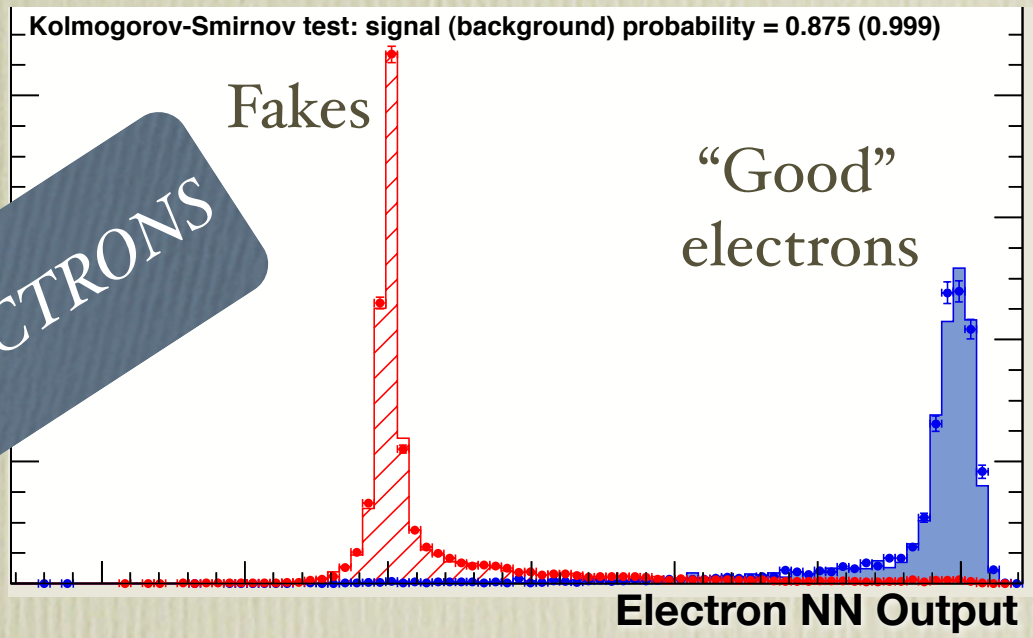
Increasing Acceptance

- Analyses have used multivariate lepton identification
- Allows for loosening of lepton cuts, if the network is trained well enough to distinguish "good" leptons from fakes
- Multivariate electron and muon ID has resulted in significant gains in the *ZH* channel
  - Over 20% more *Z* candidates
  - No significant increase in fake rates

MUONS

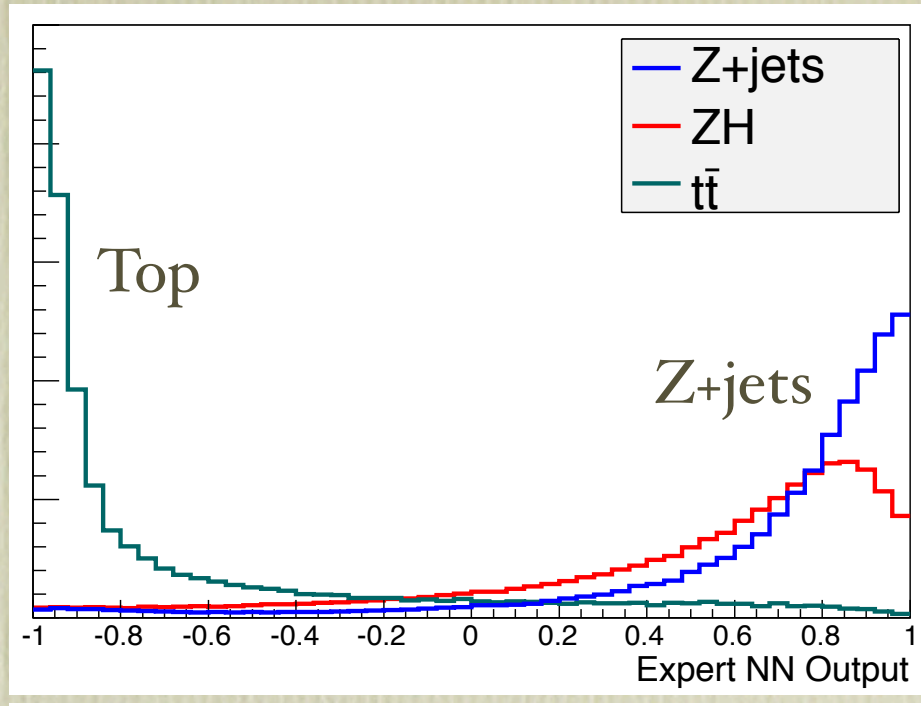


ELECTRONS

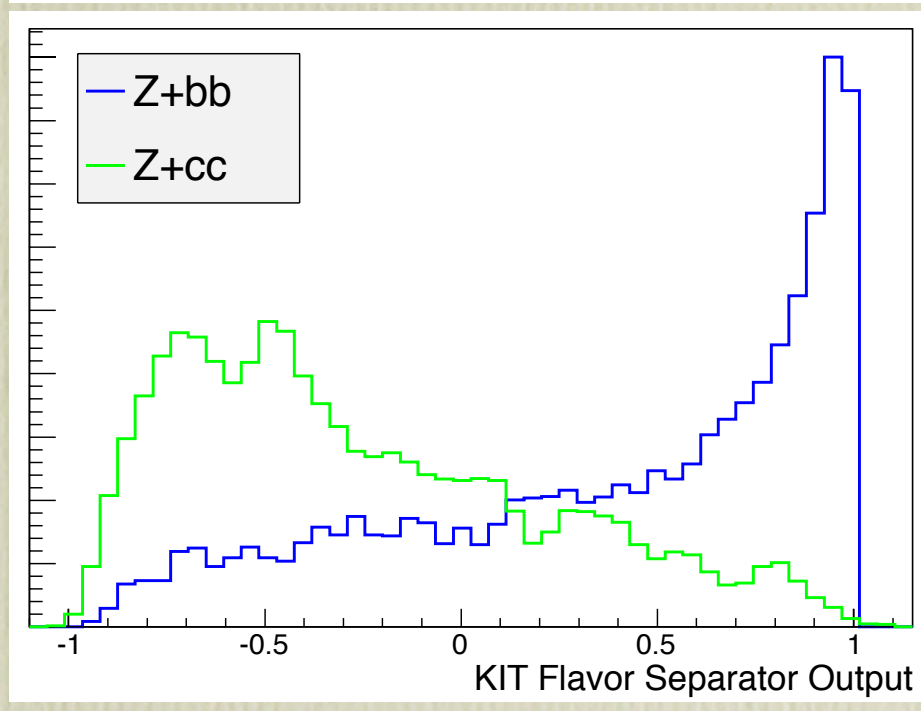


Discriminating Signal

- We use ‘expert’ discriminants to further isolate the signal-like events away from the background events
  - NNs trained to separate one process from another
  - Flavor separators (*b* vs. *c*)

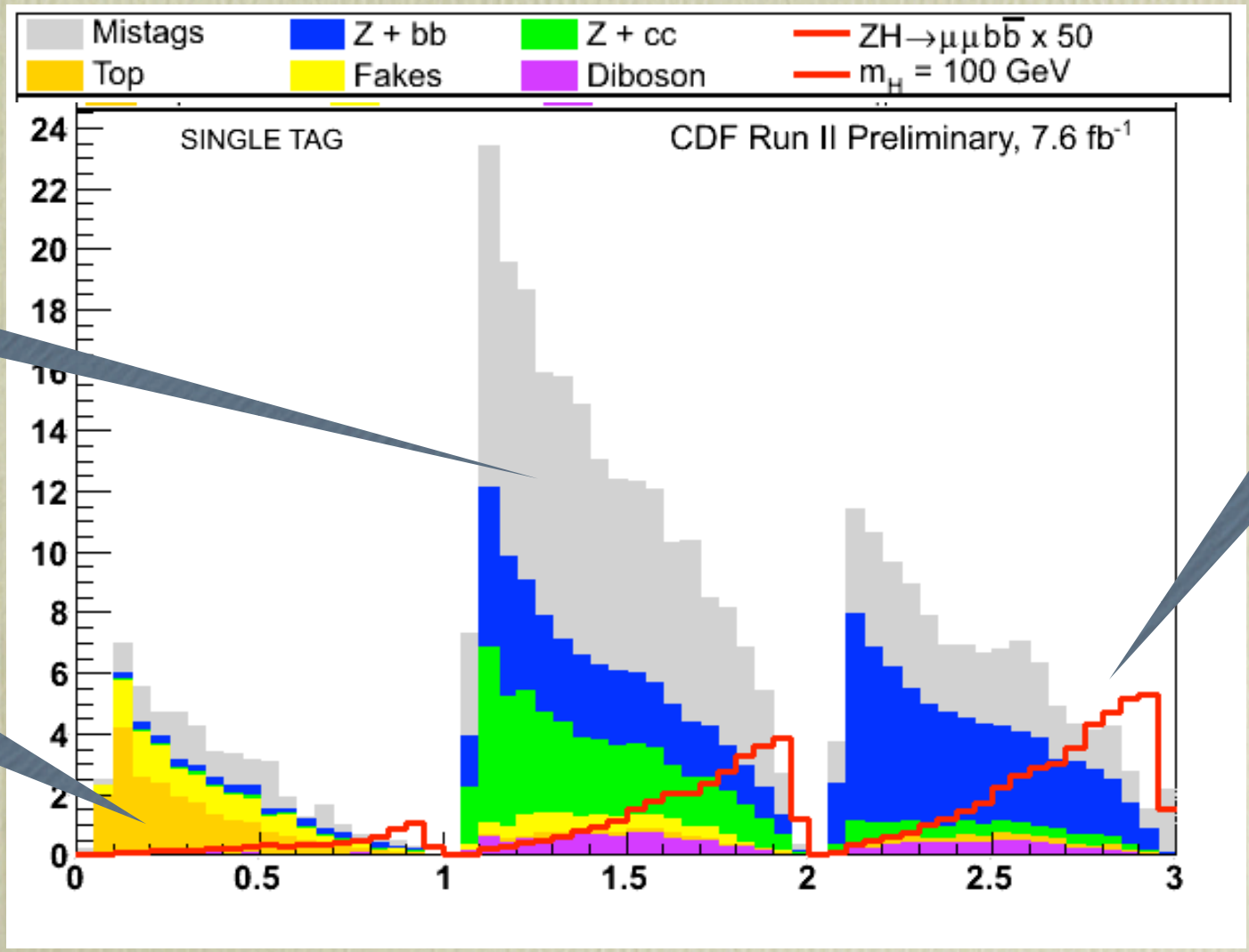


- Using a multi-step process, we can isolate a region with significantly higher S : B than just the double *b*-tag category alone



Final Event Discriminants

- Putting all the pieces together, we obtain a final discriminating distribution used to set limits
- Best output bins can have $S : B$ of 1 : 10 or better!



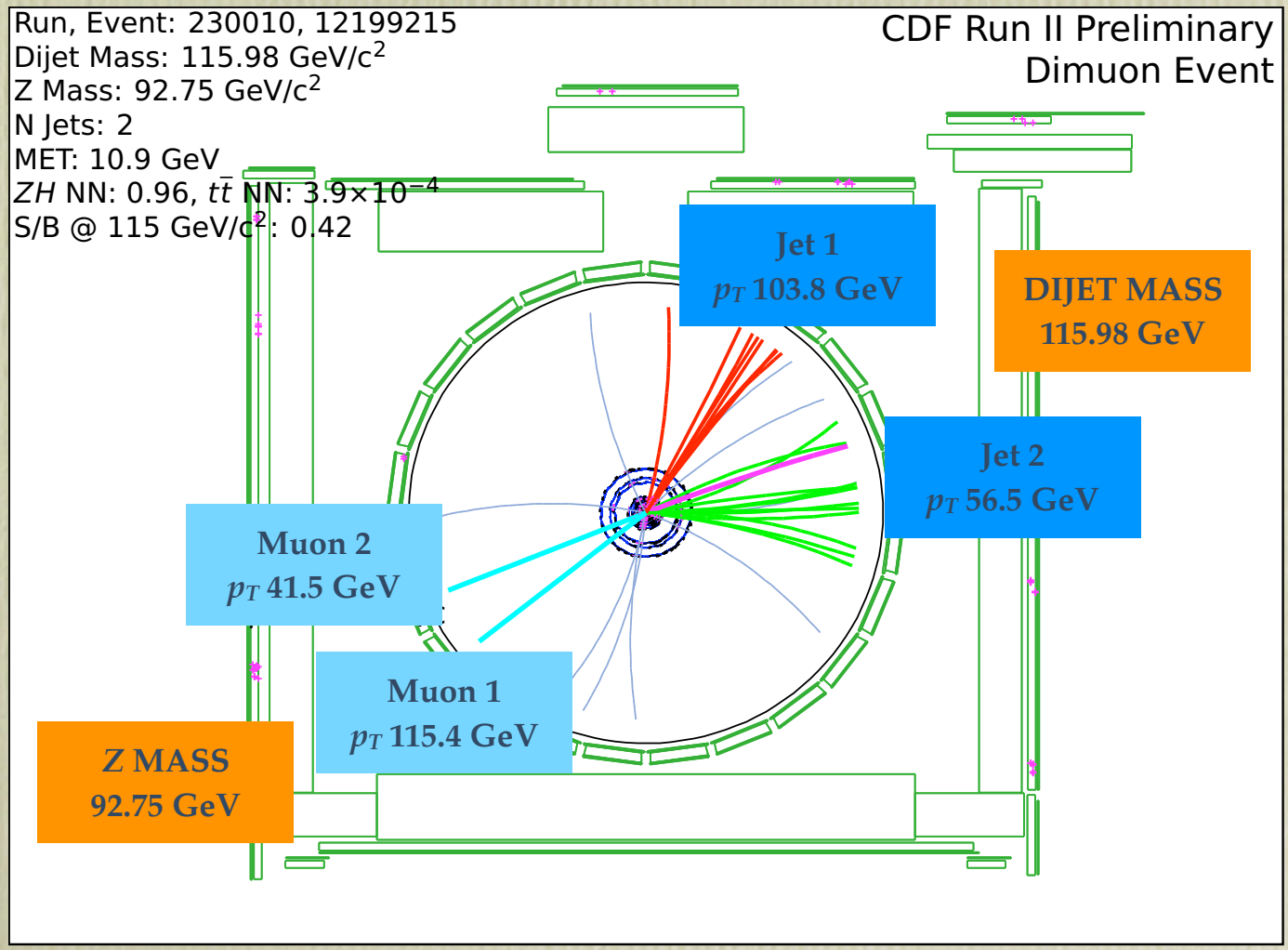
Events with light flavor jets isolated here

t-tbar region to constrain systematics

Most signal-like events end up in this most sensitive region

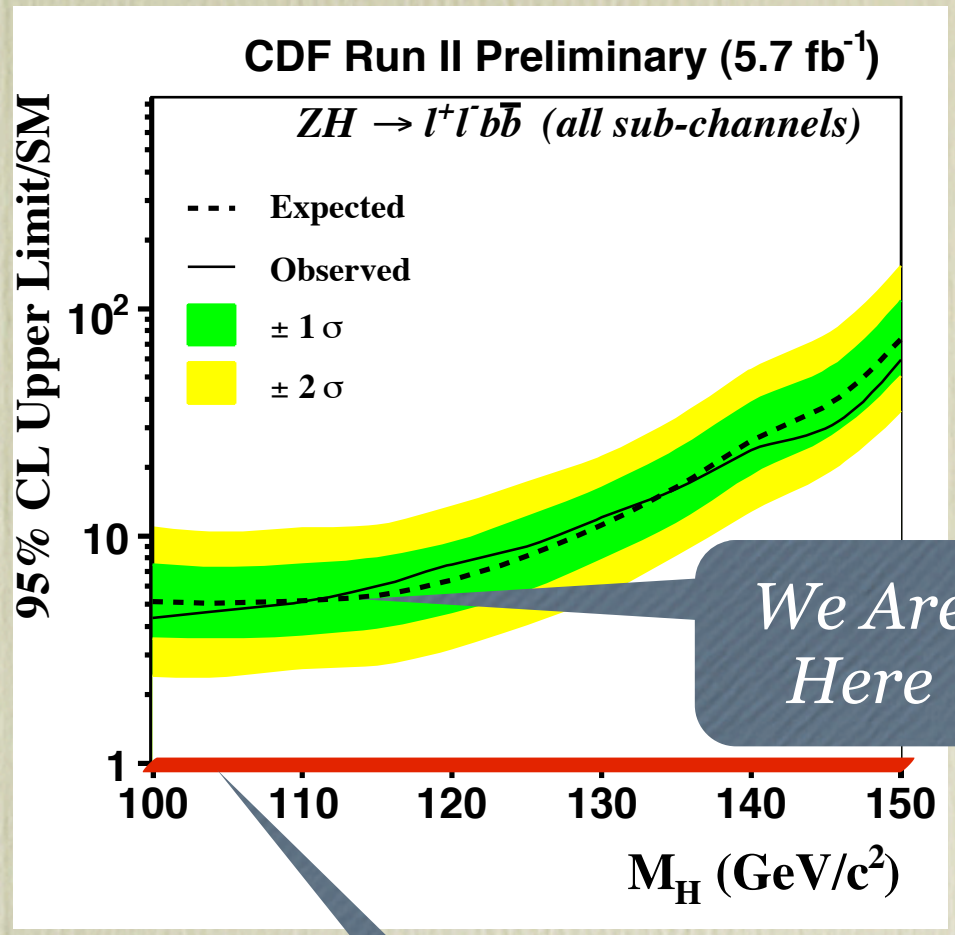
Any signal candidates ?

- We have observed 3 di-muon events and 1 di-electron event falling into high S:B output bins of the NN
- The event below falls in a bin with S:B of just under 1:2!
  - Using the $M_H = 115$ GeV/c² NN



More Work To Do!

- We need even more improvements to be sensitive to Higgs production
  - More data helps also!
- Latest analysis result (Summer 2010) places an expected limit on the Higgs production cross section for this channel at 5.5 times the SM prediction for a 115 GeV Higgs
  - Update is on the way for this Summer (~1 month away)!
  - Expecting significant gains due to the improvements described today



Conclusion

- Much work has gone into this analysis channel and others to squeeze out all possible acceptance gains and increases in sensitivity
- We have developed several techniques that could be extended to other analyses for similar gains
  - Multivariate lepton ID
  - Expert discriminants
- Even though the Tevatron will end operations soon, it is an exciting time as we come closer and closer to Higgs sensitivity!