# Search for a Standard Model Higgs at CDF

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On behalf of the CDF Collaboration

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BERKELEY LAB

# Outline

- Introduction
- Overview the Higgs Search Strategies
- Recent Improvements
- CDF Higgs Search Results  with Full Dataset
- Conclusion

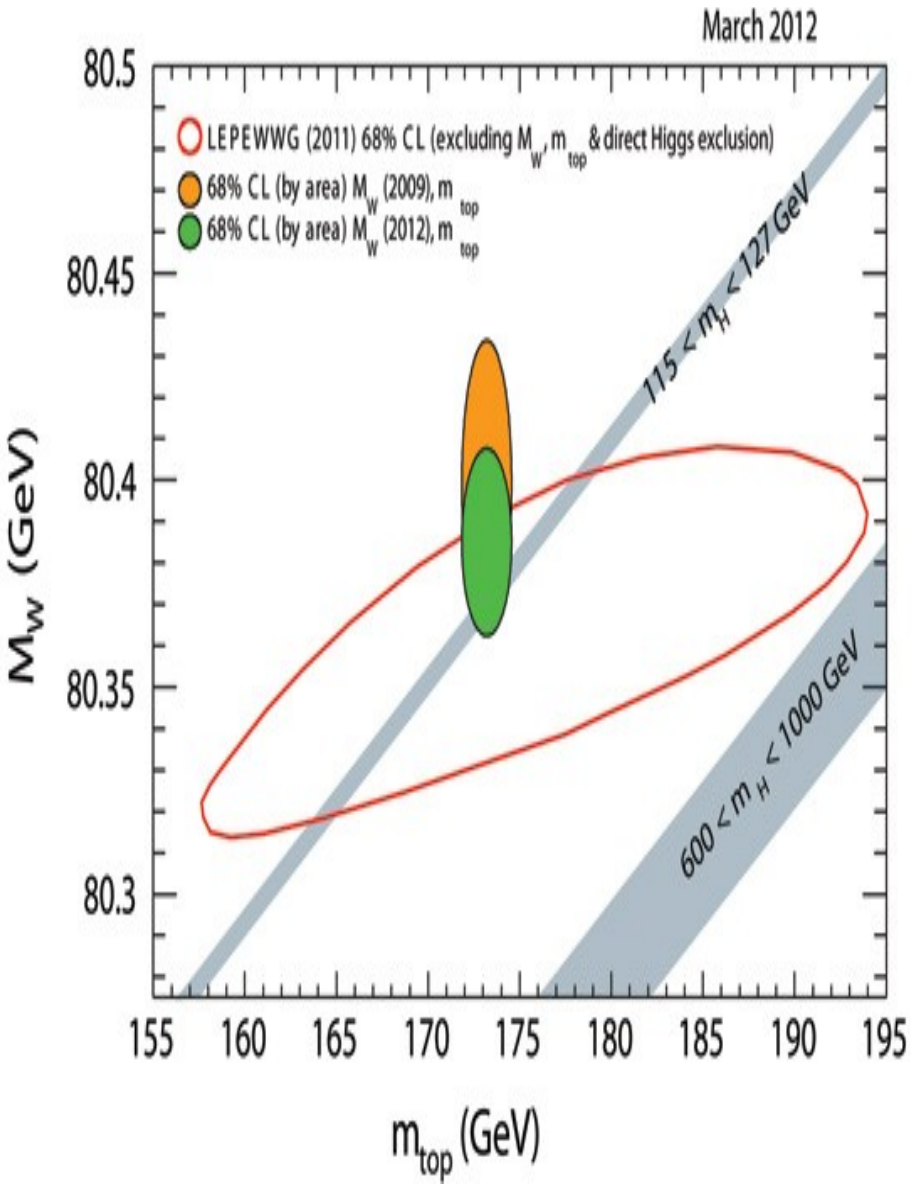
More Details:

http://www-cdf.fnal.gov/physics/new/hdg/Results.html

CDF searches in WH→lνbb, ZH→llbb, VH→metbb, and their combination with full dataset have been submitted for publication.

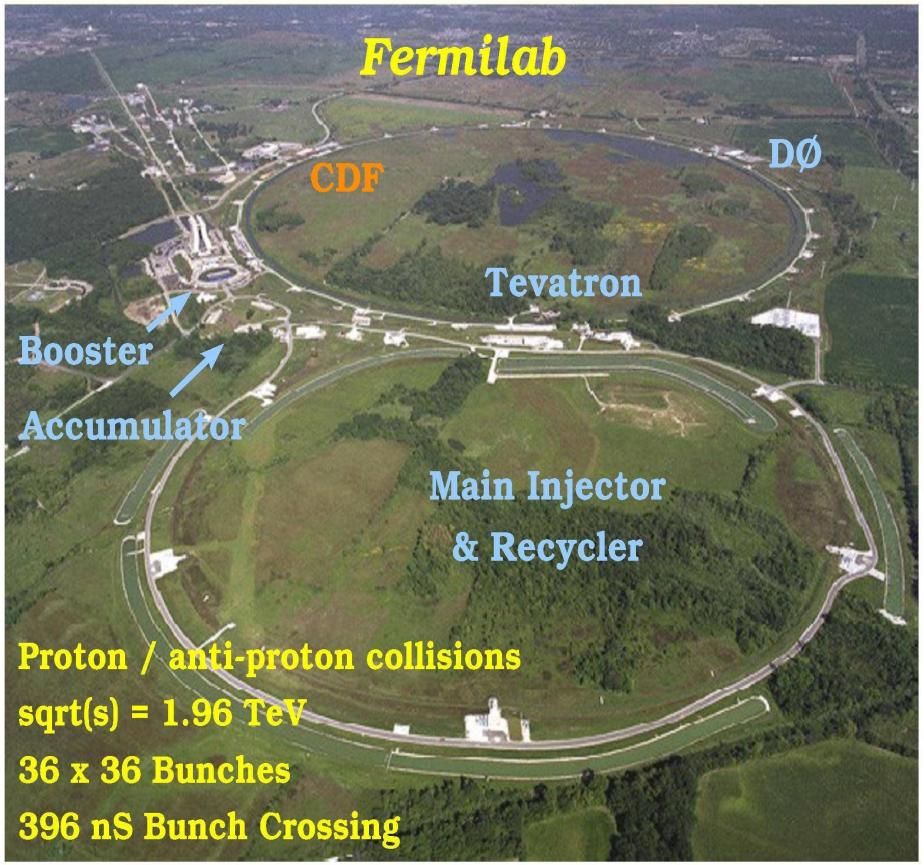
# Introduction

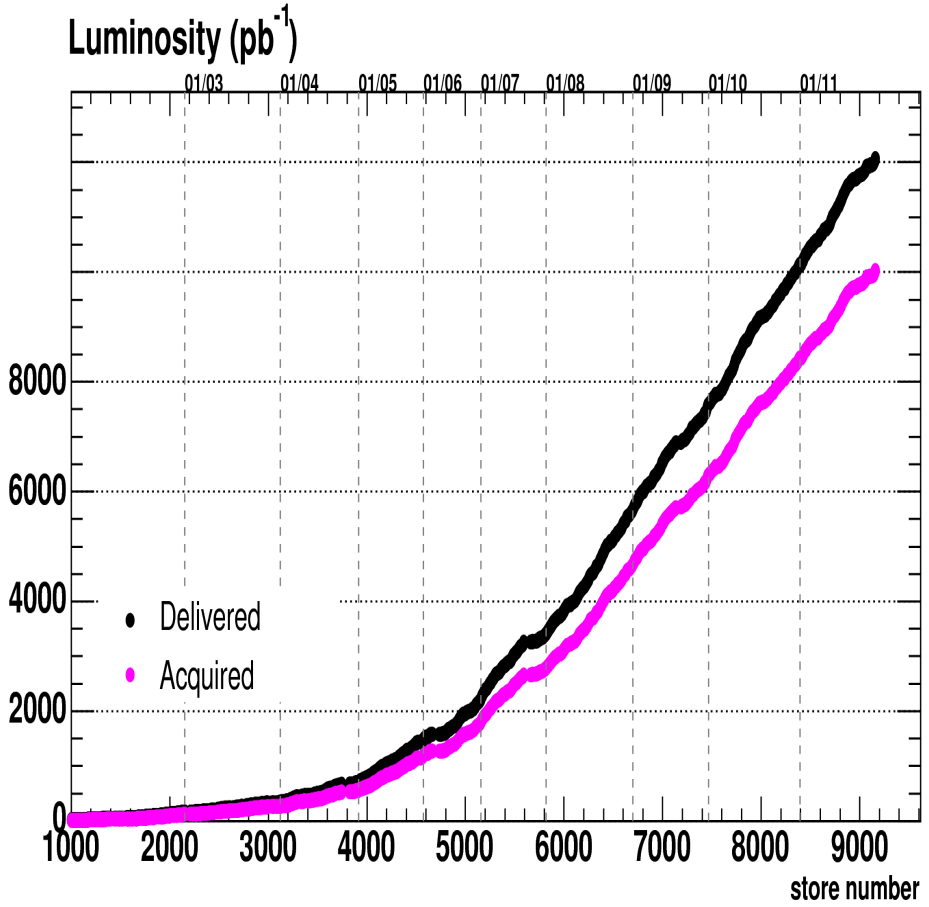
- Higgs boson is hypothesized to be the remnant of the Higgs field that responsible for the electroweak symmetry breaking.
- Higgs Mass Limits@95% CL:
  - Indirect: $M_H$<152 GeV
  - Direct: 122.5<$M_H$<127 GeV
- While LHC just discovered a new Higgs-like particle, Tevatron search of H→bb decay is still important and will provide a crucial test on the existence and nature of the Higgs boson.



# The Tevatron

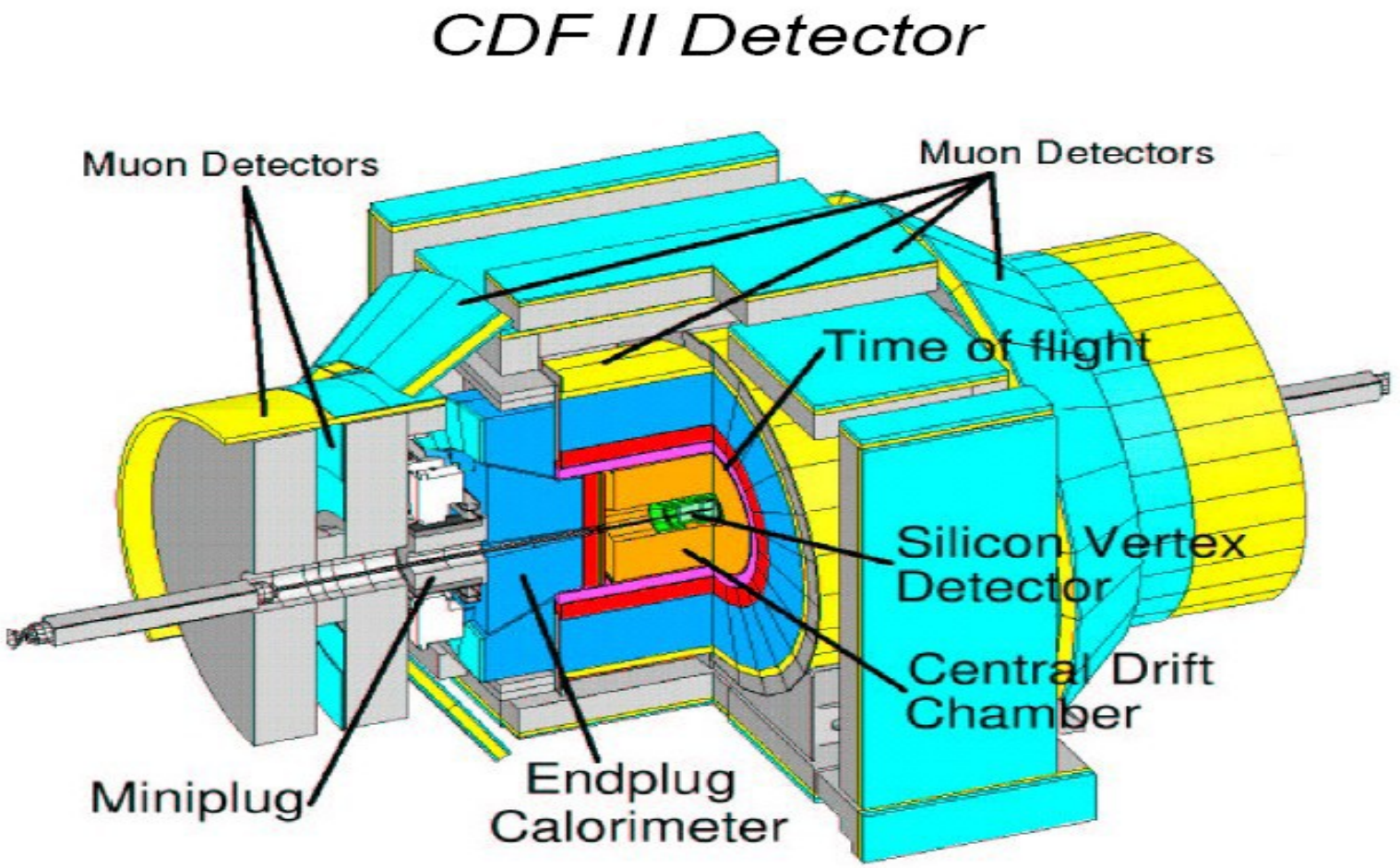
- Tevatron: p-pbar collision@1.96TeV, $L_{peak}=4.3\times10^{32}\ cm^{-2}s^{-1}$
- Delivered ~12 $fb^{-1}$ data before shutdown on 9/30/2011.
- Most results presented are based on the full dataset (~10 $fb^{-1}$)



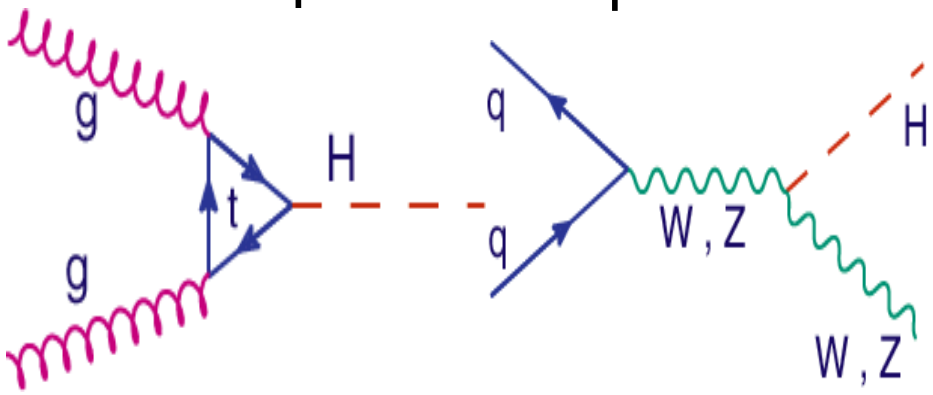
# CDF General-purpose Detector

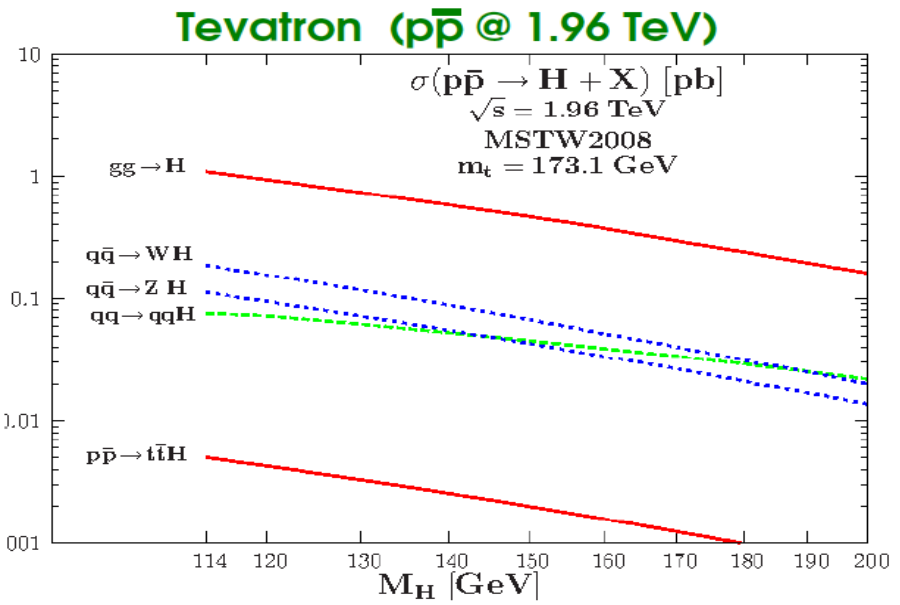
•Provides excellen: lepton ID, tracking, Vertexing, Jets, and Met.



# SM Higgs Production and Decay @ Tevatron

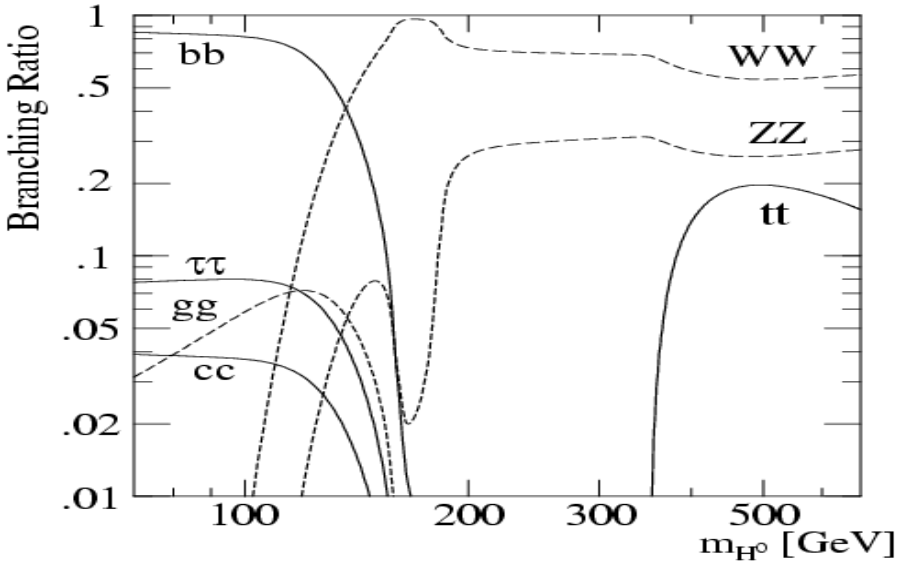
- Dominant production processes:



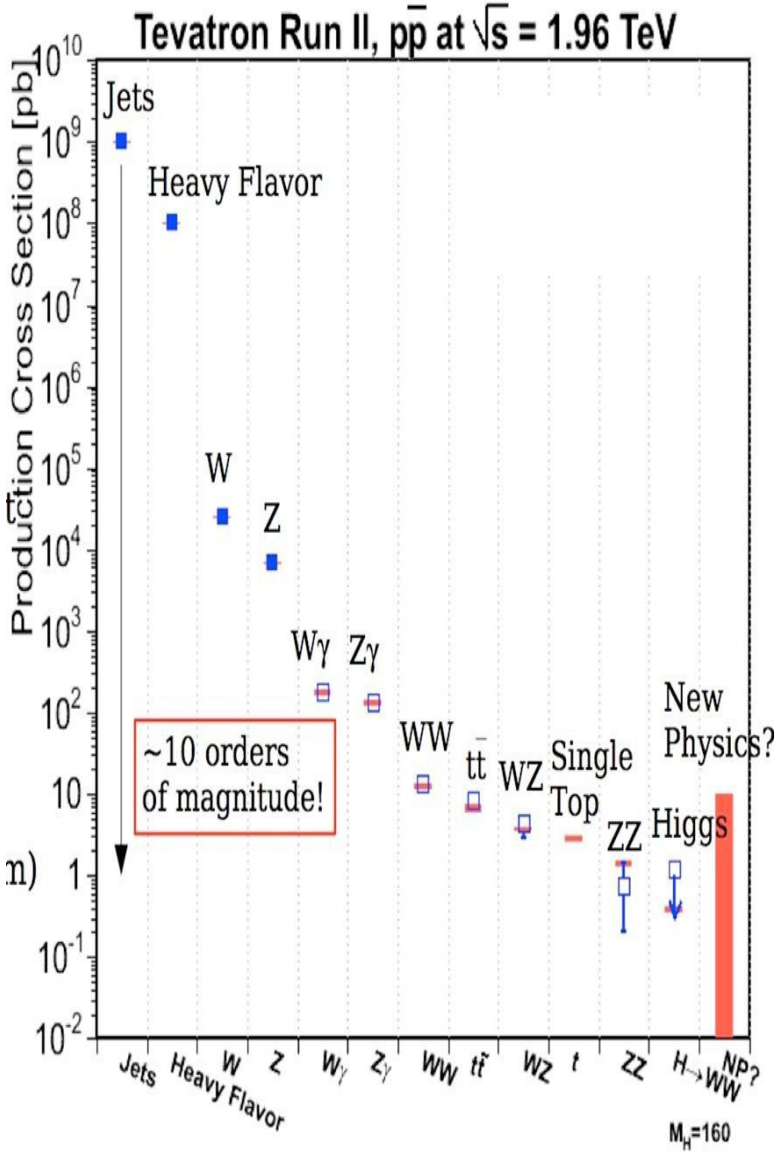

- For lower mass($M_H$<135 GeV):
  - –Main decay:H→bb in WH/ZH
  - –Direct production gg→H→bb is limited by multi-jet QCD.
- For higher mass(MH>135GeV):

  Mainly decays: gg→H→WW,ZZ
- Other decays: H→ττ,γγ, and ttH.

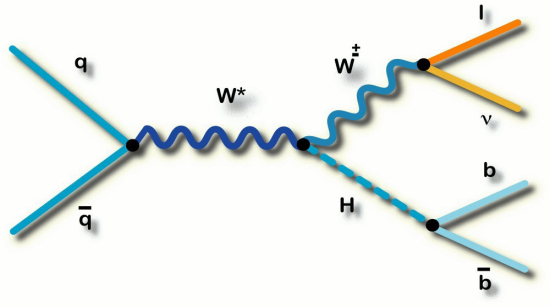


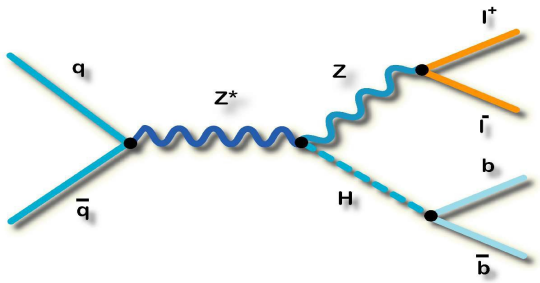
# The Challenge

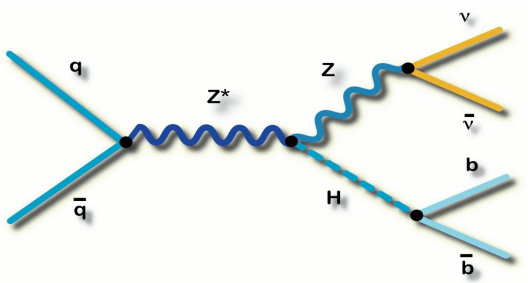
- The Challenge is due to that Higgs signal is so tiny compared to other SM process with the same final states.
- Search Strategy has evolved over years:
  - –Maximizing signal acceptances using efficient triggers, lepton ID, and b-tagging that improves S/B to ~1/100.
  - –Using multivariate analysis (MVA) to exploit kinematic differences of S and B that improves S/B to ~1/10.
- The procedures are iterated until the best sensitivity is achieved.



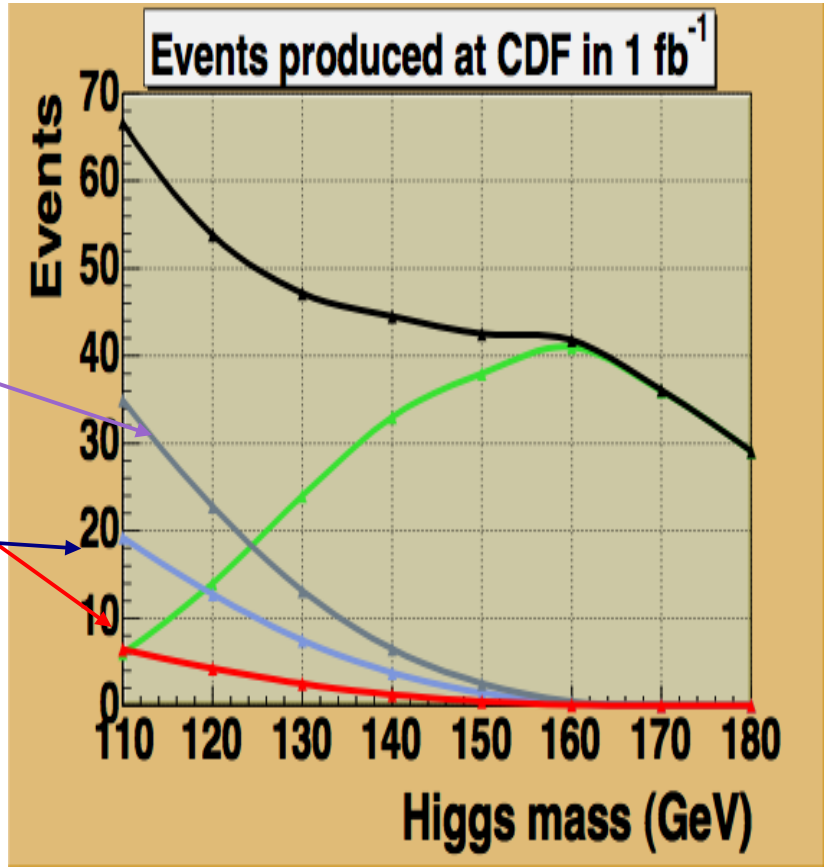
# Main Low-Mass Higgs Signatures



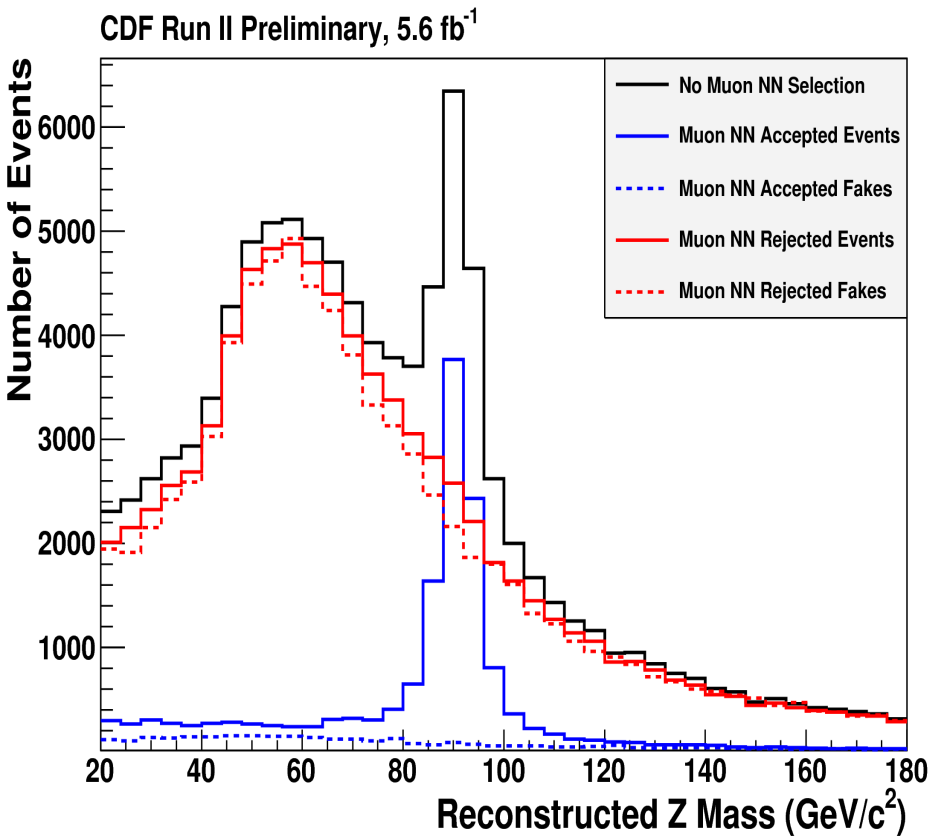



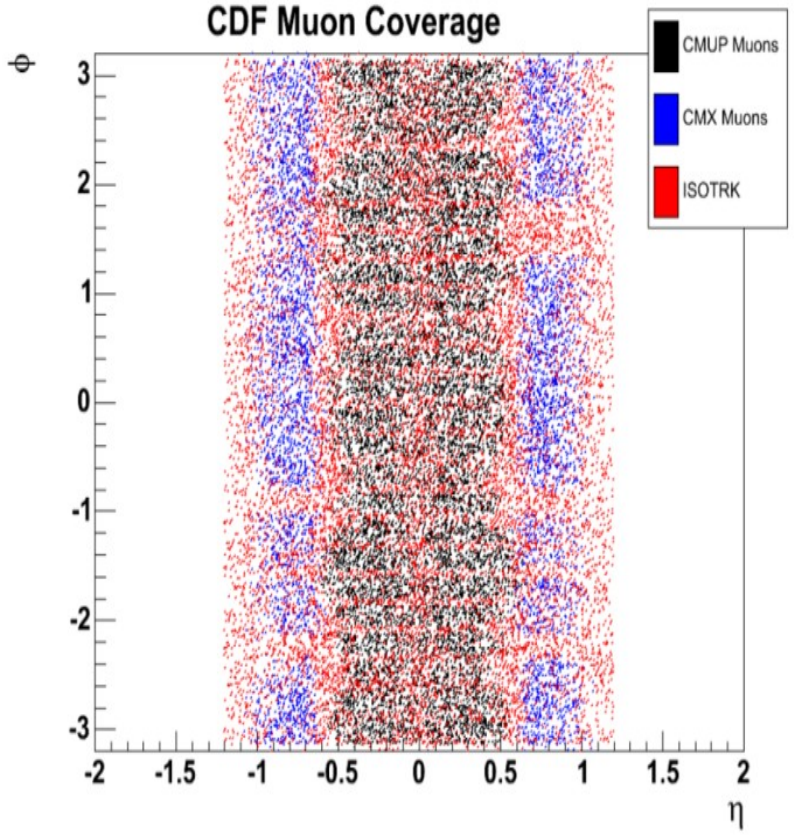

- Search for H→bb resonance in association with W or Z.
  - –WH→lνbb, most sensitive low-mass channel: one lepton+MET+ 2b
  - –ZH→llbb: two leptons + 2b
  - –ZH→νν, WH→ (l)νbb: met + 2b
- Expect total ~300 events with 10 $fb^{-1}$ for $m_H$=125 GeV/$c^2$ before detector acceptances.



# Maximizing Lepton ID & Triggers

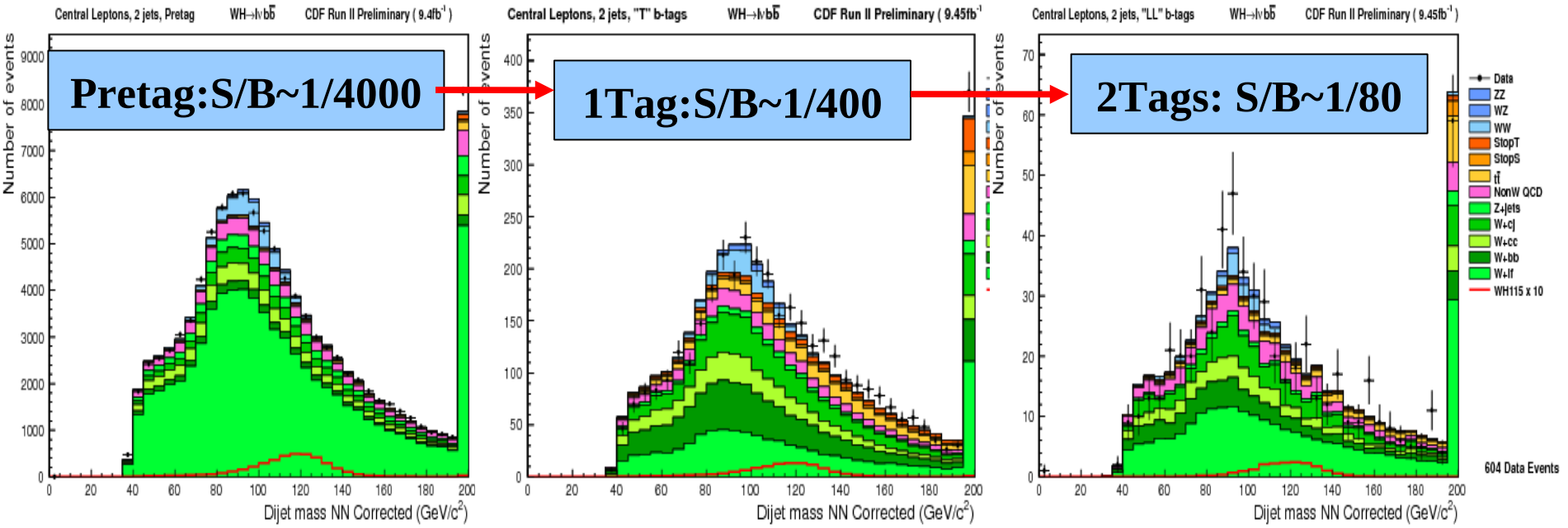
- Selecting high Pt lepton with multivariate ID gains 20% more Z's than the cut-based selections.
- Including isolated high Pt track from met triggers.



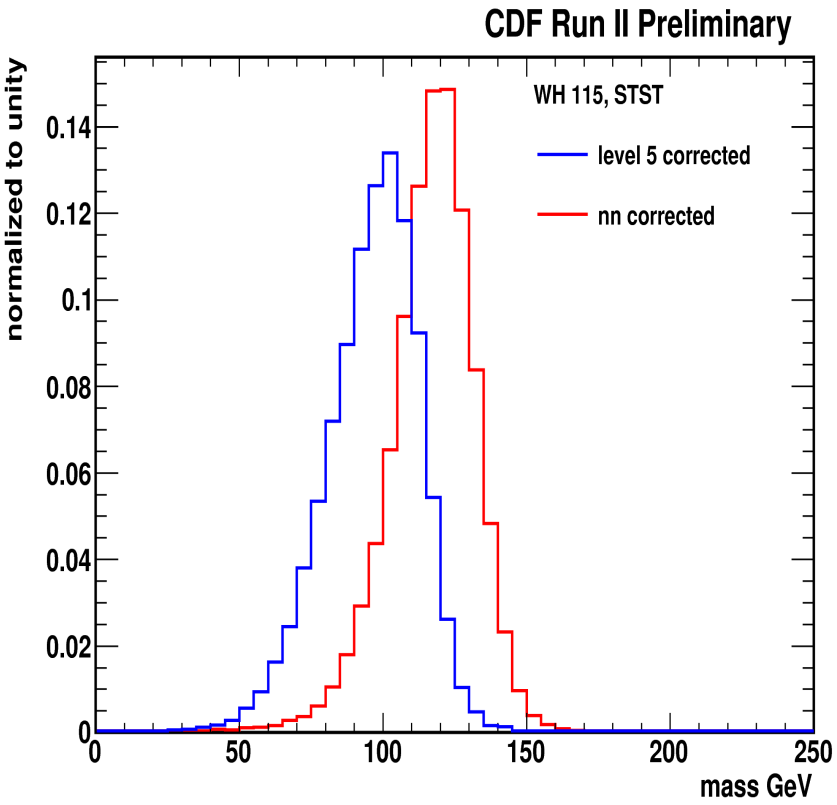
# Improvement of b-tagging

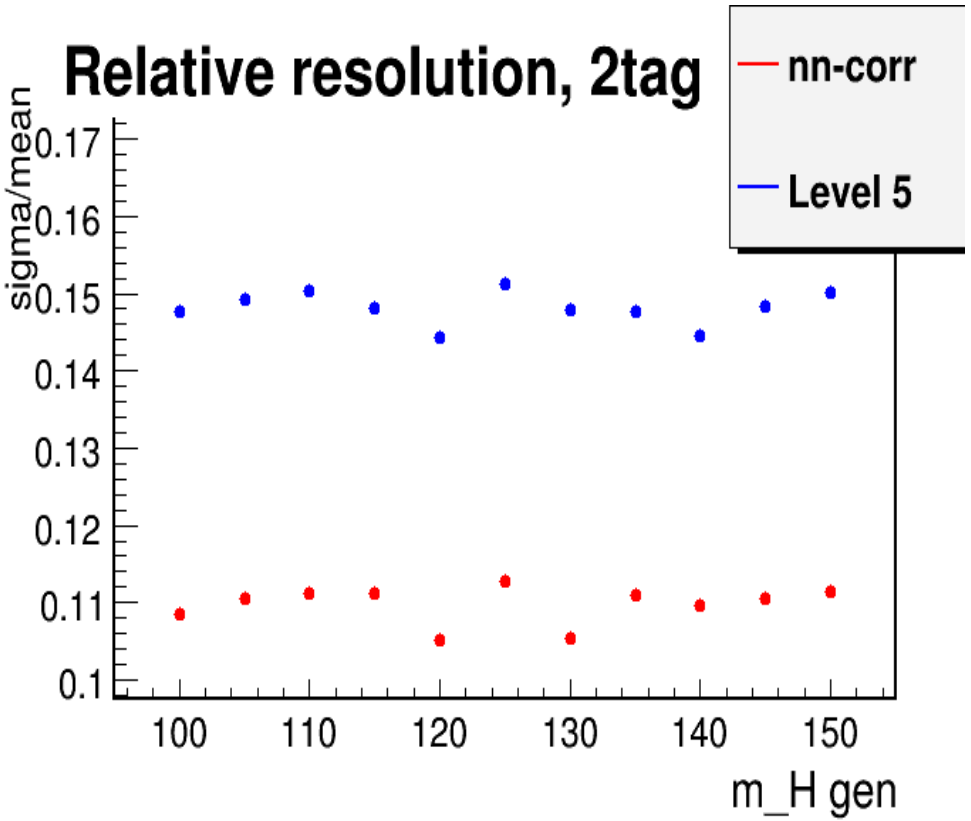
- CDF uses MVA techniques to improve b-tagging that exploits the decay of long-lived B hadron as displaced tracks/vertices. Typical eff:40-70% with mistag rate:1-5%.
- Recently CDF combined existing b-tags into a Higgs optimized b-tagger (HOBIT), which improves eff by 20% while keeping mistag rate same.
- Requiring b-tag improves S/B from 1/4000 to 1/80 in WH→lνbb.



# Improving Dijet Mass Resolution

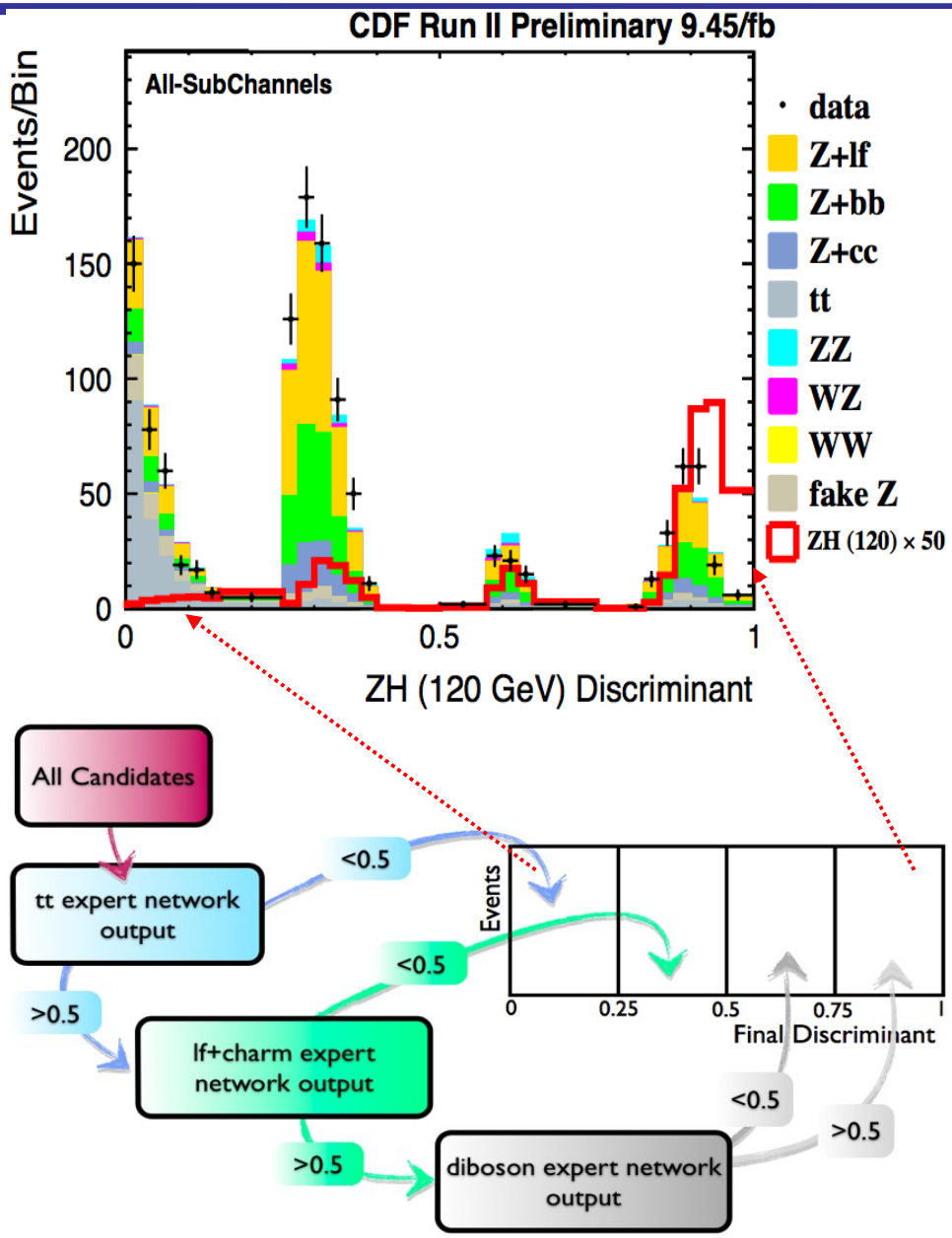
- Invariant mass of two b-jets provides most discriminant power to separate signal from backgrounds.
- Important to achieve its best resolution by combining calorimeter and tracking information using Neutral Network.



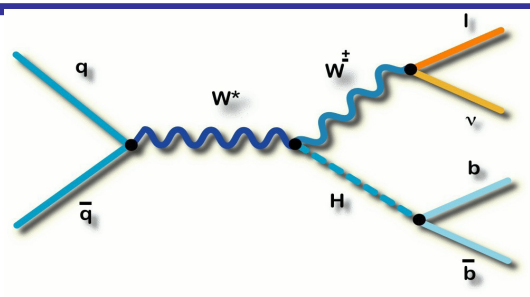
# Improvement of Multivariate Discriminant

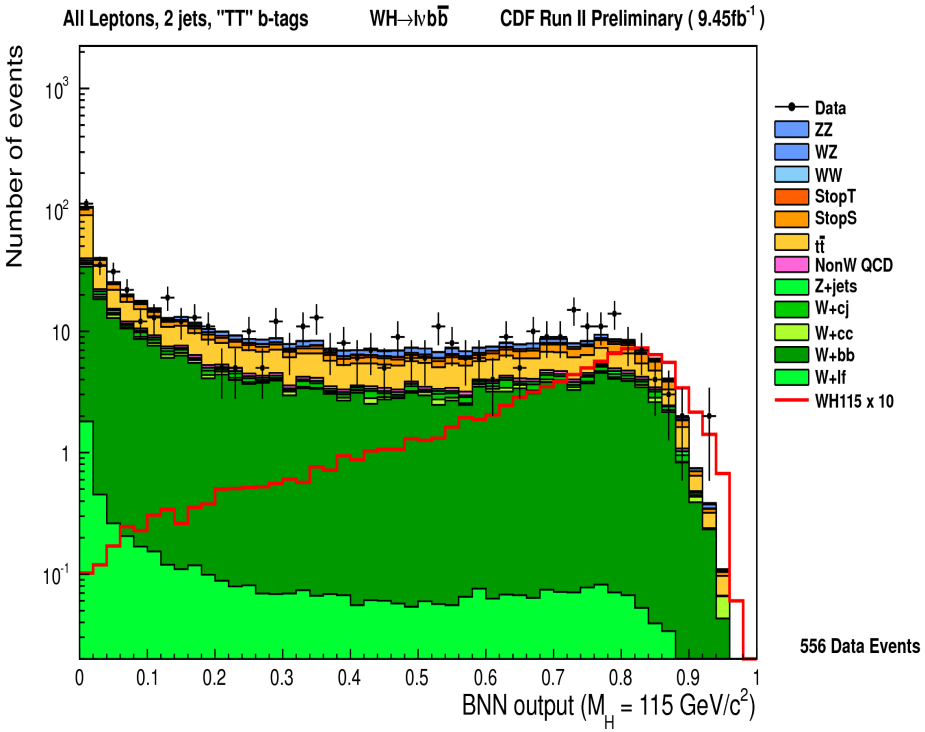
- Most Higgs Analysis uses MVA to improve bkgd rejection with a sensitivity gain of 25%, compared to single variable alone, e.g. dijet mass.
- We can further improve MVA by training against multiple bkgds, splitting analysis into subchannels based on S/B, e.g. lepton type, number of jets.
- Trained ZH→llbb against ttbar, z+c, diboson, separately to build the final discriminant.

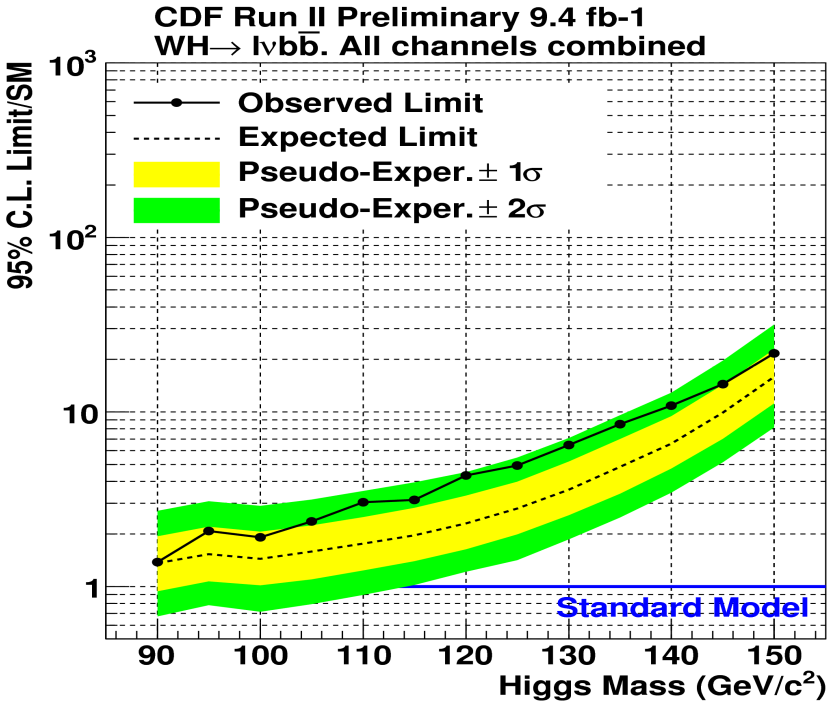


# Search for WH→lvbb

- WH->lvbb is one of most sensitive channel.
- Easy to trigger on lepton, missing Et, 2 and 3 jet.
- Require b-tag & MV discriminant (26-ch).



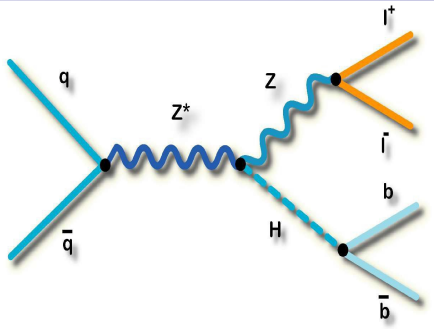



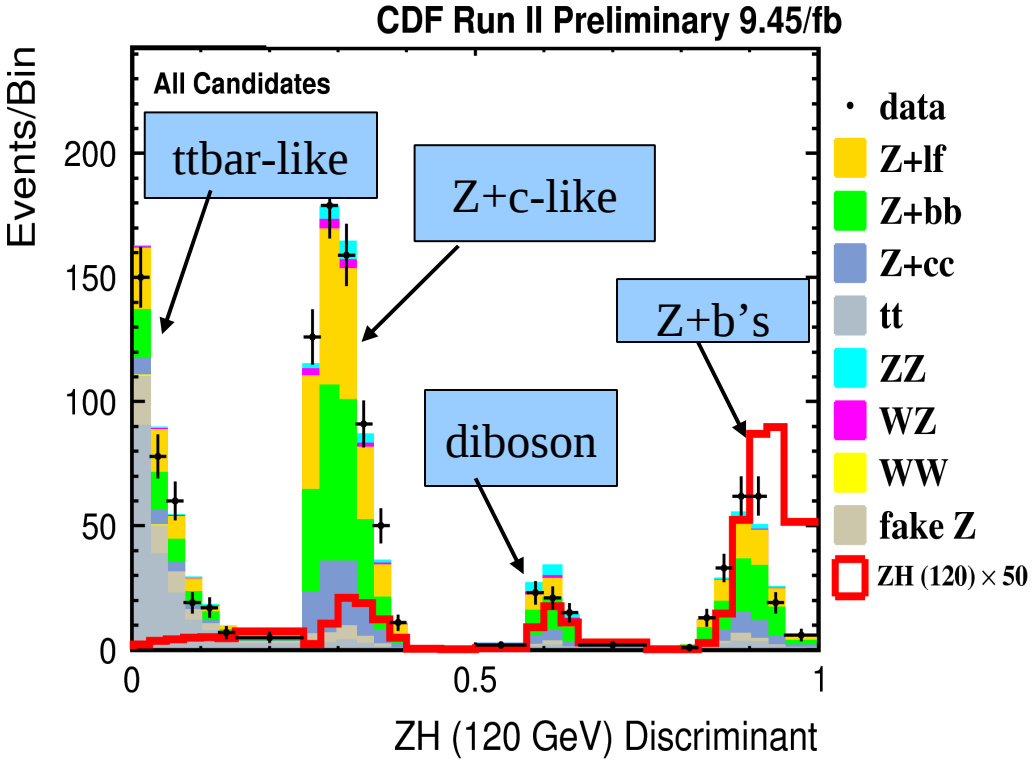



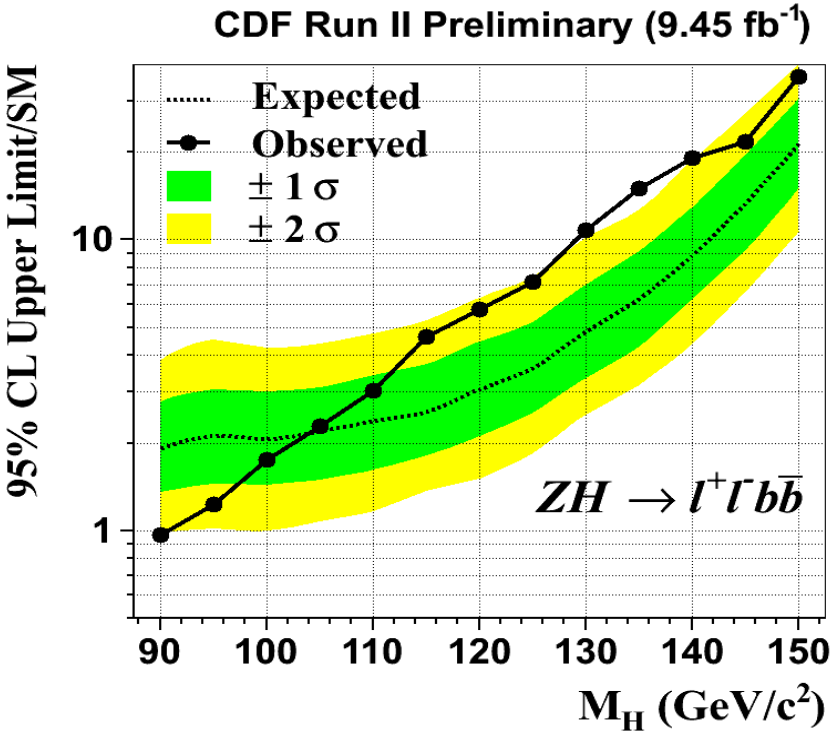

- Set 95% CL obs/exp limits: 4.9/2.8 @ mH=125 GeV.

# Search for ZH→llbb

- Low event rate but clean signature.
- Select two leptons for Z→ll, 2/3 jets with btag (8-ch).
- Train NNs to isolate H from top, Z+c's, diboson,Z+b's.



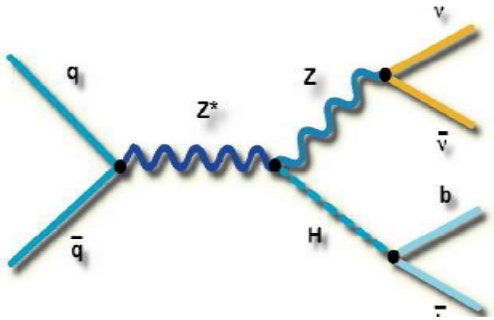



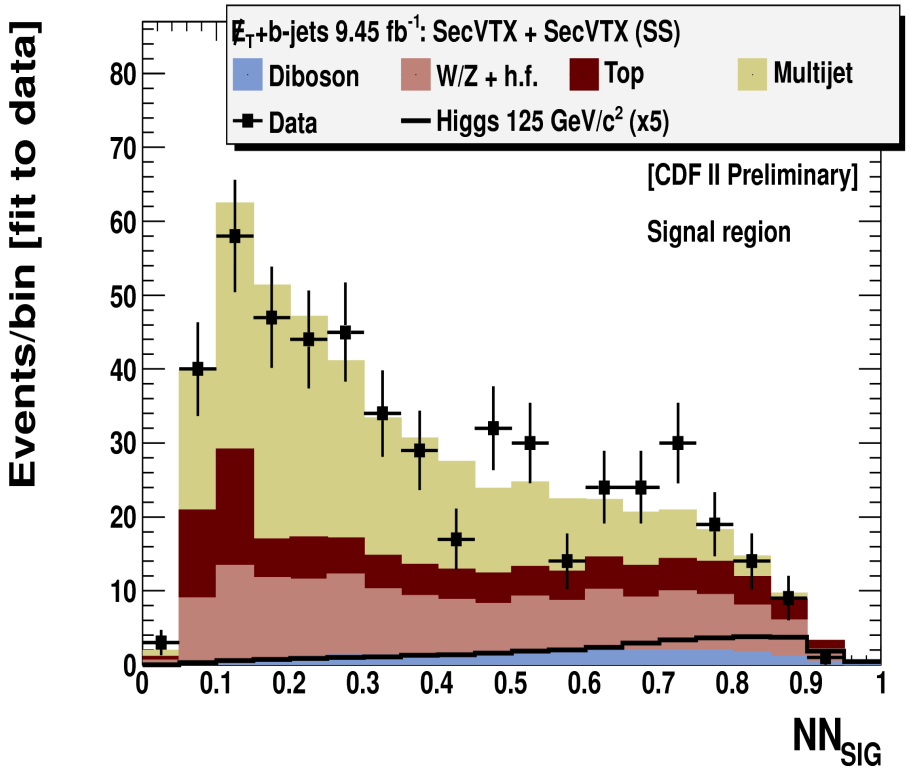



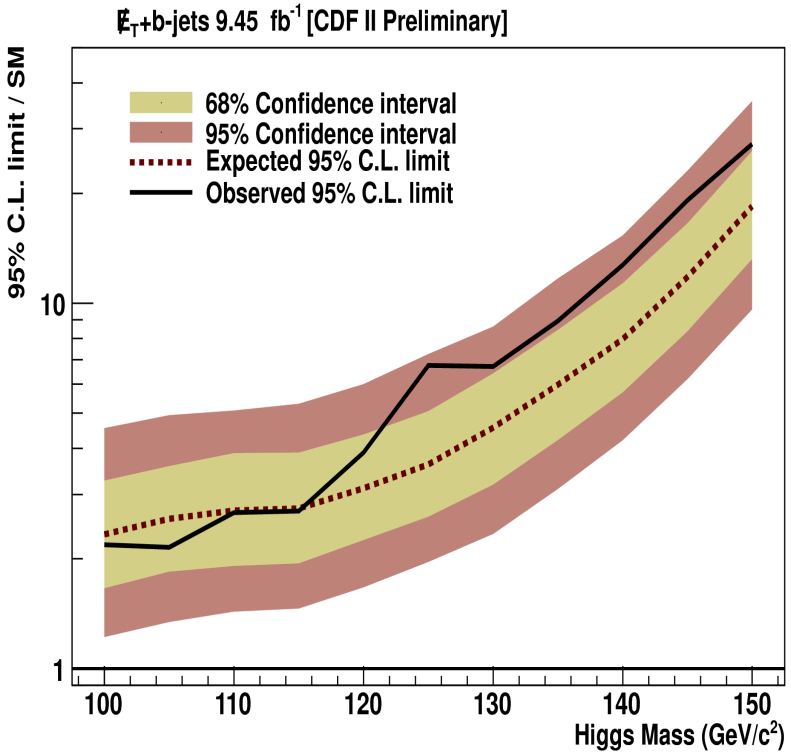

- Set 95% CL limits on obs/exp: 7.1/3.9 @ mH=125 GeV.

# Search for ZH→vvbb, WH→(l)vbb

- Large event rate with large QCD MJ, very difficult
- Require met>50 GeV + 2/3 jets, b-tagging (3-ch).
- Train NN to separate Signal, background, QCD.

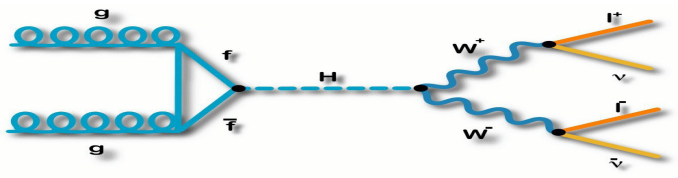


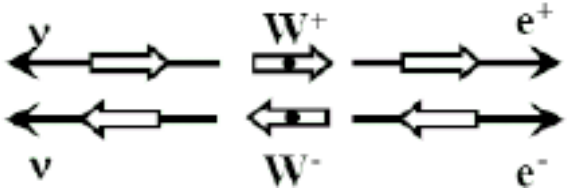



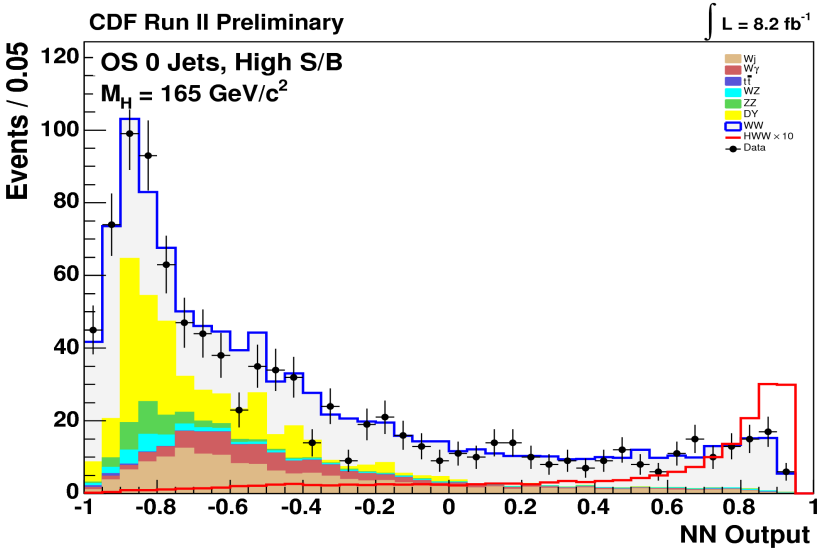

- Set 95% CL limits on Obs/exp: 6.7/3.6 @mH=125 GeV.

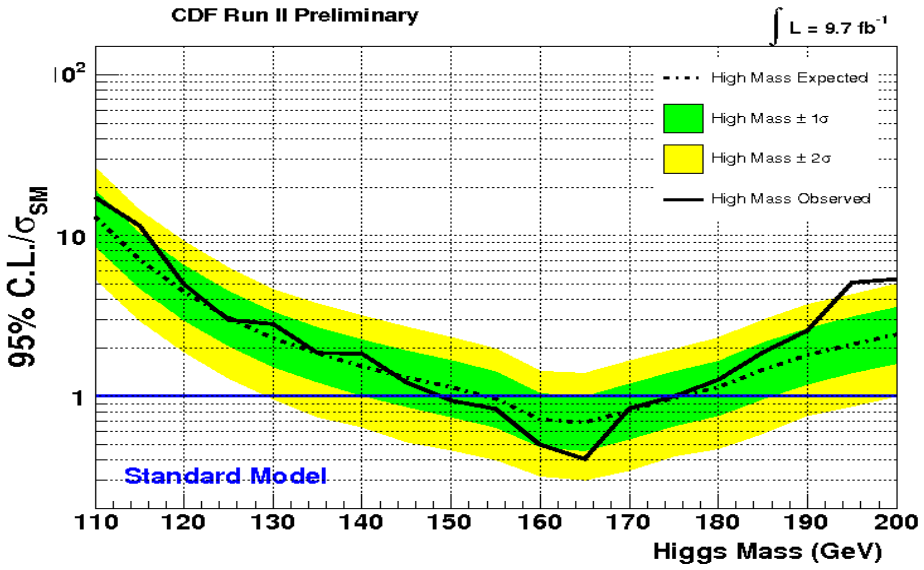
# High Mass Signatures




- Search for HWW inclusively that leads to many interesting final states.
- Most sensitive channels is H→WW→llvv: OS dilepton+met+0,1,2 jets (13 ch).
- Use MVA to separate signal from main backgrounds: WW and top.

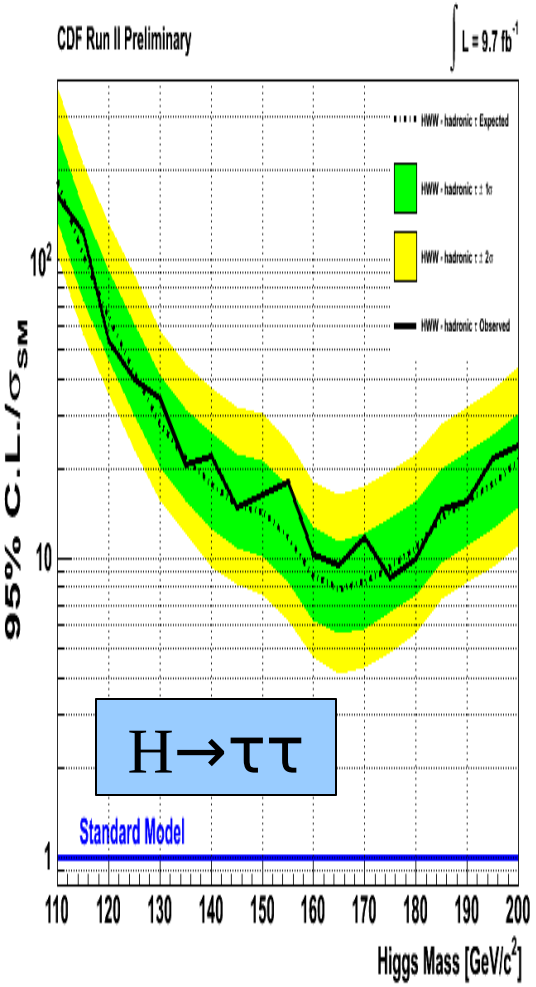


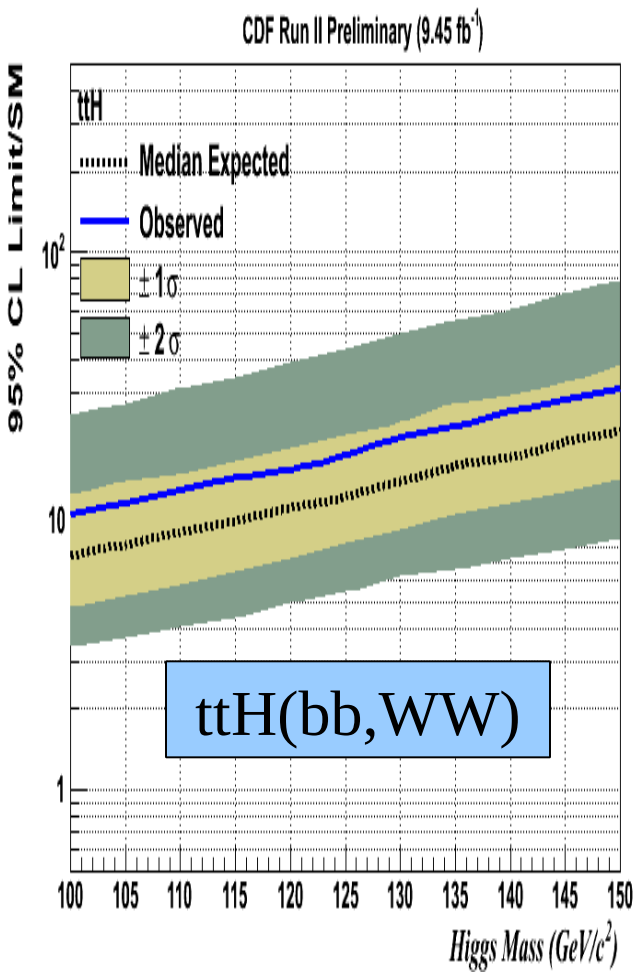



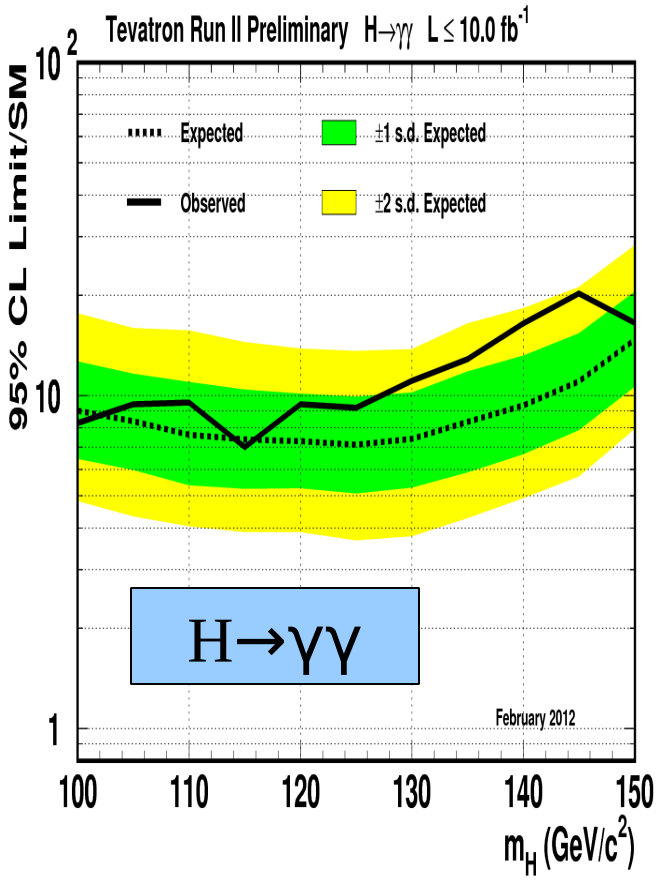

- Set 95% CL Obs/Exp Limits: 0.40/0.67 @165 GeV

# Other Searches

- Other searches(H→ττ, ttH,H→gg) are also being considered.
- They're not sensitive in SM, but every bit helps.



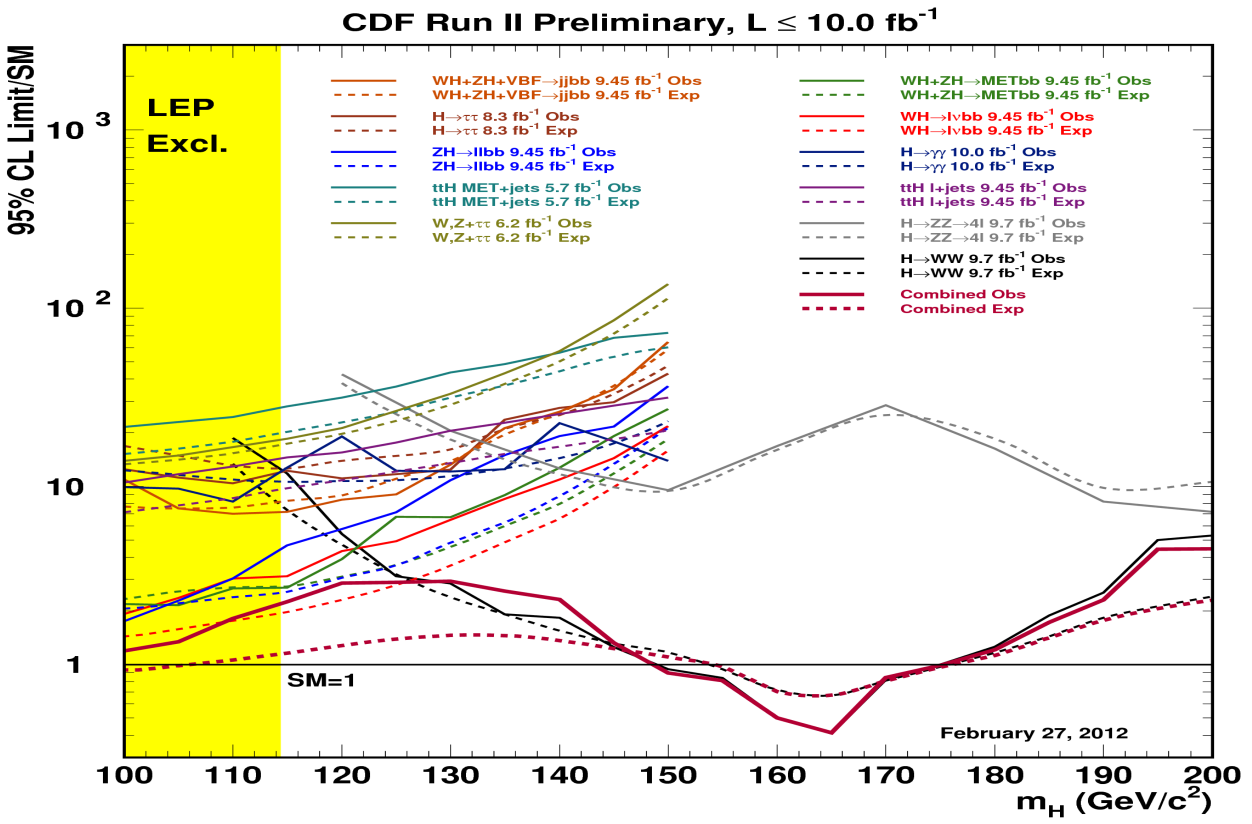



# Combined Limits on SM Higgs Production

- CDF have searched for all possible SM Higgs production and decays and set limits with respect to nominal SM predictions.
- Combining all the channels to improve the CDF Higgs limit.

WH→lνbb
ZH→ννbb
ZH→llbb
H→WW→lνlν
WH/ZH→jjbb
ttH→WbWb bb
H→γγ
H→ττ
VH→(lν,ll)ττ
H→WW→lνjj
VH→VWW
H→ZZ

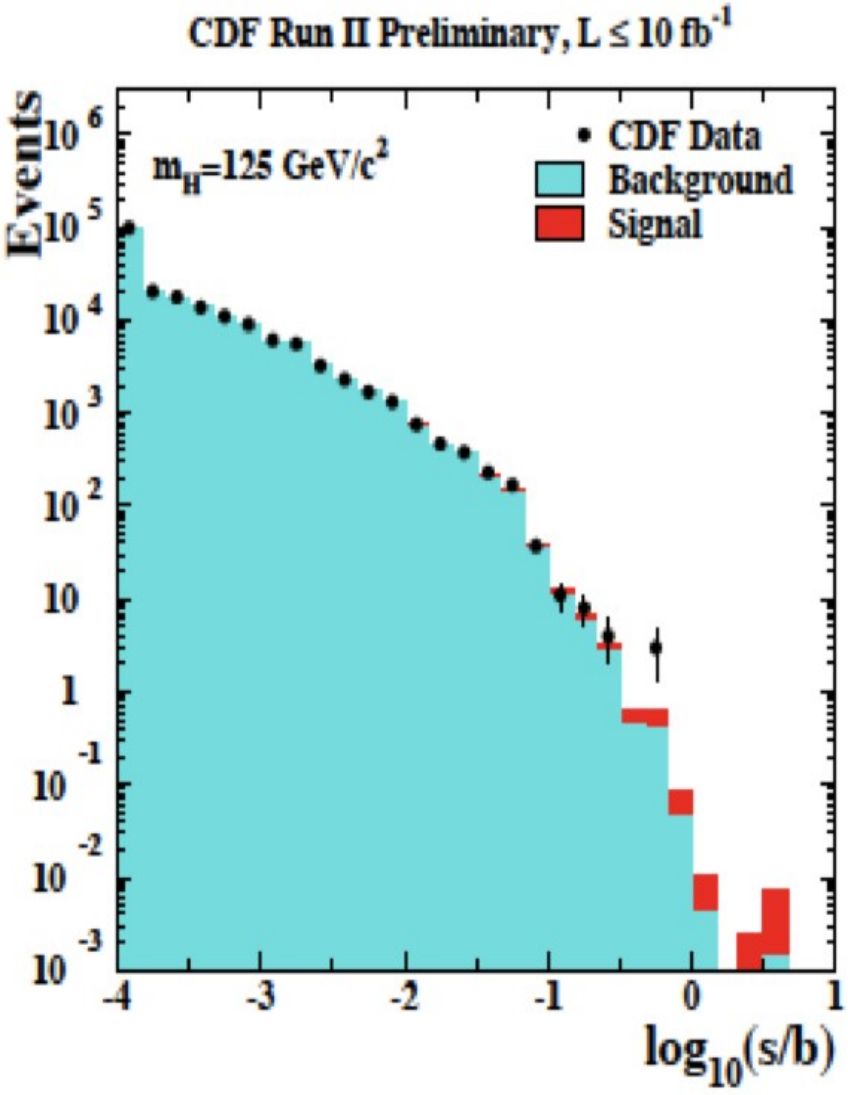


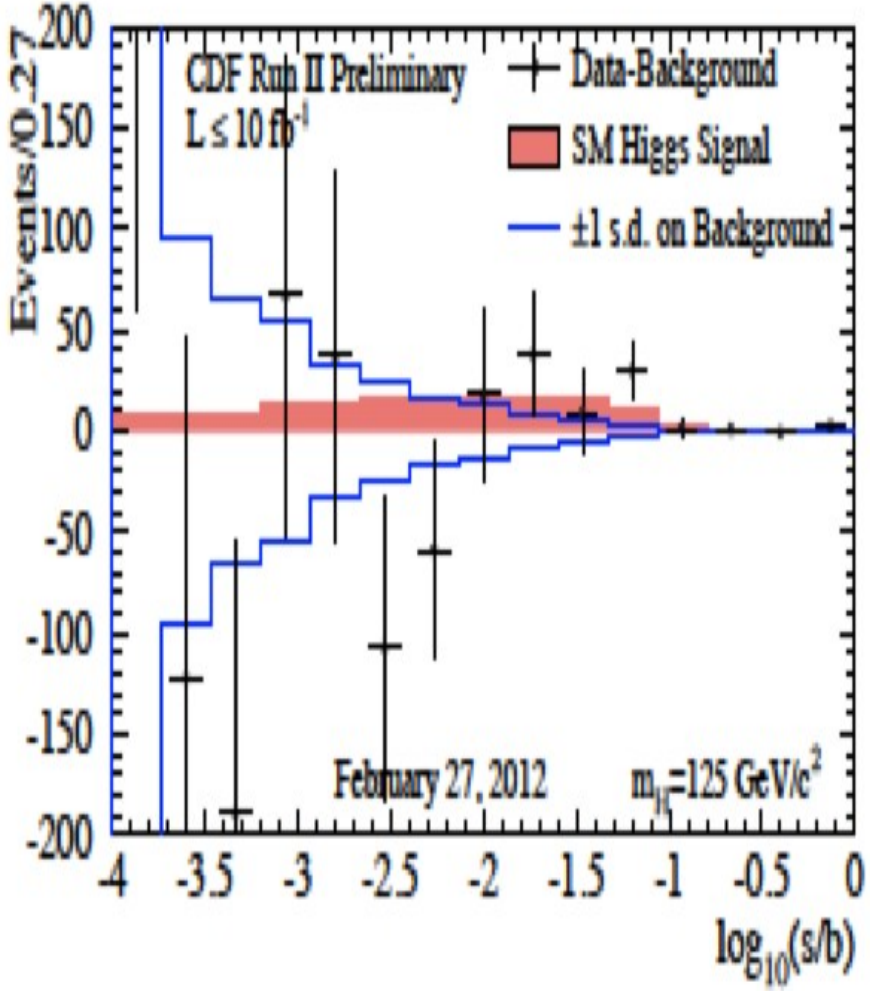
# Systematic Uncertainties

- Two types of systematic on estimated signal and background:
  - Rate systematic: only affect overall normalization
  - Shape systematic: change differential distribution, i.e. due to JES, MC modeling
- Systematic correlated between channels:
  - Integrated luminosity (6%) , Trigger eff and Lepton Id (2-5%)
  - Btag SF (3.9-7.8%), Mistags (10-20 %)
  - JES(rate+shape), ISR/FSR + PDF + $Q^2$ (rate)
  - Theoretical cross sections (rate)
  - MC simulation of W/Z+HF (rate only)
- Instrumental backgrounds (no-W) are treated as independent (30%).
- Most of nuisance parameters are well constrained in the dominant background region and are not sensitive to the initial input values.
- Reweight W+HF MC to the pretag data and no effect on NN output is found.

# Cumulative Discriminant at $M_H$=125 GeV

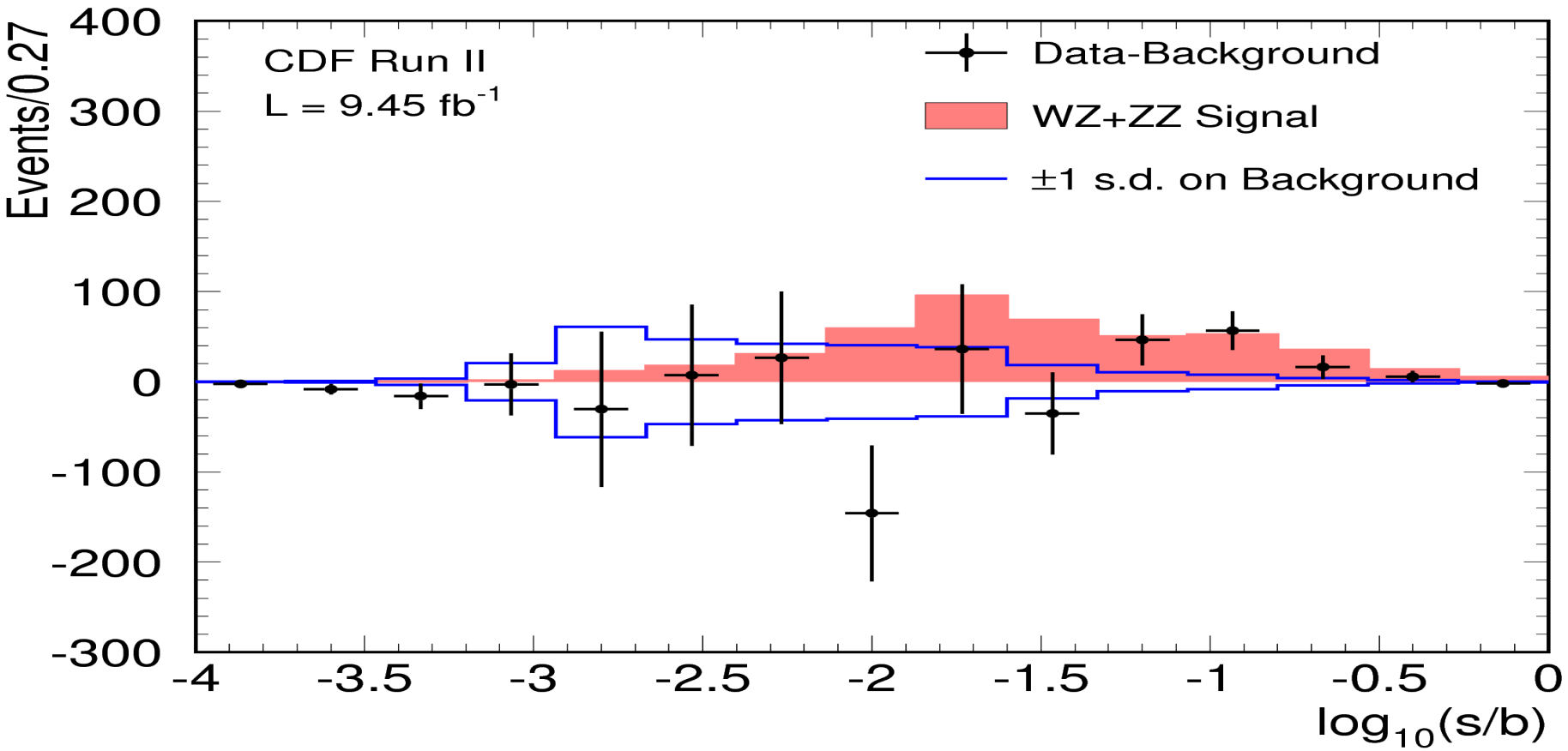
- Display events from all channels, ordered by S/B for $M_H$=125 GeV.



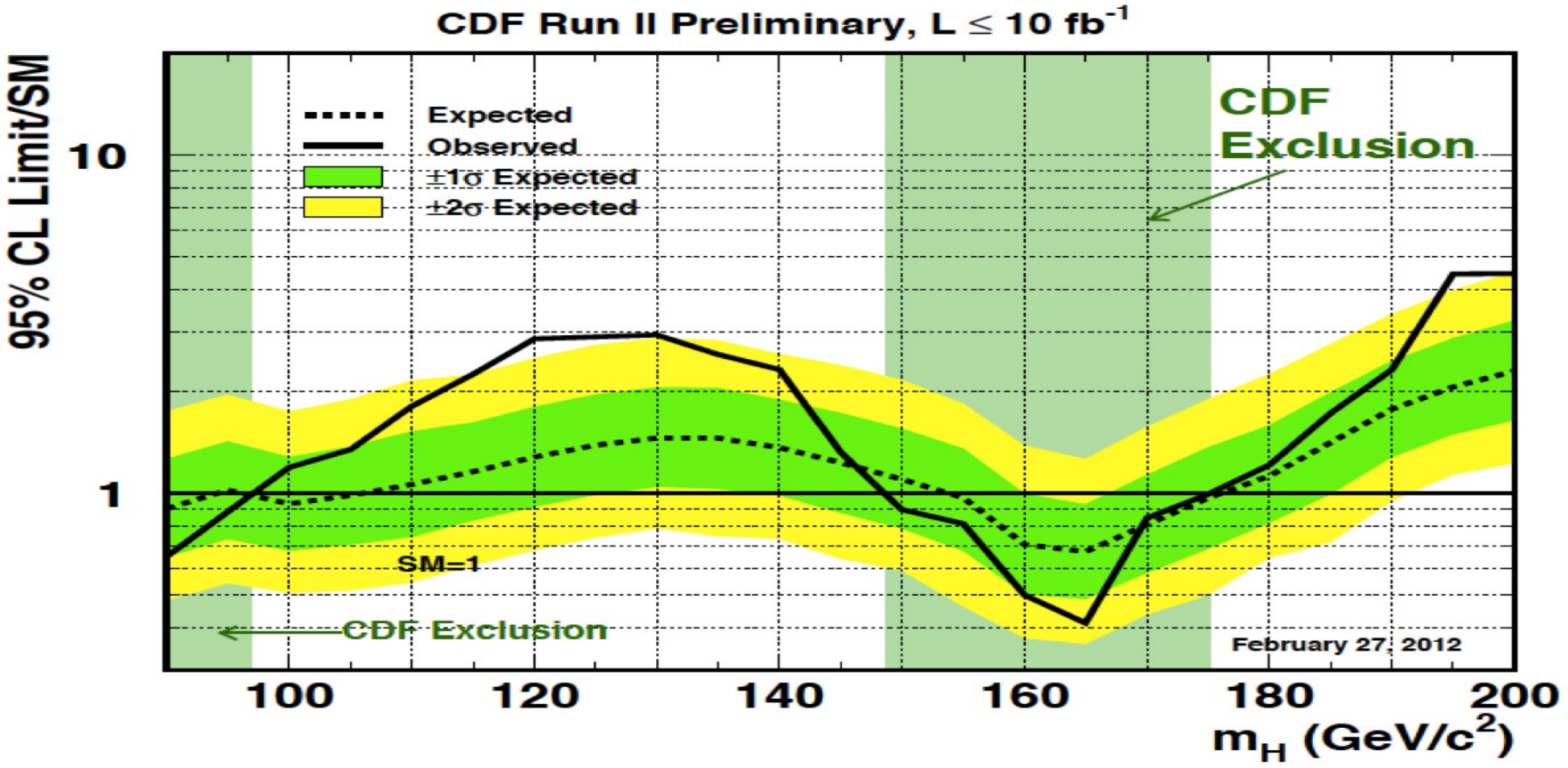
# Searching for Z→bb

- To validate search strategy, we have looked for Z→bb in association with a W or Z using similar signatures:WZ/ZZ->llbb, lvbb,vvbb.
- Measured $\sigma_{WZ+ZZ}$=4.1+1.4-1.3pb, compared to SM prediction of 4.4pb



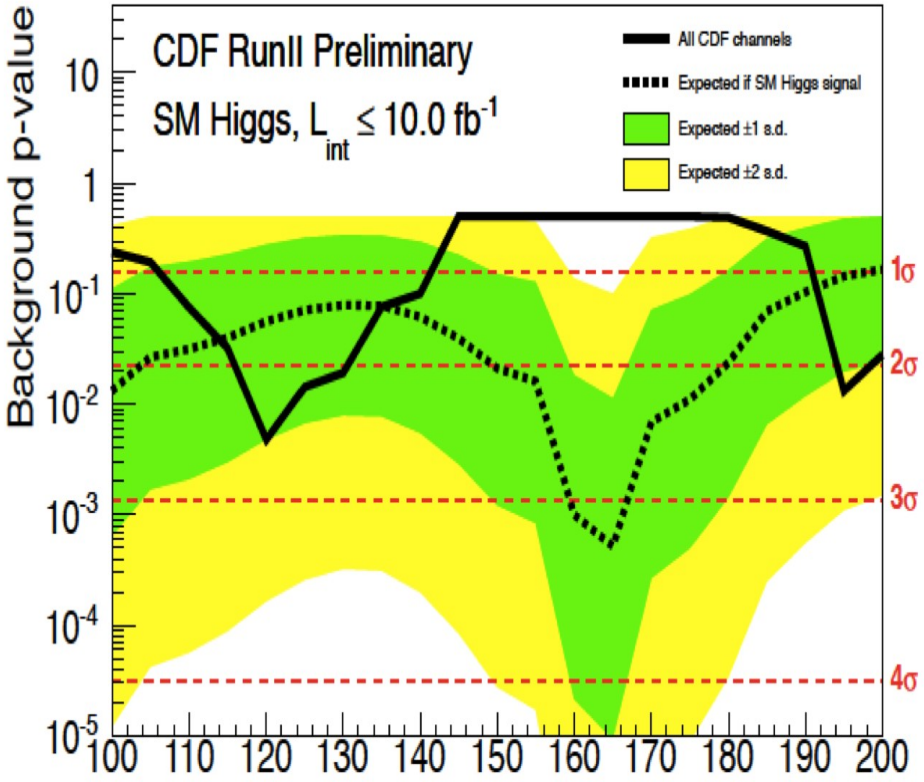
# CDF Combination

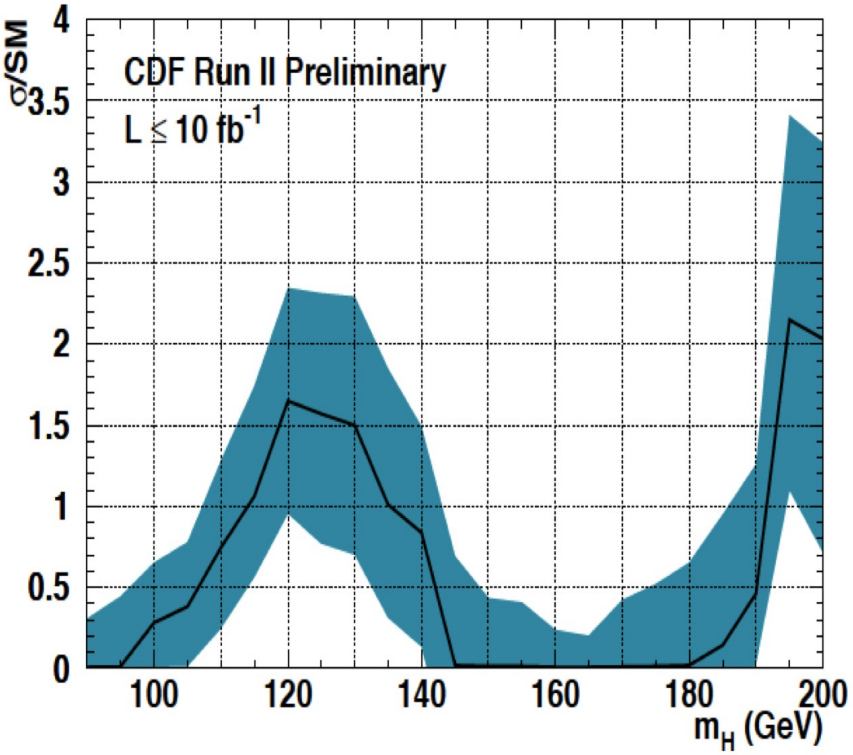
- Exclude high mass: 148.8-175.2 with expectation of 153.8-176.1 GeV/c2 and low mass: <96.9 with expection of <94.2 and 96.1-106 GeV/c2.
- Broad excess(>2σ) observed between 115-130 GeV/c2.



# Quantifying the Excess

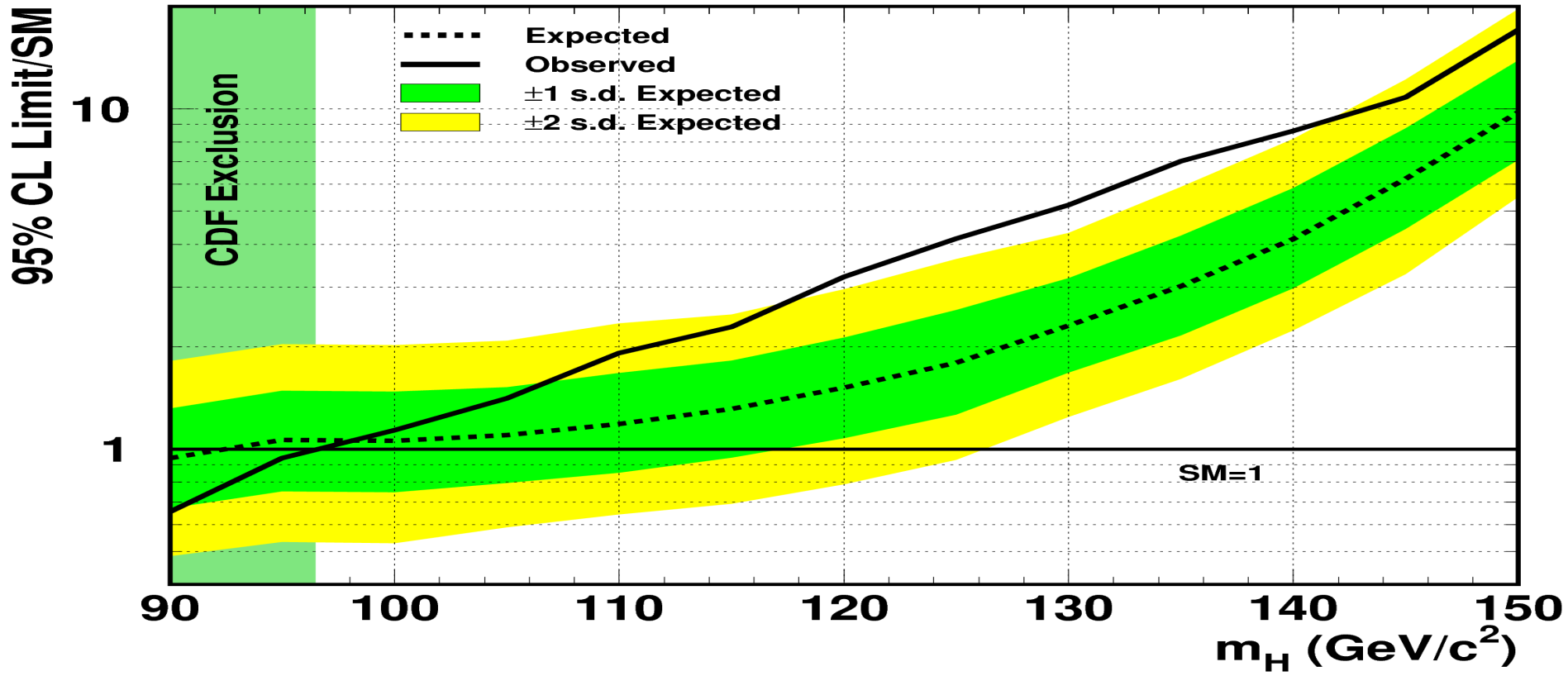
- Calculating local p-value distribution for background-only hypothesis.
- Broad excess observed between 115-130 GeV with a global p-value of 2.1 sigma with LEE factor of 4
- Fits to the cross section strength, consistent with SM Higgs Production.



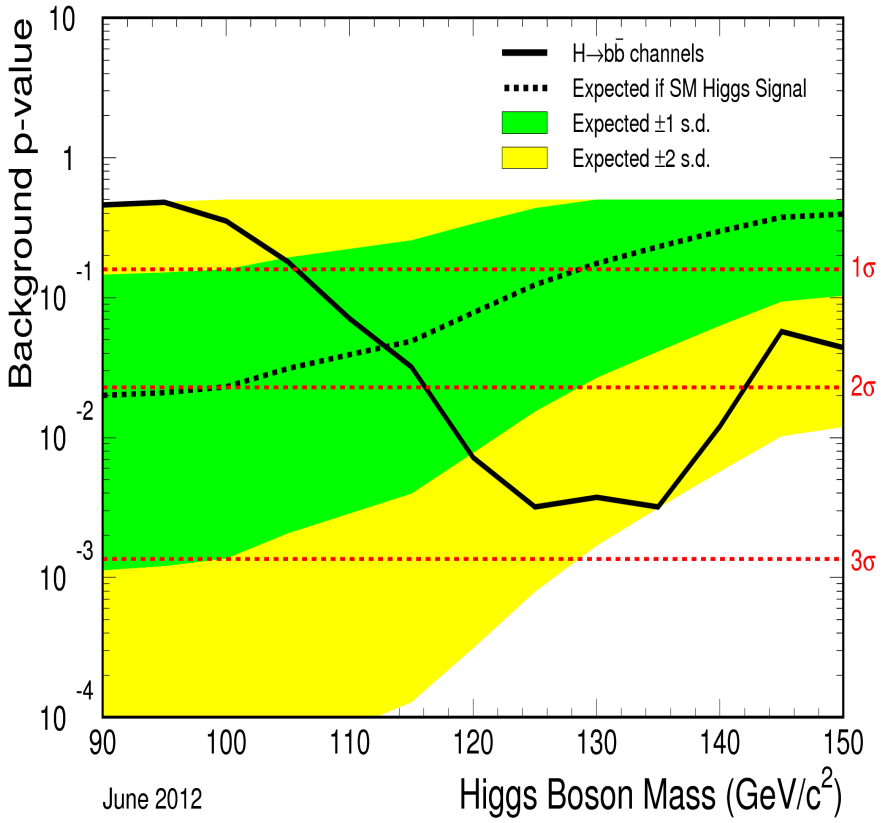
# CDF H→bb Combination

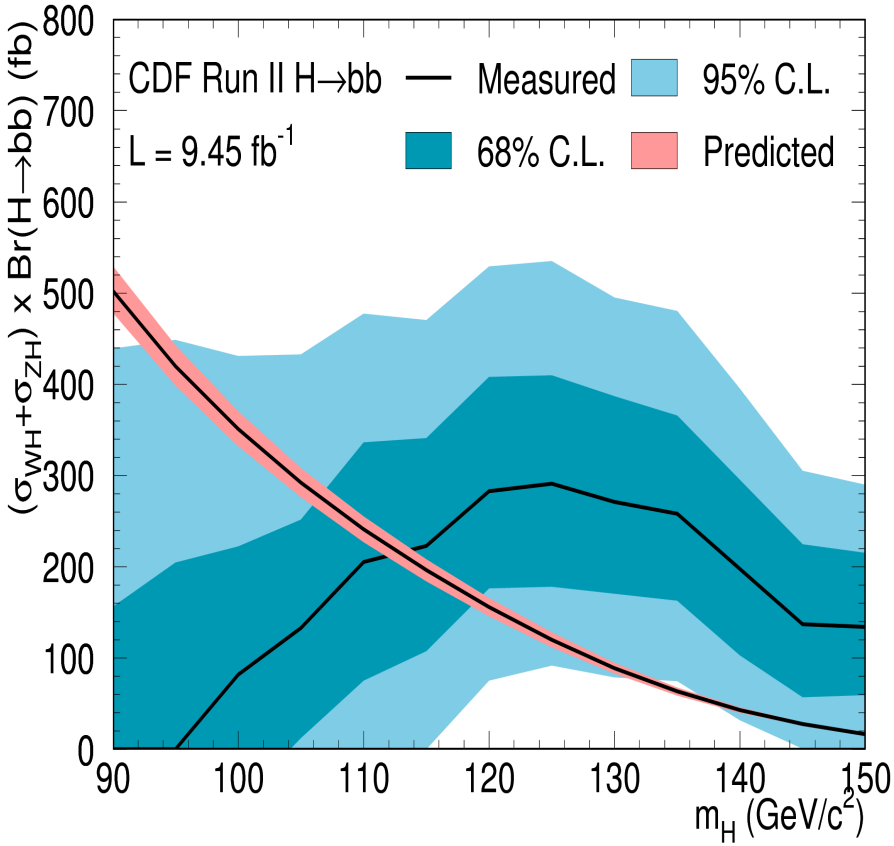
- Combining H→bb separately to see where excess comes from.
- Excess mainly driven by H→bb, which has >2σ excess in 115<mH<140 GeV.
- Set 95% CL Obs/Exp limits: 4.15/1.80 @ mH=125 GeV.



# Quantifying H→bb Excess:

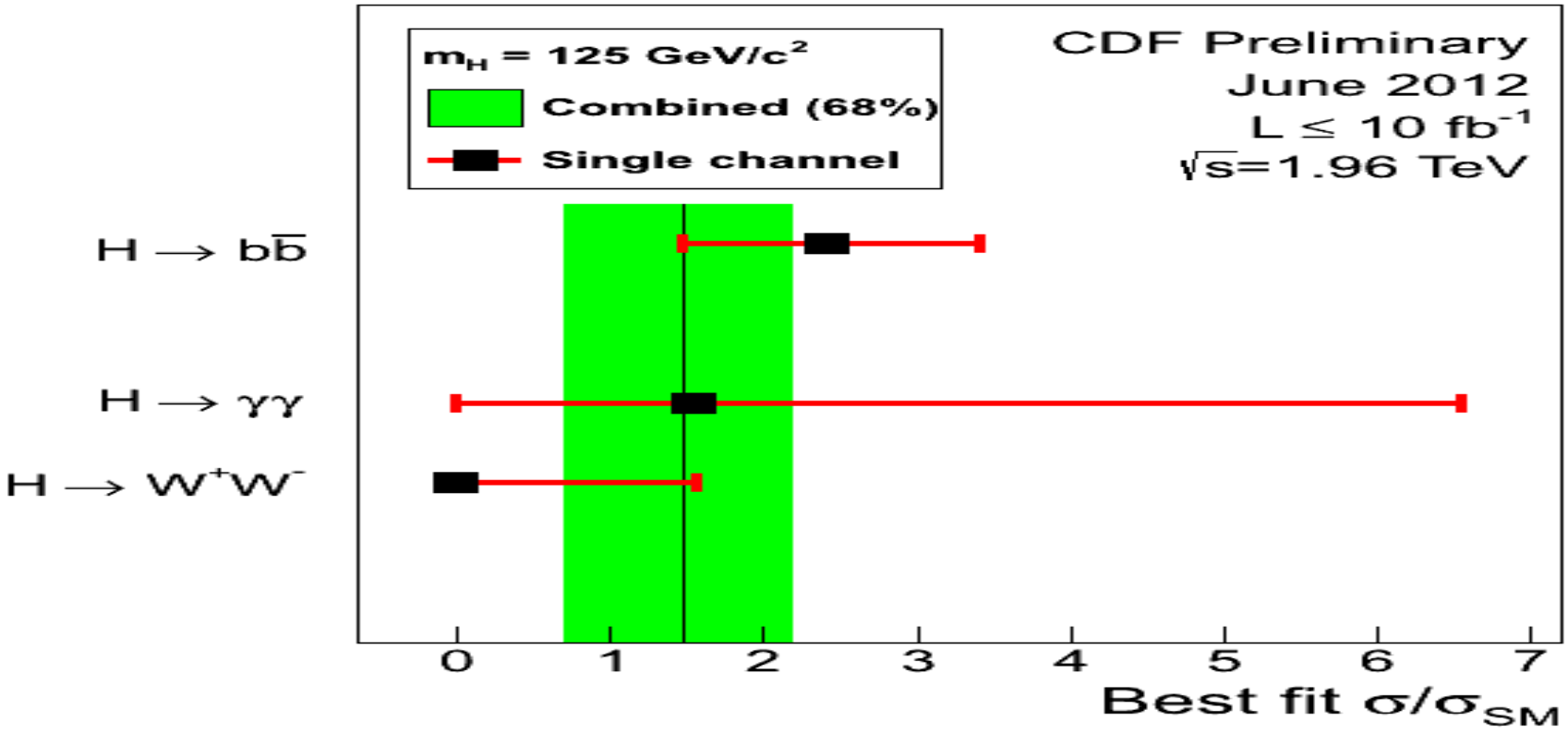
- Calculating local p-value distribution for background-only hypothesis.
- Local p-value=2.7σ at 135GeV gives global p-value=2.5σ with LEE factor 2.
- Signal strength is consistent with the SM predictions.



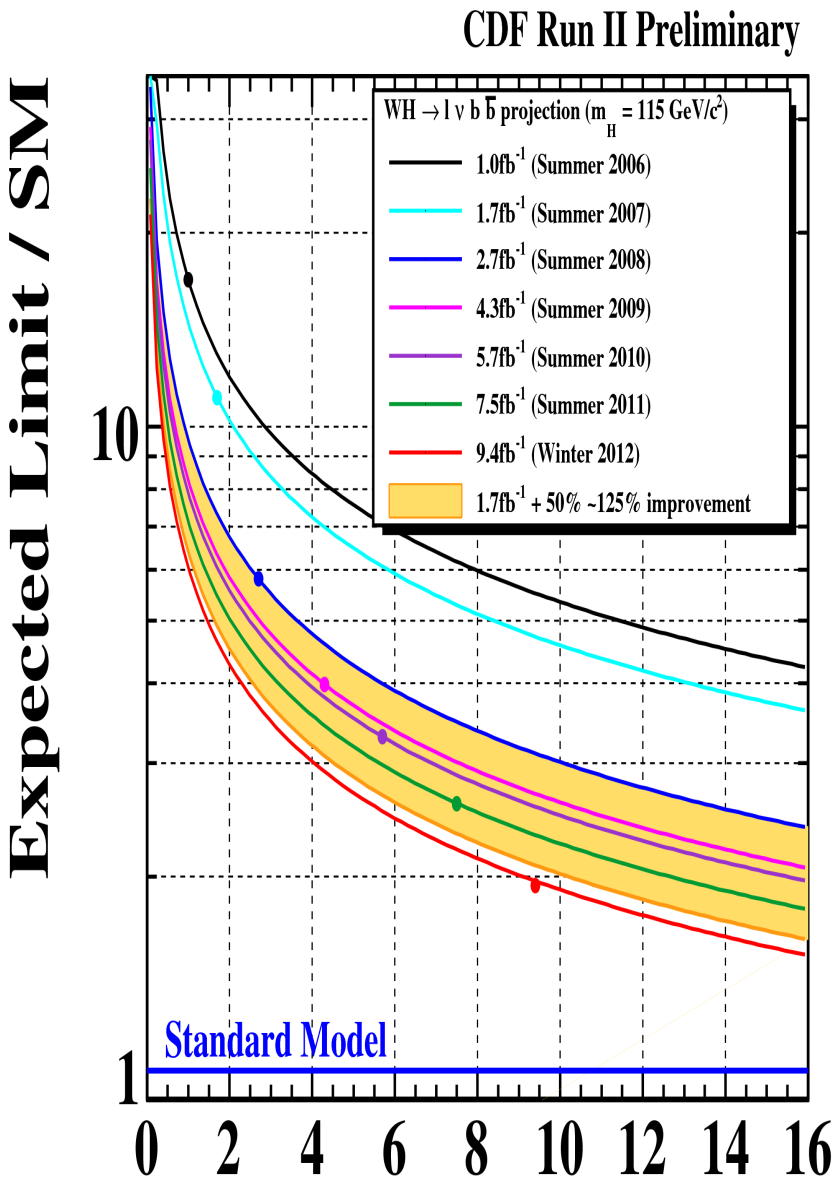
# Comparison of Signal Strength

- Fit to data with H→bb, γγ, WW, and combined signal cross section times BR respect to the SM prediction as a free parameter.
- Combined fit of 1.5+-0.7, consistent with SM Higgs @mH=125 GeV.



# Conclusion

- With full dataset, many years hardwork, CDF have exceeded our most optimistic sensitivity projection based on 2007 summer results.
- CDF observed small excess of events in H→bb in the mass range between 115 and 140 GeV with a global p-value~2.5σ.
- This is exciting and looking forward to H→bb discovery at LHC.



# BACKUP

# Compatible with SM Higgs at 125 GeV

- Compared LLR after injecting Higgs(125) to bkgd-only pesudo-experiments.
- MVA is not optimized for mass, but for S/B separation, expect a broad excess.