Probing the Higgs Boson Coupling to Bottom Quarks at the Tevatron

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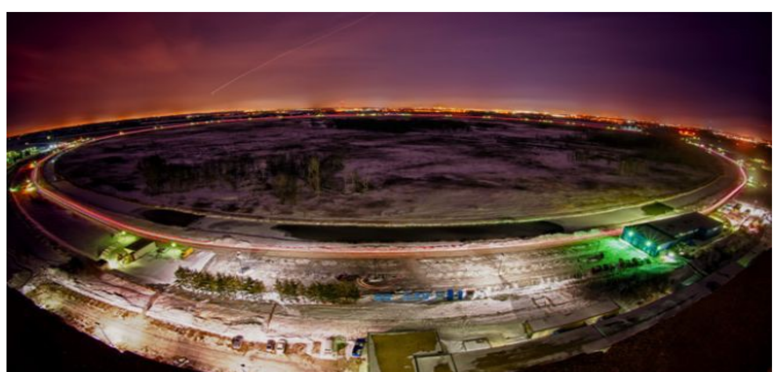
On behalf of the CDF and D0 Collaboration

The HEP Seminar at SJTU, Nov. 9, 2012



Outline

- Introduction
- Overview the Higgs Search Strategies
- Recent Improvements
- Tevatron Higgs Results with Full Dataset
  - Evidence for H→bb in WH/ZH production(PRL 109 071804, 2012)
- Conclusion

λMore Details (some updates expected at HCP 2012):

http://www-cdf.fnal.gov/Physics/S12CDFResults.html

http://www-d0.fnal.gov/Run2Physics/D0Summer2012.html

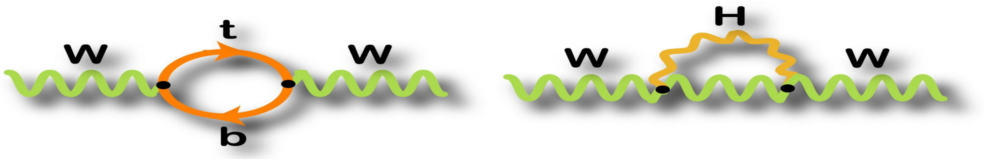
http://tevnphwg.fnal.gov/results/SM_Higgs_Summer_12/

- Both CDF and D0 have published their searches in WH→lvbb, ZH→llbb, VH→metbb, and the combination with full dataset.

Introduction

•Higgs boson is hypothesized to be the remnant of the Higgs field that is responsible for the electroweak symmetry breaking.

•M_H is unknown,but indirect constrained by the global fit: M_H<152GeV@95%CL.



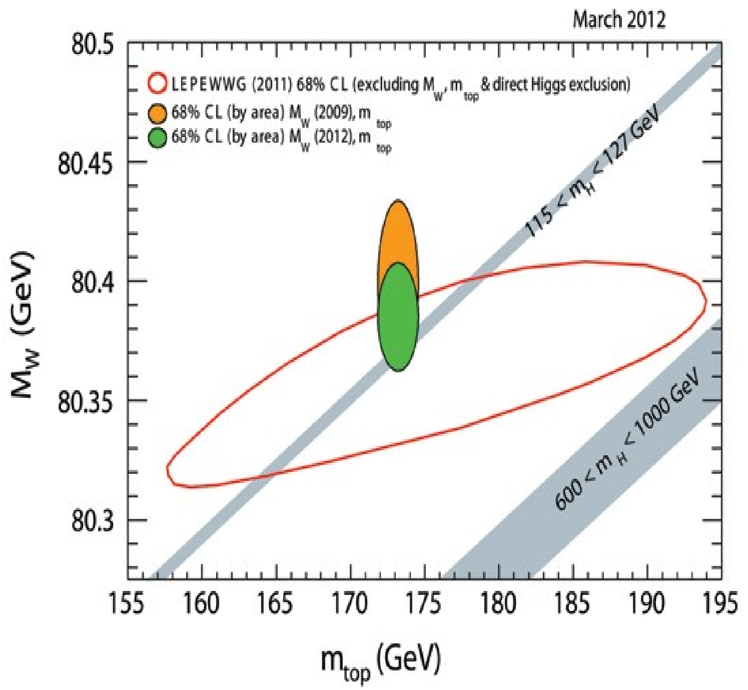
•Direct searches @95% CL:

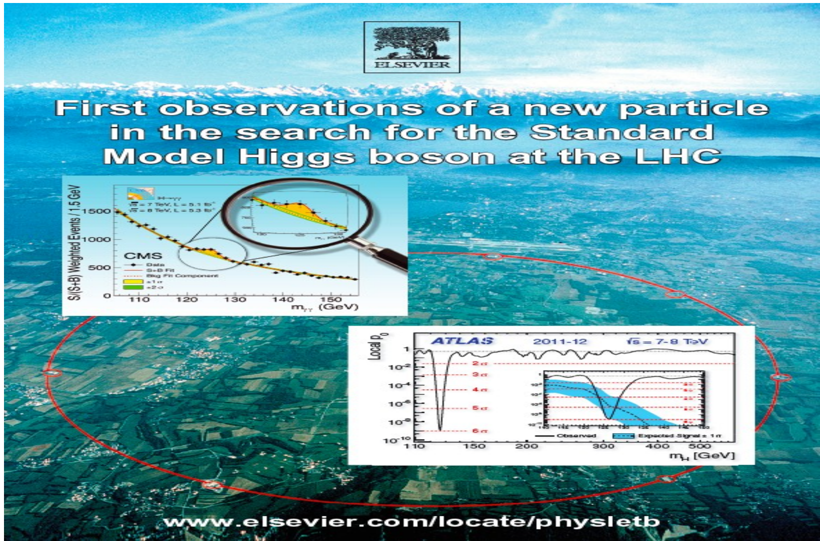
– LEP, M_H>114.4 GeV

– Tevatron: exclude 147<M_H<179 GeV

– LHC:122<M_H<127 GeV.

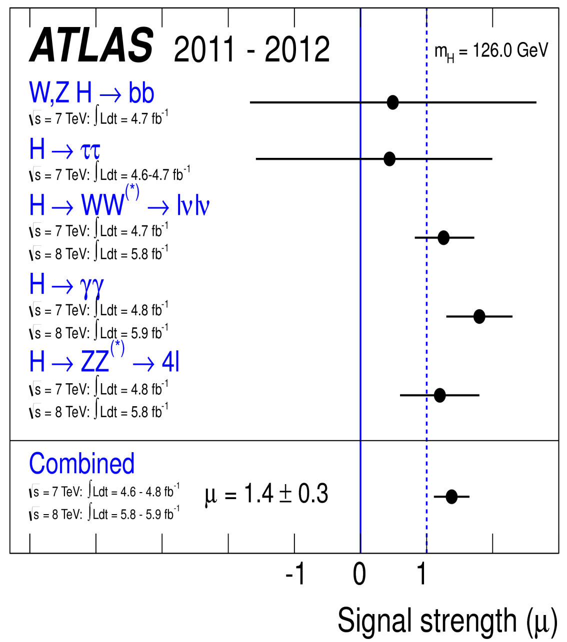
•Consistent with the LHC observation of a Higgs-like particle at 125 GeV.

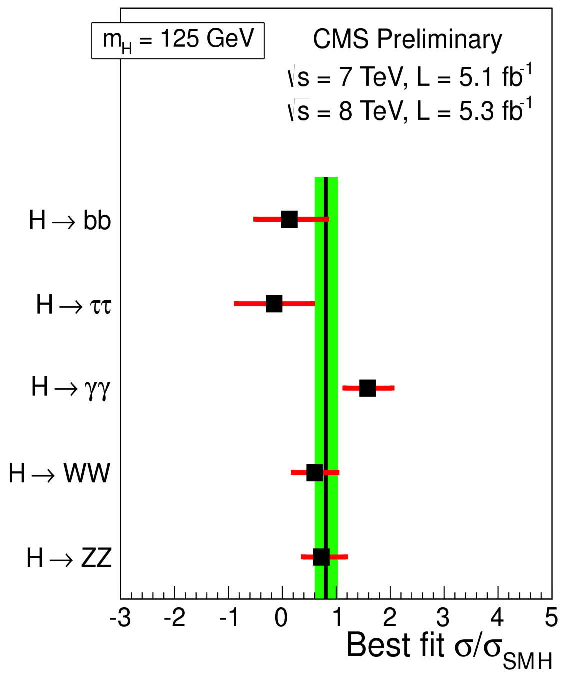


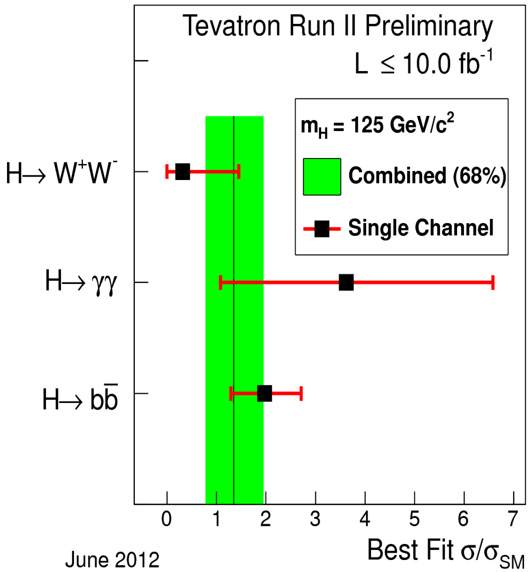


What is it ?

- In SM, bosons and fermions expected to gain mass through Higgs coupling.
- Both ATLAS and CMS report strong signal for Higgs decays to γγ, WW, ZZ, which probe the coupling of Higgs to bosons. But no coupling to fermions yet.
- Tevatron reported 3.1σ excess of H→bb in recent RPL, which could provide the first evidence of Higgs coupling to b quarks.

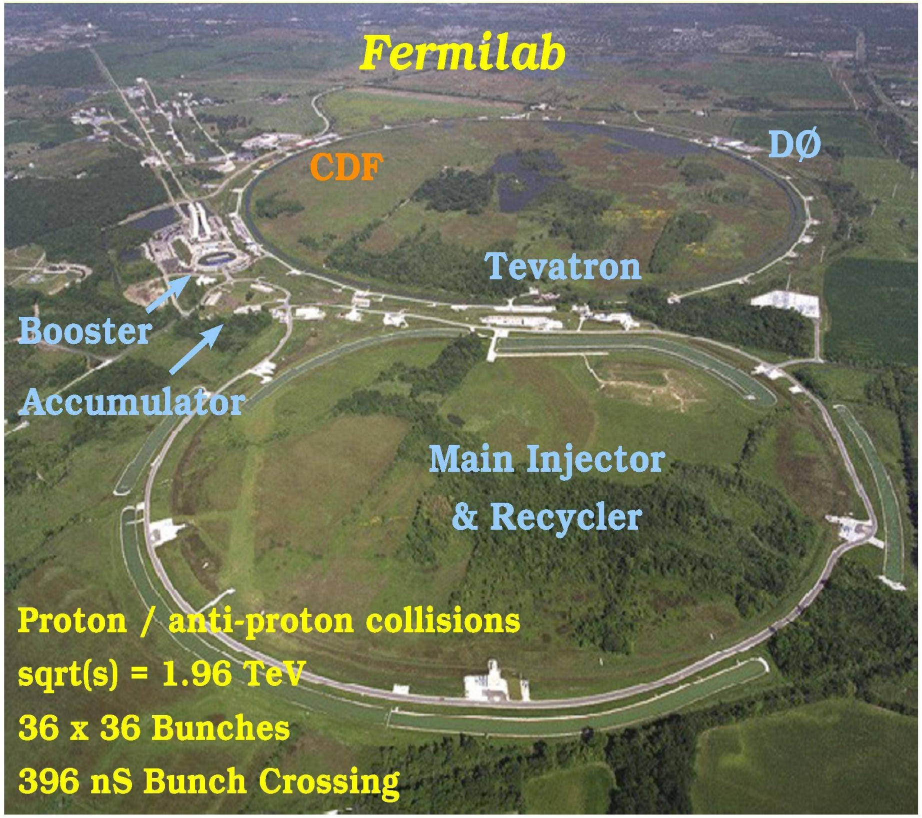


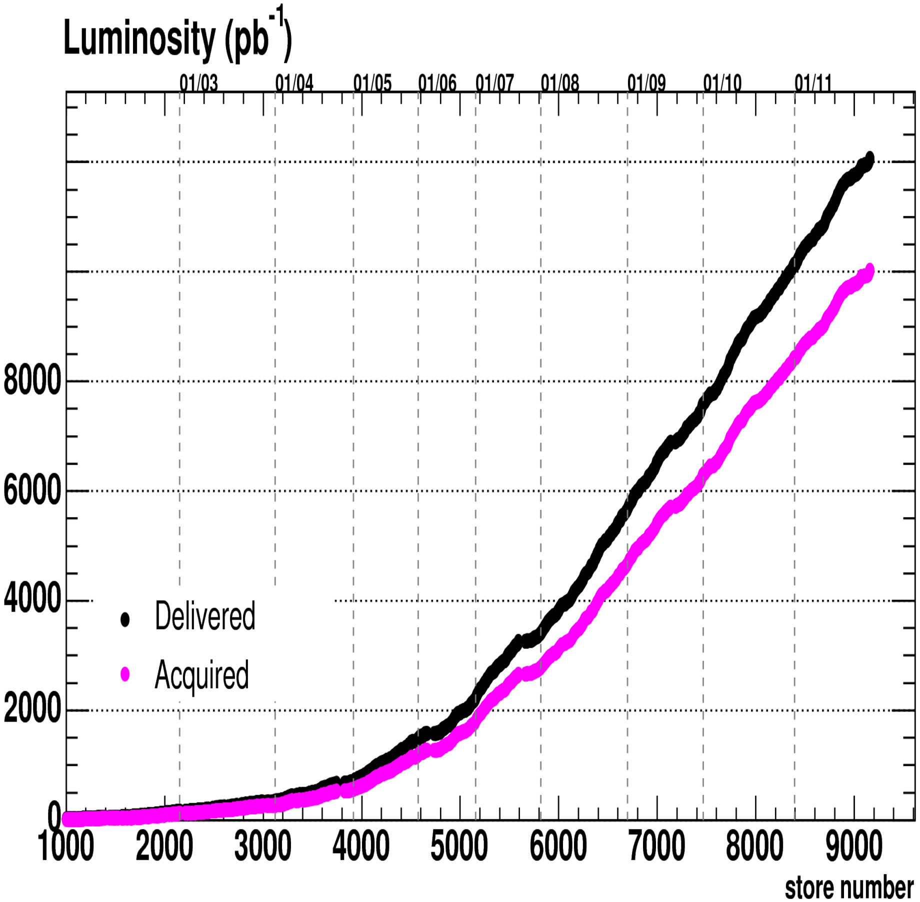




The Tevatron

- Tevatron: p-pbar collision@1.96TeV, L_{peak}=4.3x10^{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})

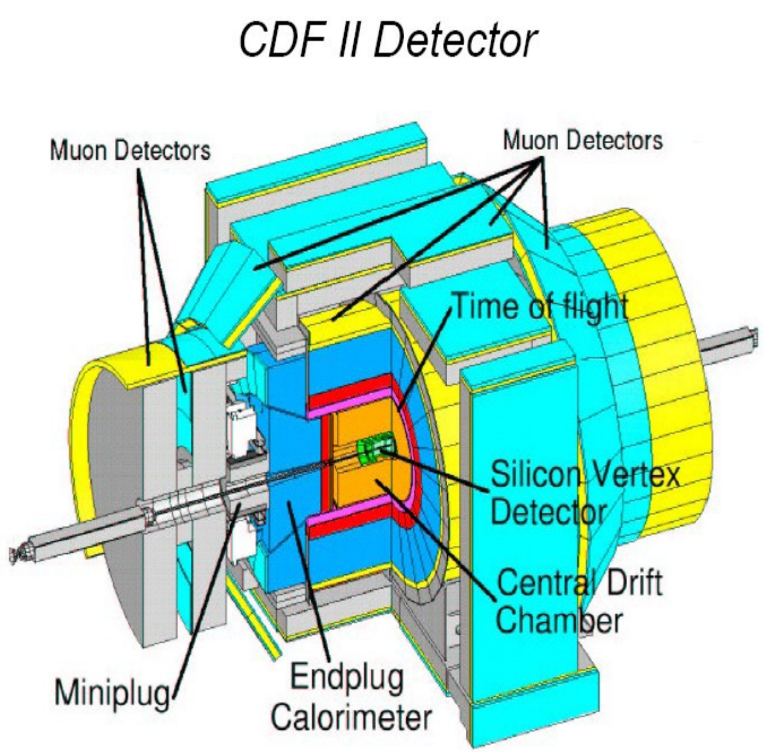




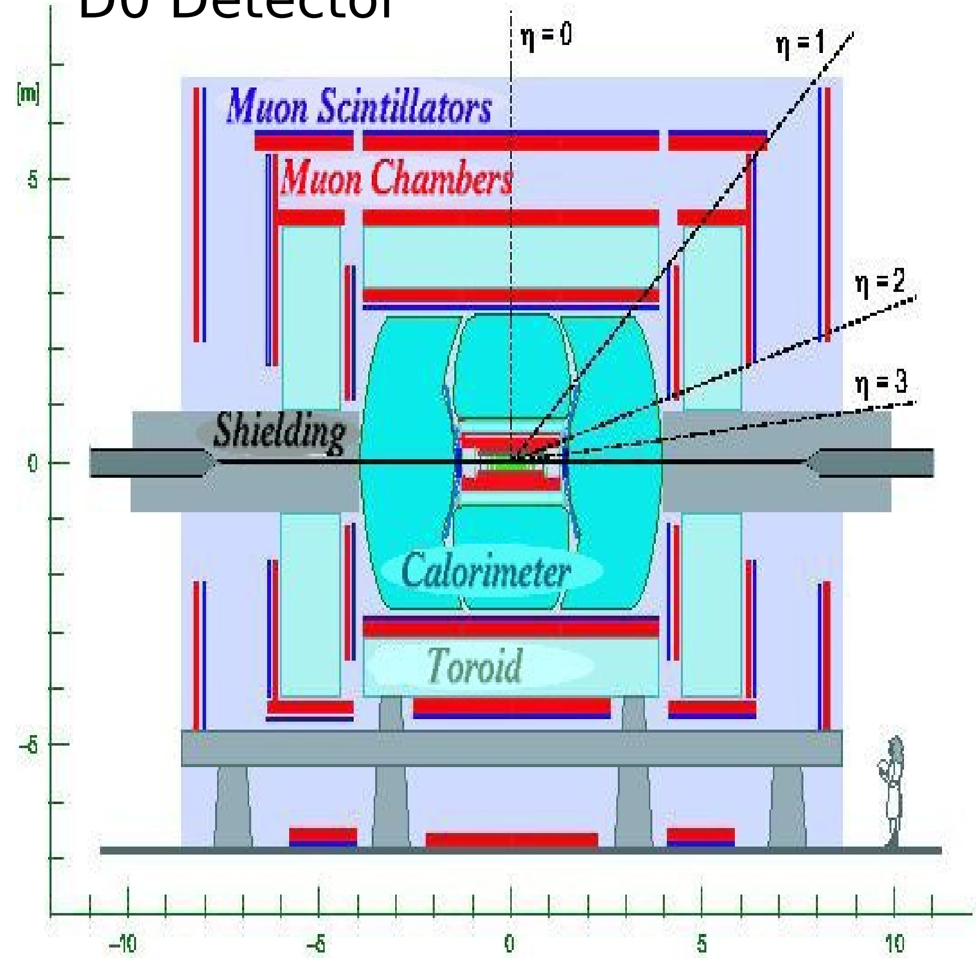
CDF & D0 General-purpose Detectors

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

•Efficient multi-level triggers to select events with the combination of leptons, met, and jets in the final states.

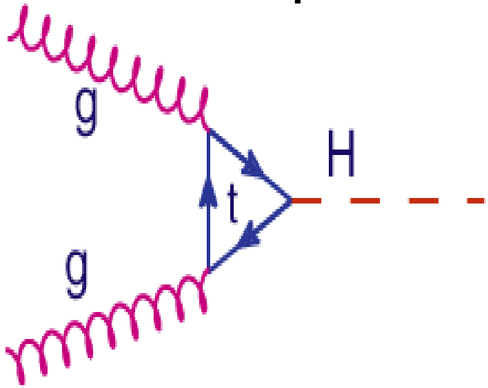


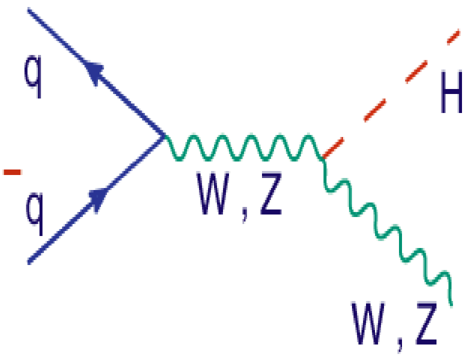
D0 Detector



SM Higgs Production and Decay @ Tevatron

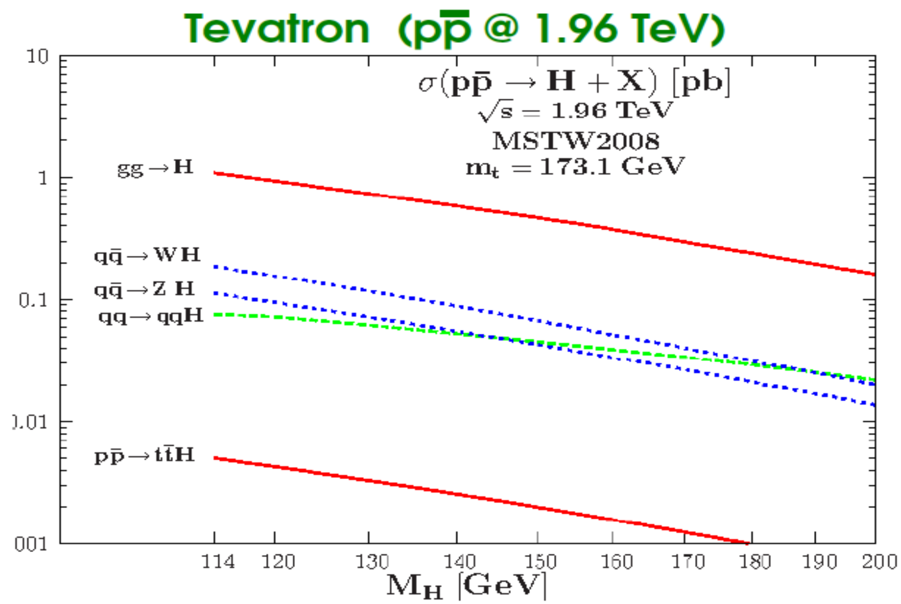
- Dominant production processes:

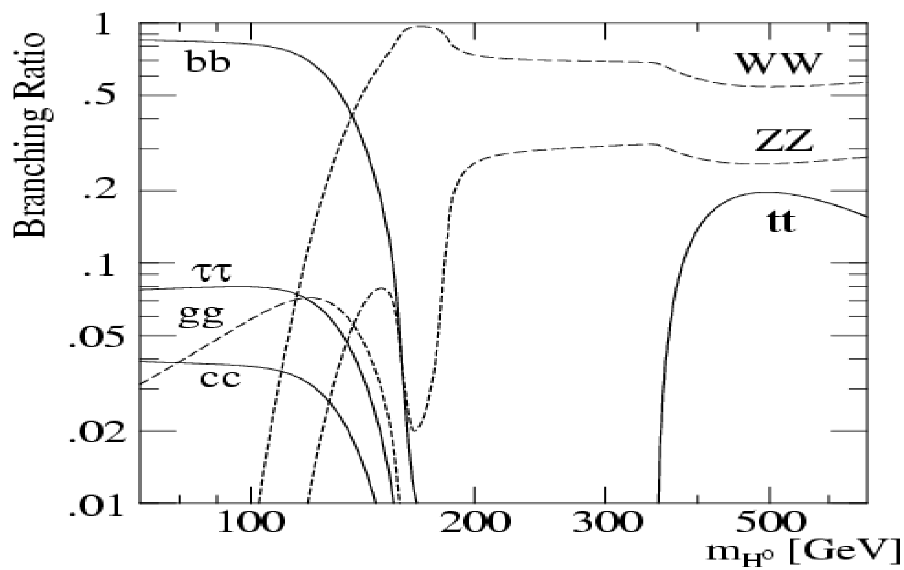




- For lower mass(M_H<135 GeV):
  - Main decay:H→bb in WH/ZH
  - Direct production gg→H→bb is limited by multi-jet QCD.
- For higher mass(MH>135GeV):

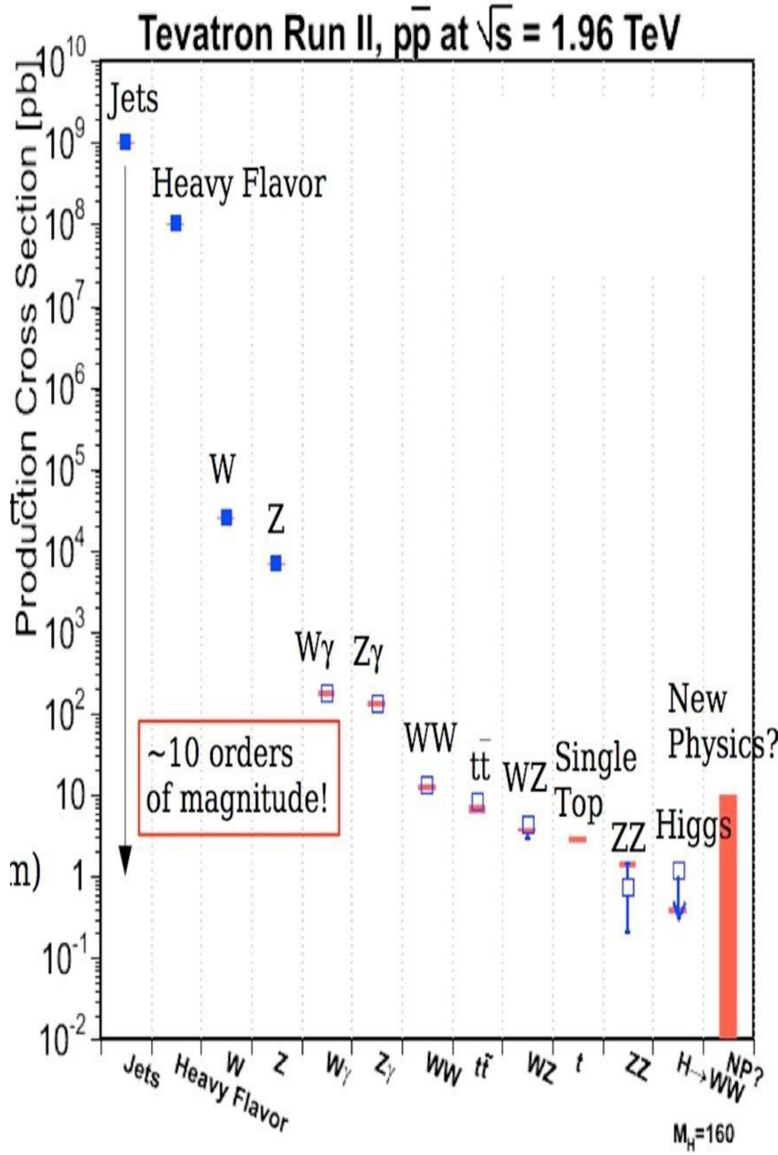
  Mainly decays: gg→H→WW,ZZ
- Other decays: H→ττ,γγ, and ttH.





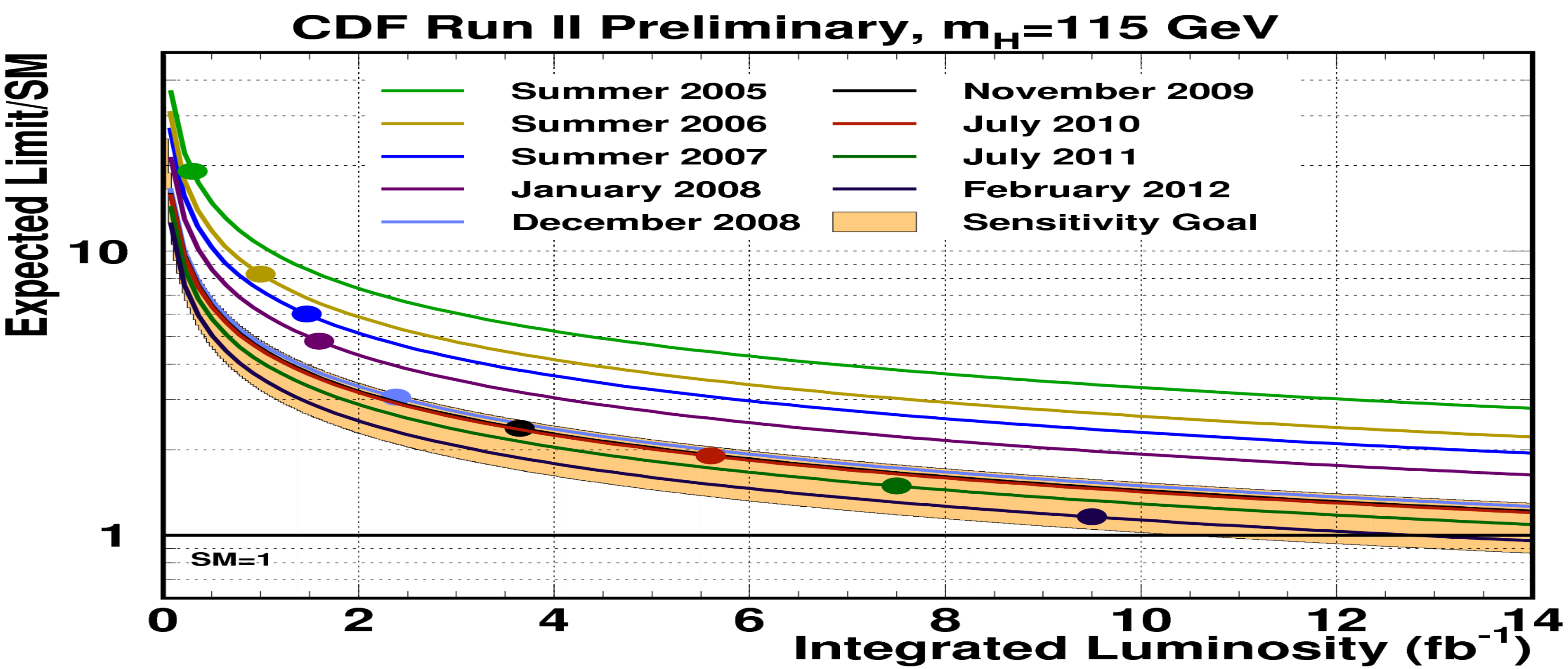
The Challenge

- The Challenge for Higgs search at Tevatron is 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.



Sensitivity Improvement

- In the past, we constantly introduced and improved analysis techniques that boost sensitivity beyond expectation from increased luminosity.
- Orange band corresponds to our conservative and aggressive sensitivity projection based on 2007 summer results.

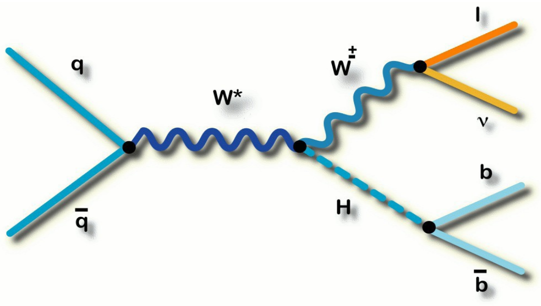


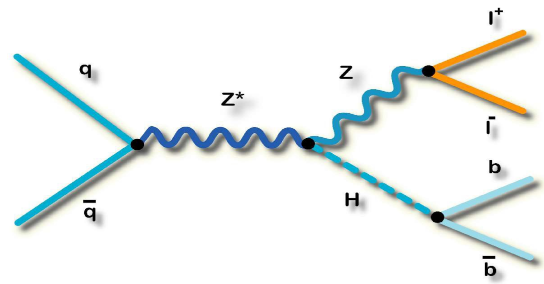
SM Higgs Event Yield Expectation

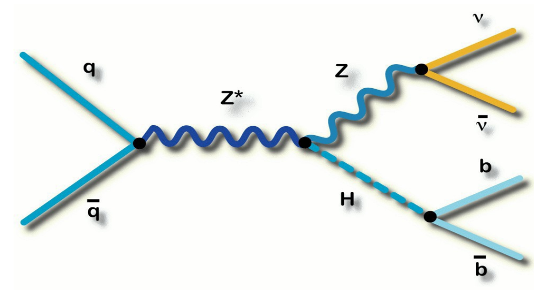
- Expected number of events per detector for selection in 10 fb^{-1} before acceptance, which is about 10% for H→bb, 25% for H→WW

Higgs Mass	WH→lvbb	ZH→llbb	ZH→vvbb	H→WW→lvlv
115 GeV	280	60	140	100
125 GeV	180	40	100	180
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

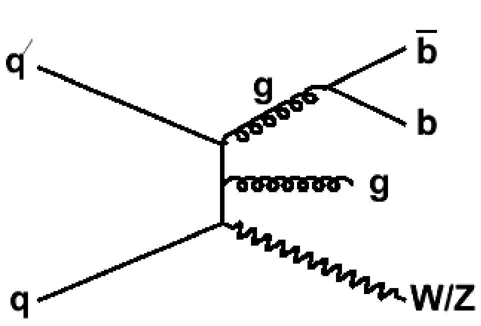
Search for H→bb

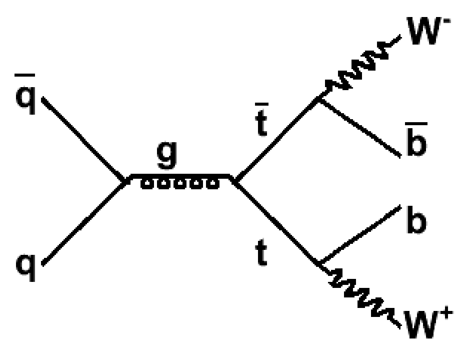


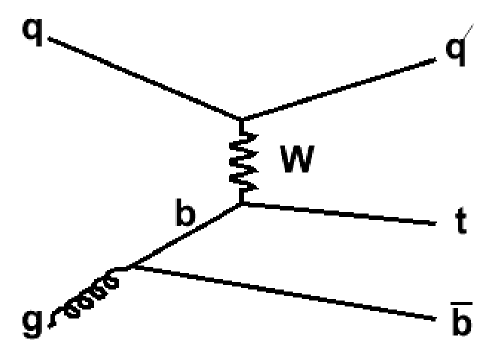




- Search for H→bb resonance in association with W or Z.
  - –WH→lνbb, most sensitive low-mass channel: one lepton+MET+ 2b
  - –ZH→llbb: two leptons + 2b
  - –ZH→νν, WH→ (l)νbb: 0lep+met + 2b
- Major backgrounds: W+jets, Z+jets, ttbar, singletop, diboson, QCD





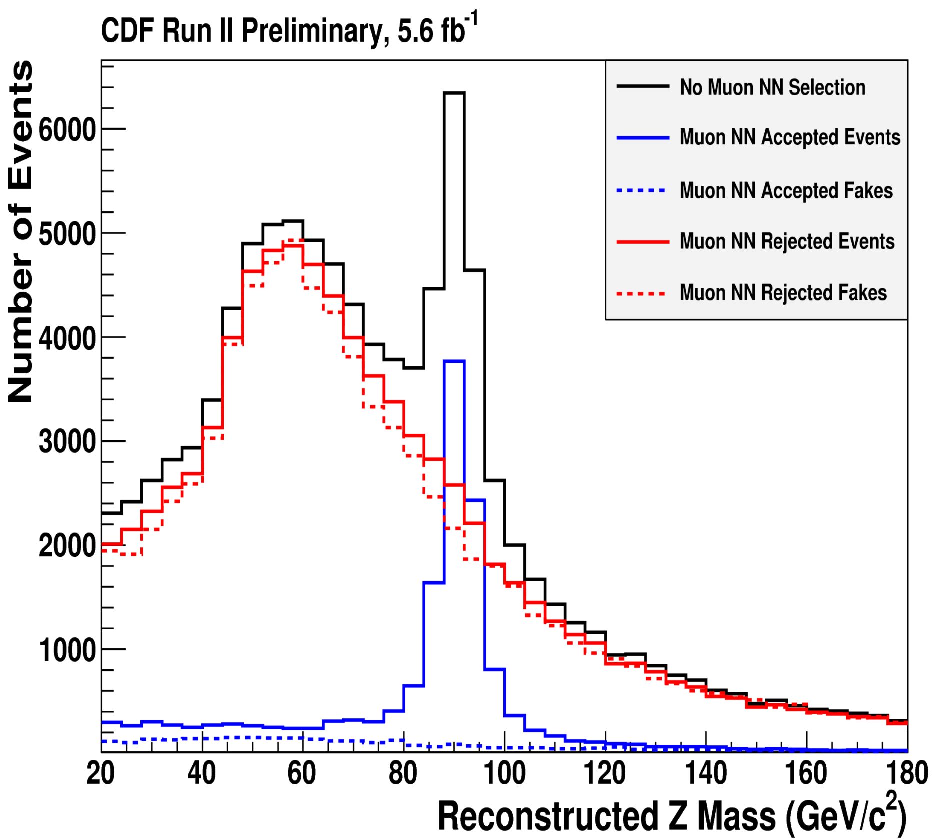


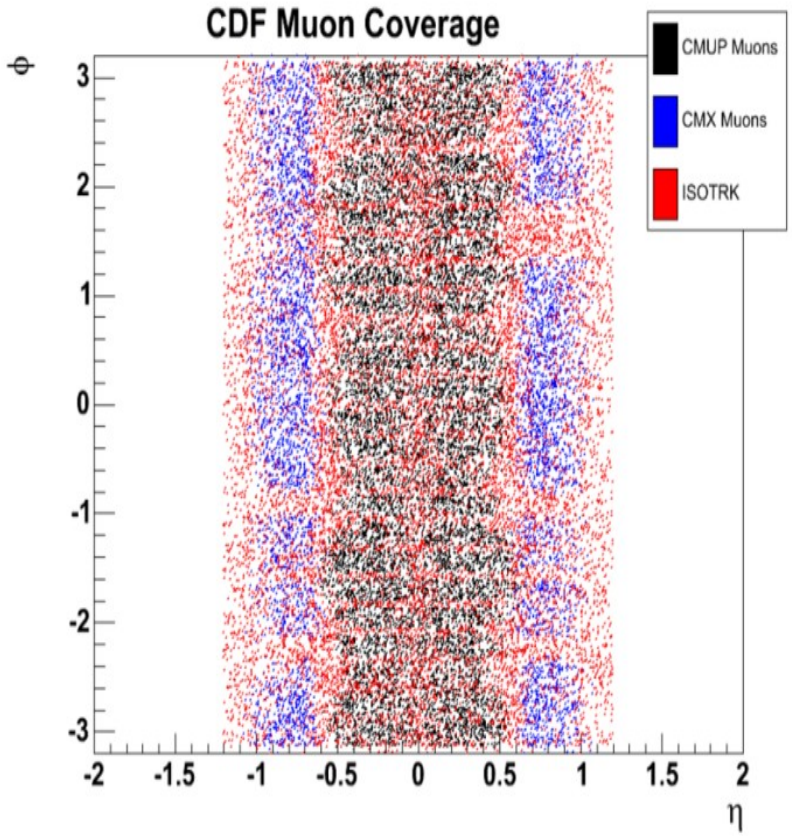
Streamline Searches

- Analysis: common tools to maximize the sensitivity.
  - Optimized selections(Maximize acceptance,minimize backgs)
  - Reduce W/Z+jets background with b-tagging
  - Improving $H \rightarrow bb$ dijet mass resolution.
  - Multivariate discriminant (NN, BDT)
- Systematic: careful treatment of systematic, correlation cross channels & experiments as appropriate
  - Integrated luminosity(6%), Trigger and Lepton ID(2-5%)
  - B-tagging (3.9-7.8%), mistags (10-20%)
  - JES shape and rate, ISR/FSR/Q2
  - Theoretical cross sections uncertainties
  - MC simulation of W/Z+HF(rate only)
- Interpretation: extract 95% CL Upper limits on Higgs production rate using Bayesian & Cls statistical techniques.
  - Most nuisance parameters are well constrained in the background dominated region.

Maximizing Lepton ID & Triggers

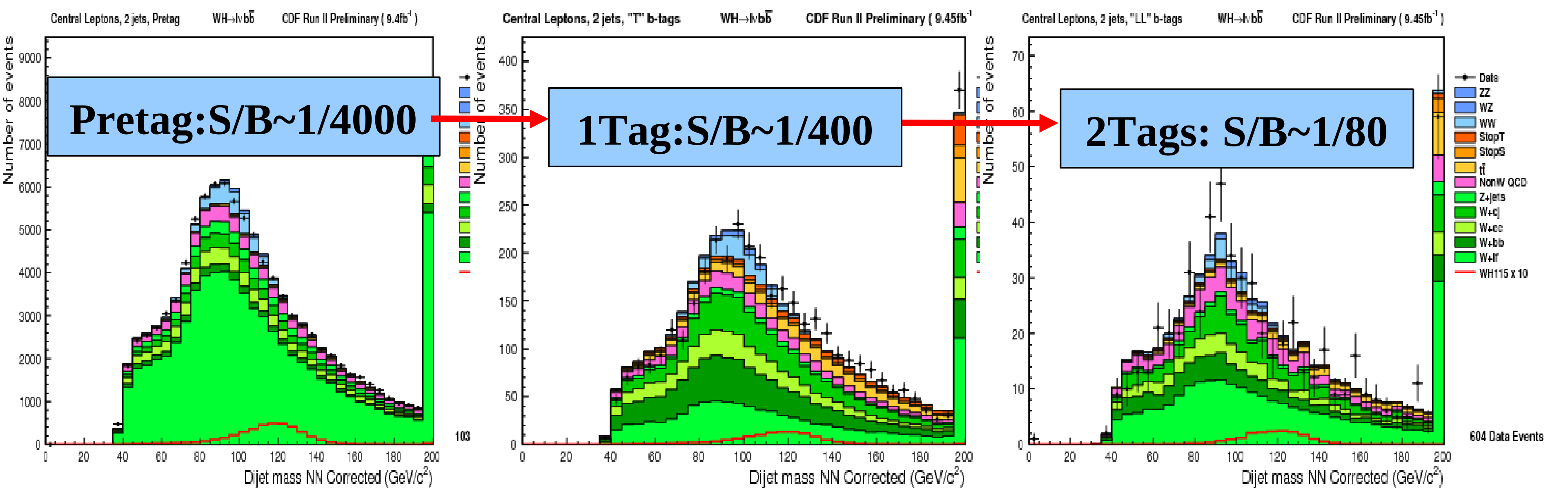
- Selecting high Pt lepton with multivariate ID gains 20% more Z's than the cut-based selections.
- Including isolated high Pt track from met triggers.





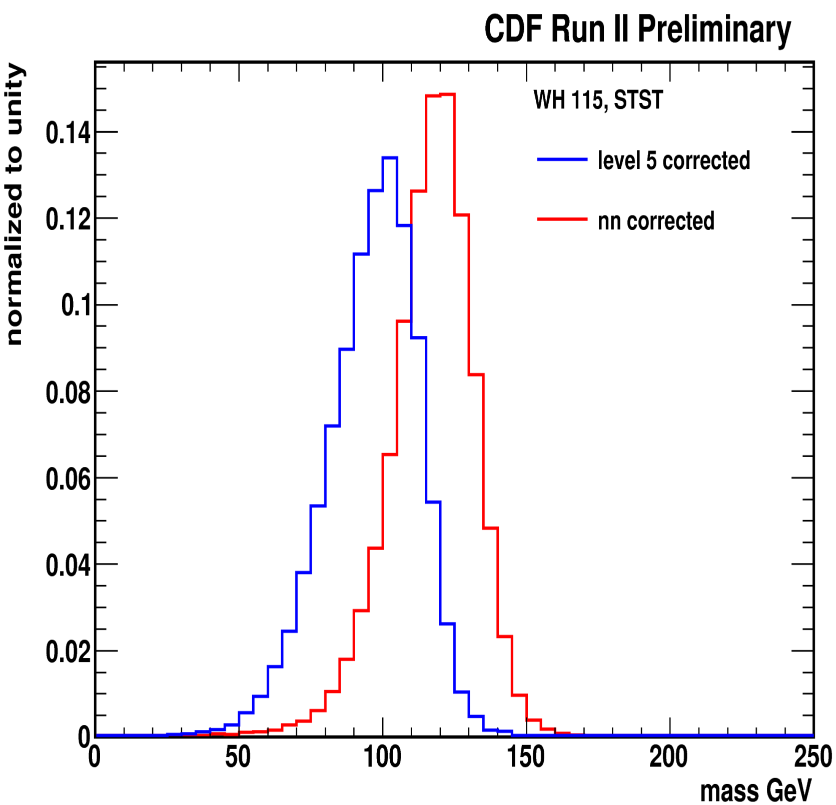
Improvement of b-tagging

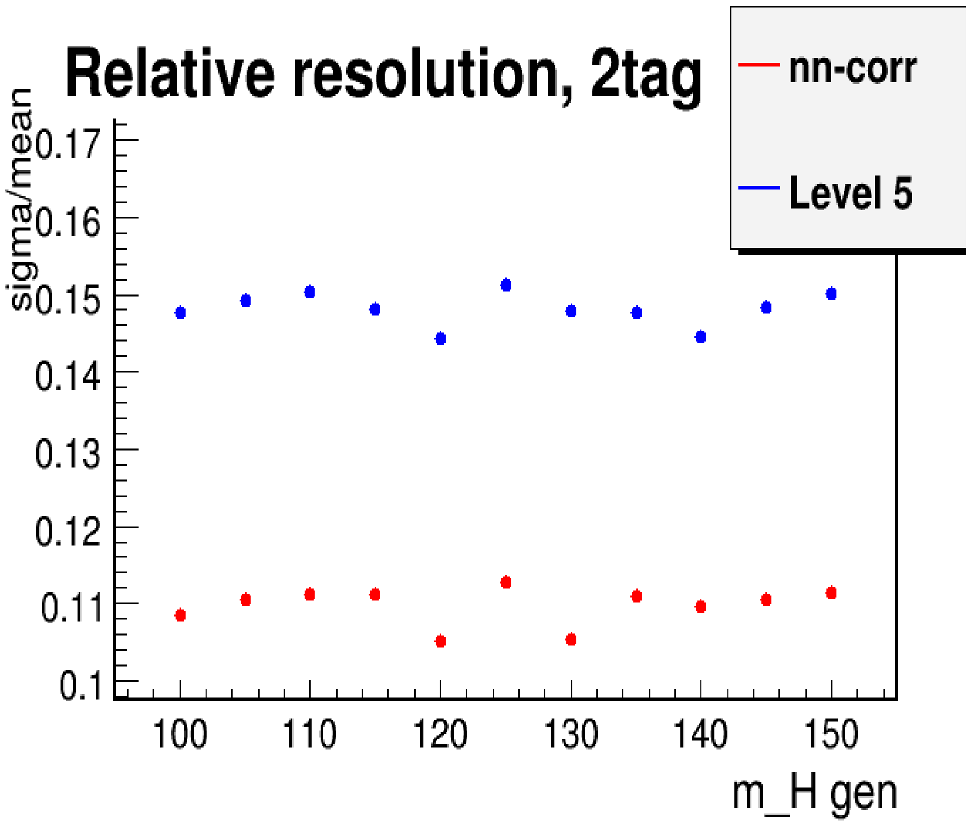
- CDF & D0 use MVA technique to improve b-tagging that exploits the decay of B hadron as displaced tracks/vertices. Typical eff:40-70% with mistag:1-5%.
- Recently CDF combined existing b-tags into a Higgs optimized b-tagger (HOBIT), which improves eff by 20% while keeping mistag rate same.
- Requiring b-tag enhance S/B by a factor of 50 in WH→lvbb.
- Plots also demonstrated excellent SM background modeling.



Improving Dijet Mass Resolution

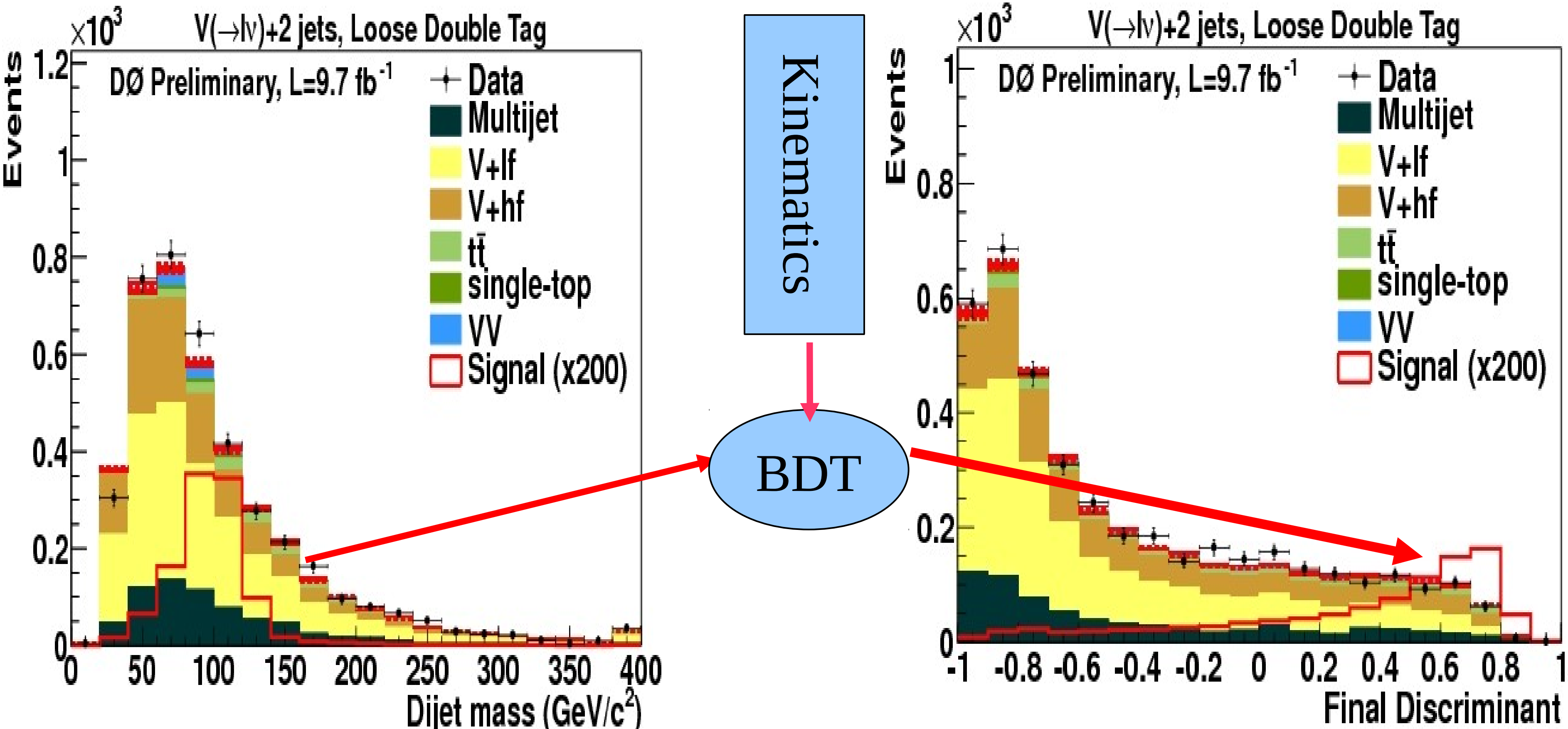
- Invariant mass of two b-jets provides most discriminant power to separate signal from backgrounds.
- Achieve best resolution by combining calorimeter and tracking info.(Et, Pt, Ptmax, ctau...), 9 inputs using Neutral Network (CMS tried as well).





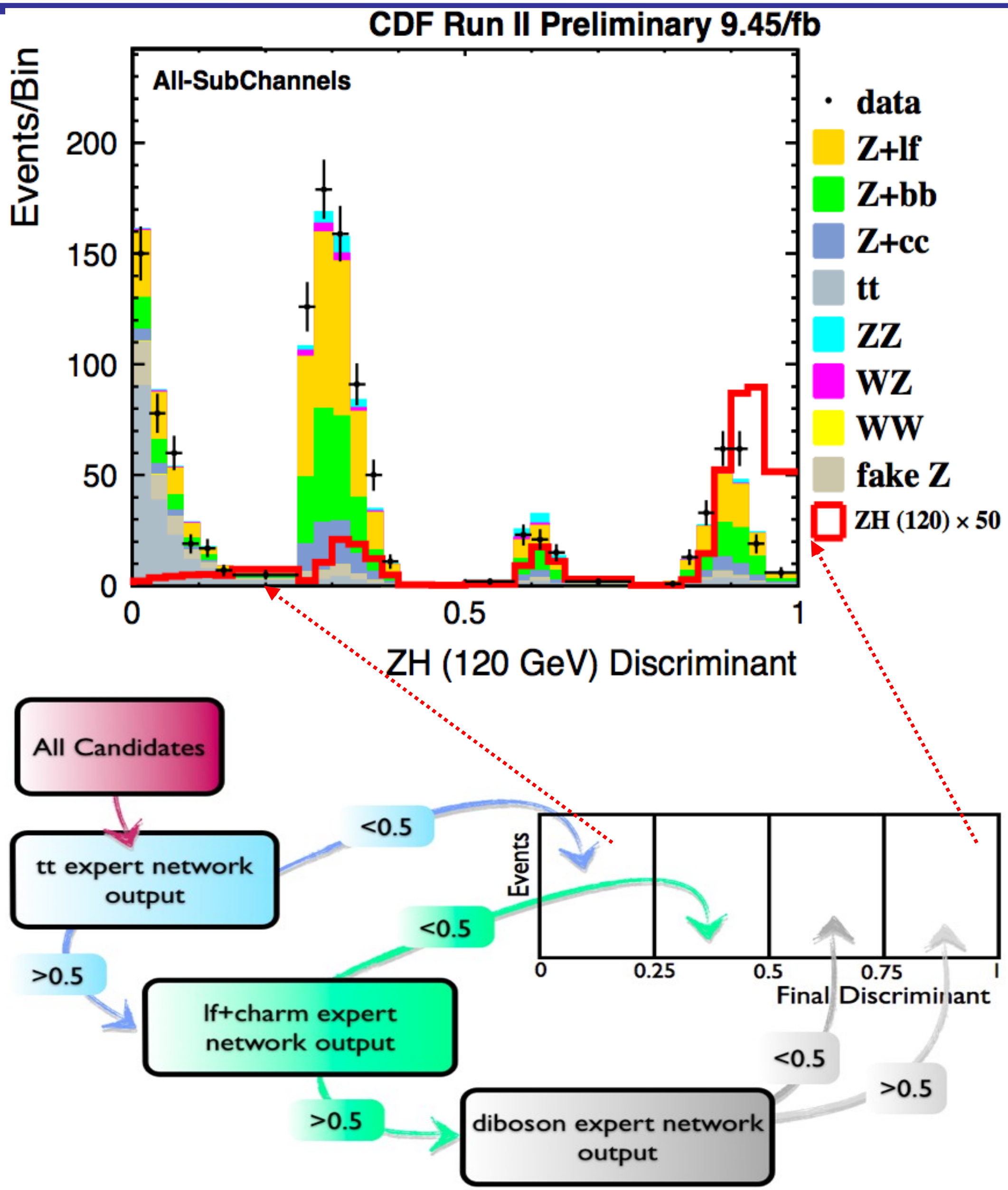
Multi Variate Analysis (MVA)

- Most Higgs analysis use MVA to improve background rejection by combining mjj with additional event kinematic.
- Gains ~25% sensitivity than a single variable



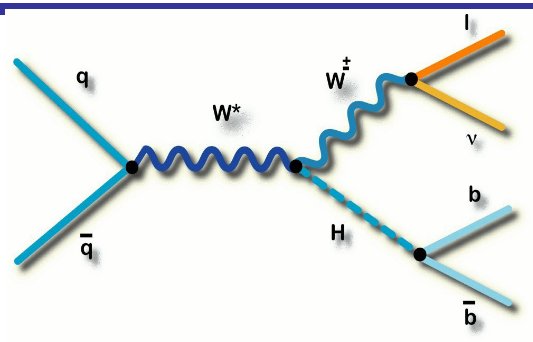
Improvement of Multivariate Discriminant

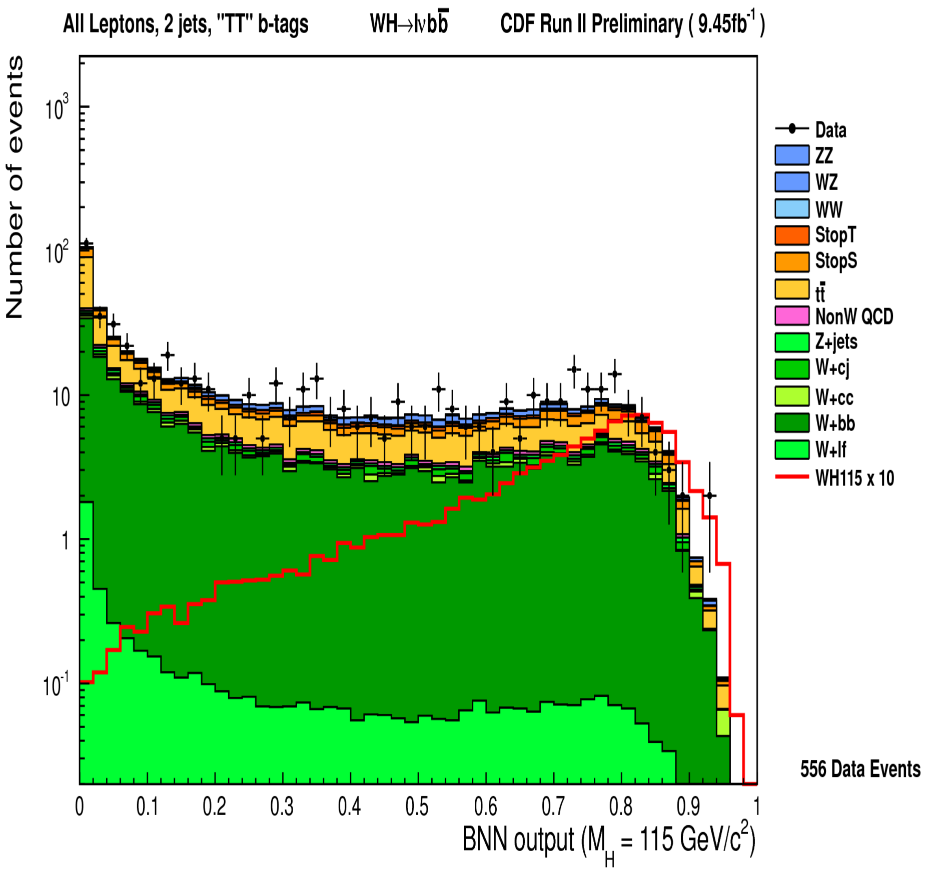
- We can further improve MVA by training against multiple bkgds, splitting analysis into sub-channels based on S/B, e.g. lepton type, number of jets.
- Trained ZH→llbb vs ttbar, z+c, diboson, separately to build the final discriminant.
- Gain another ~10-15% improvement in sensitivity.

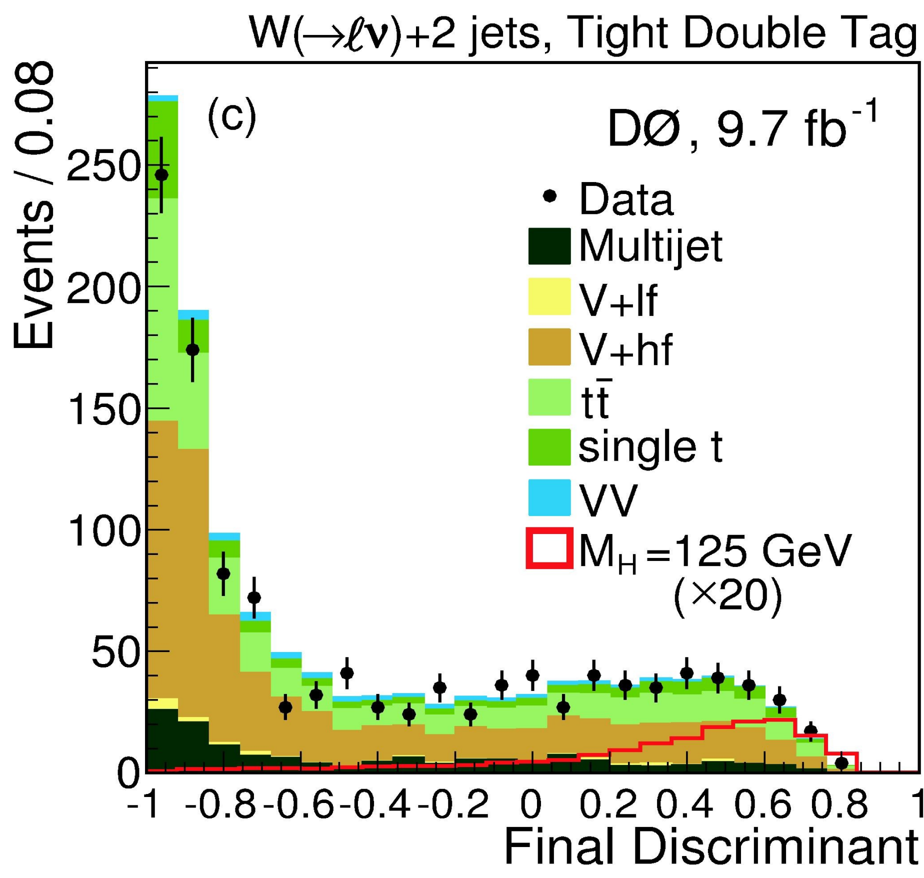


Search for WH→lvbb

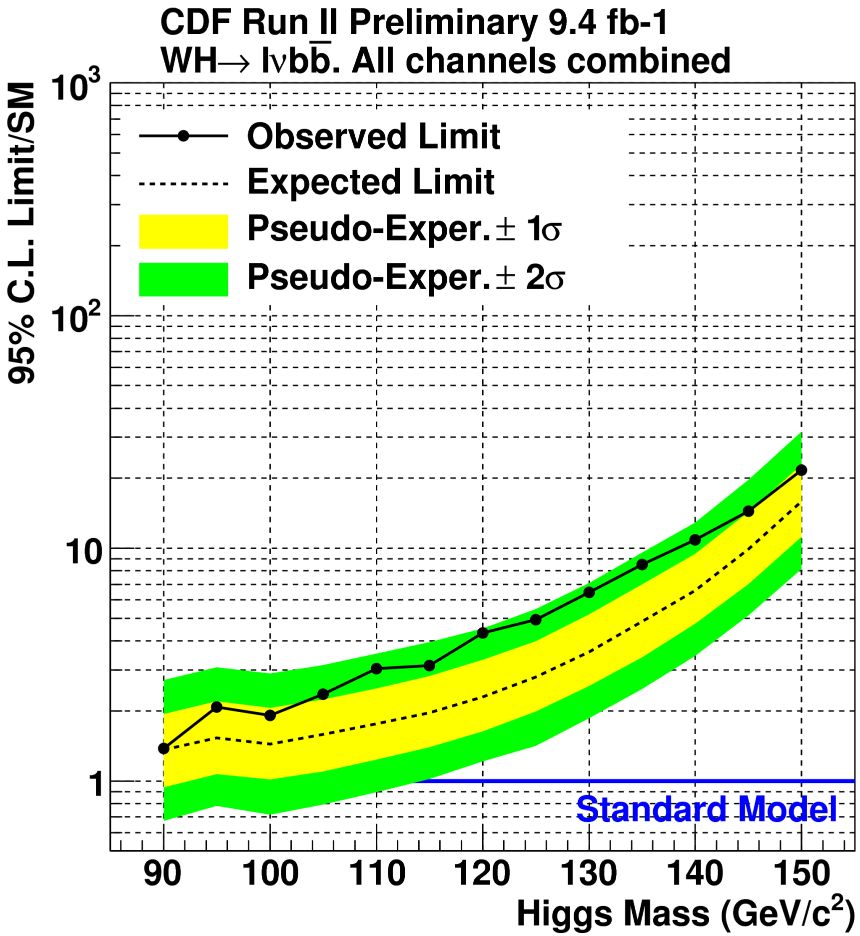
- •WH→lvbb is one of most sensitive channel.
- •Easy to trigger on lepton, missing Et, 2 and 3 jet.
- •Require b-tag & MV discriminant.

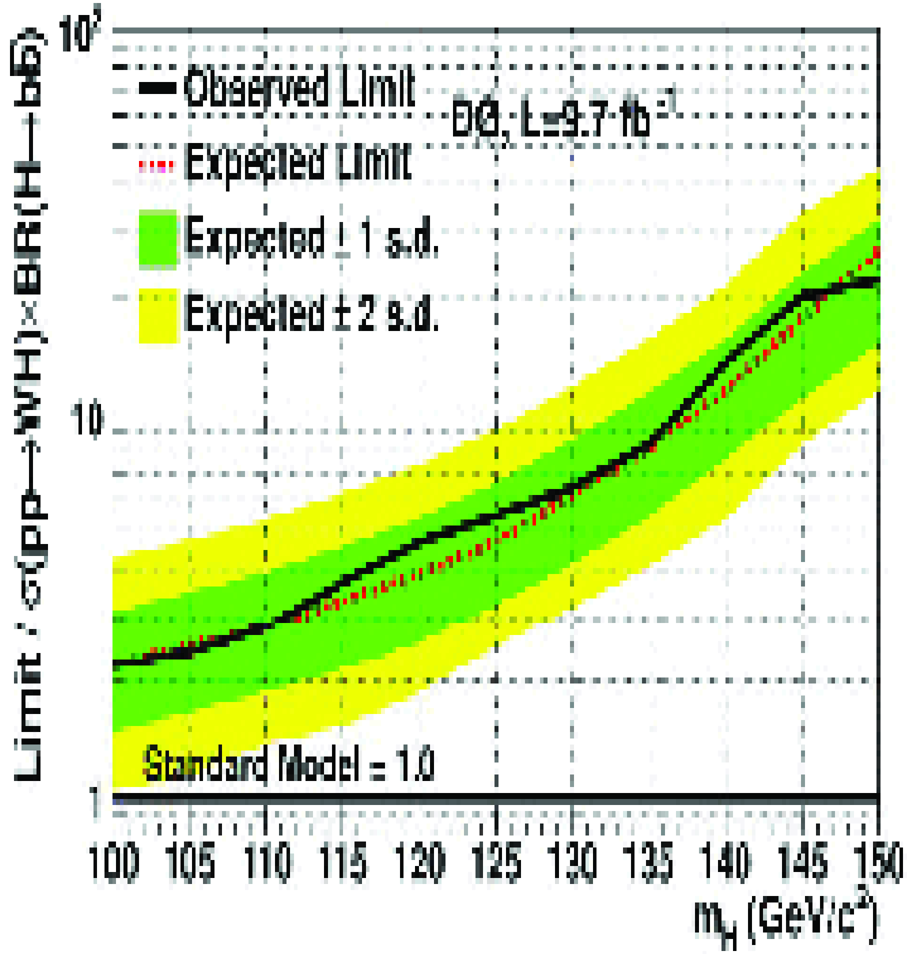






WH→lνbb Limits

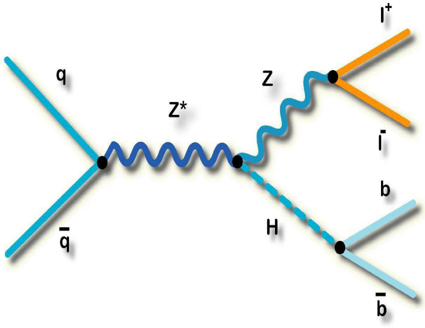




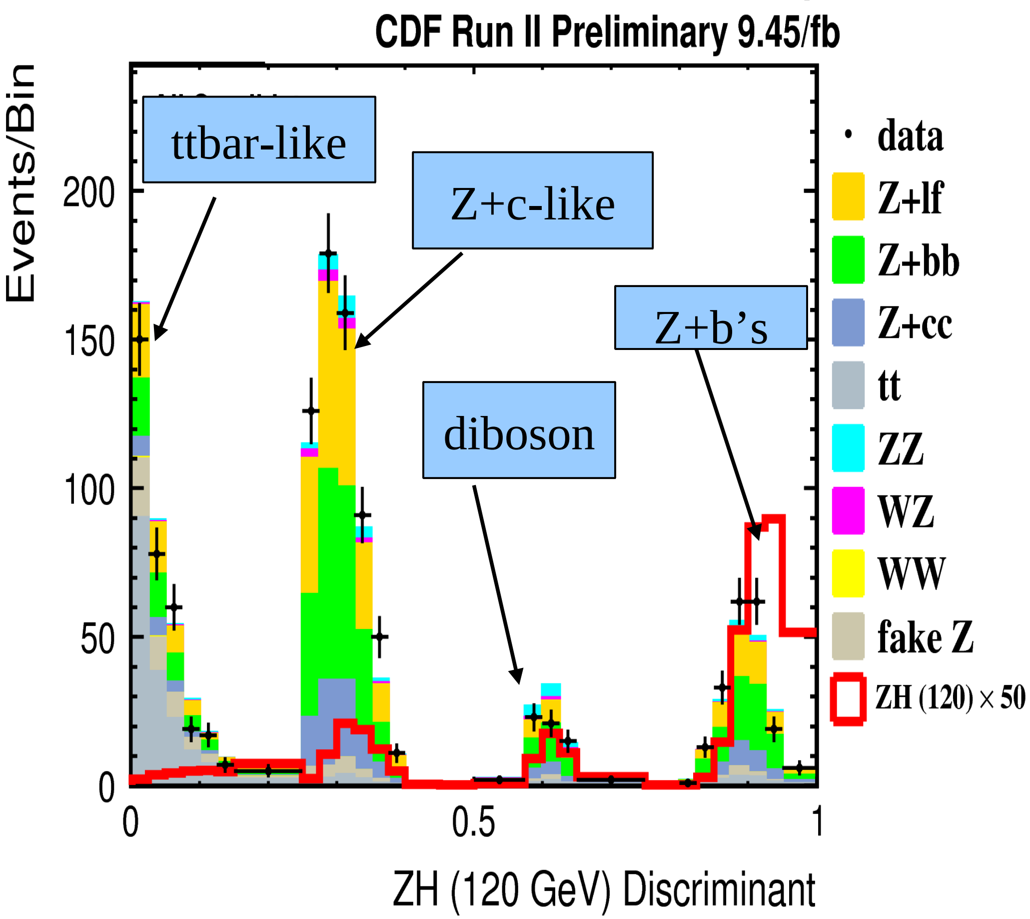
•Set 95% CL obs/exp limits: 4.9/2.8(CDF) and 5.2/4.7(D0) @ 125 GeV.

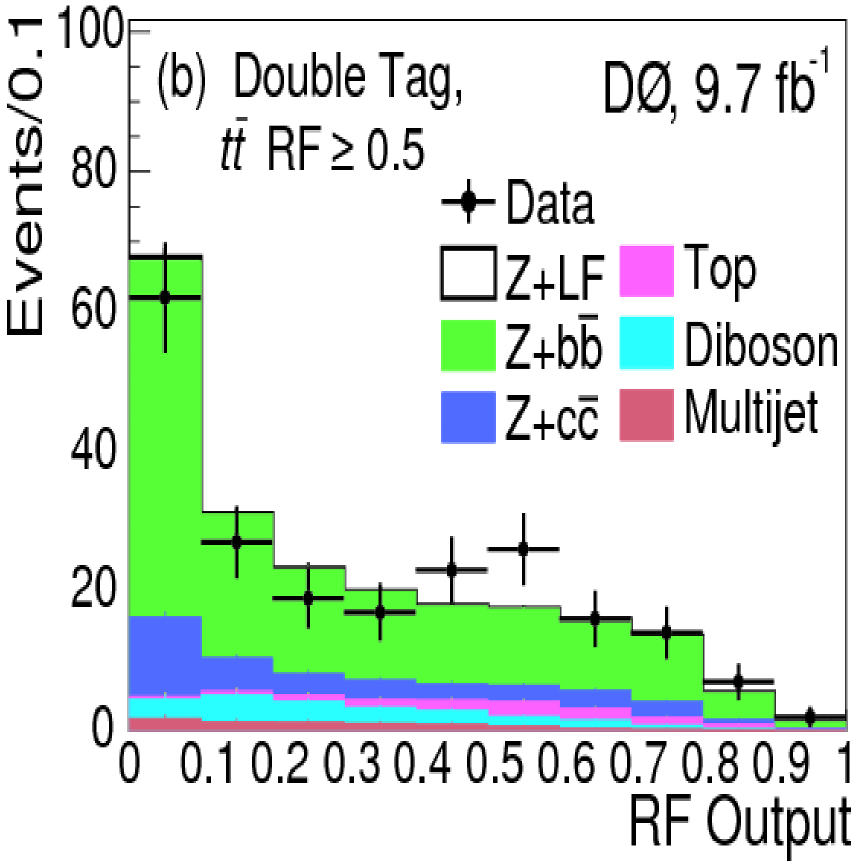
•PRL 109, 111804, 2012(CDF), PRL 109, 121804, 2012(D0)

Search for ZH→llbb

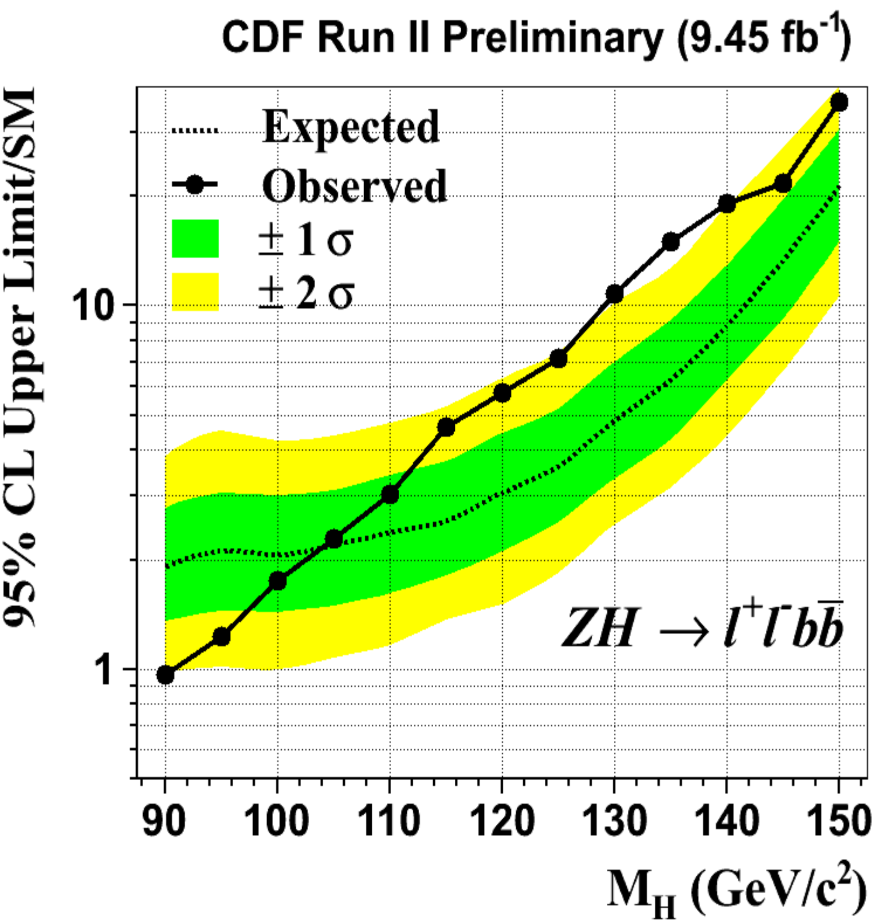


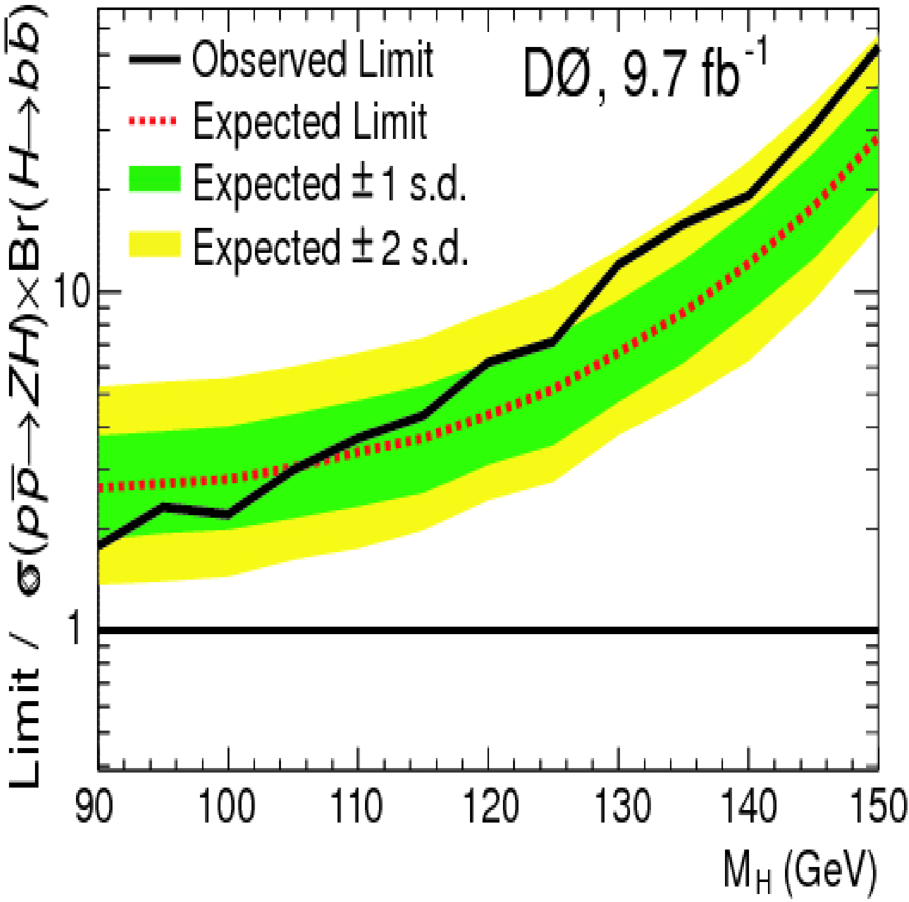
- Low event rate but clean signature.
- Select two leptons for Z→ll, 2/3 jets with btag.
- Train NNs to isolate H from top, Z+c's, diboson,Z+b's.





ZH→llbb Limits

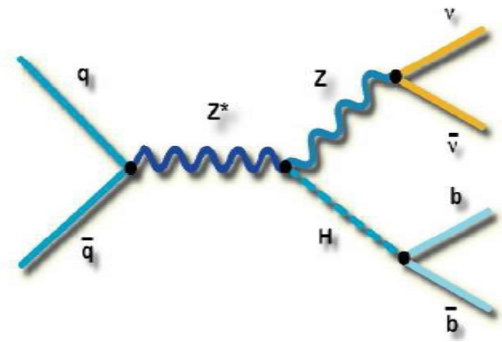


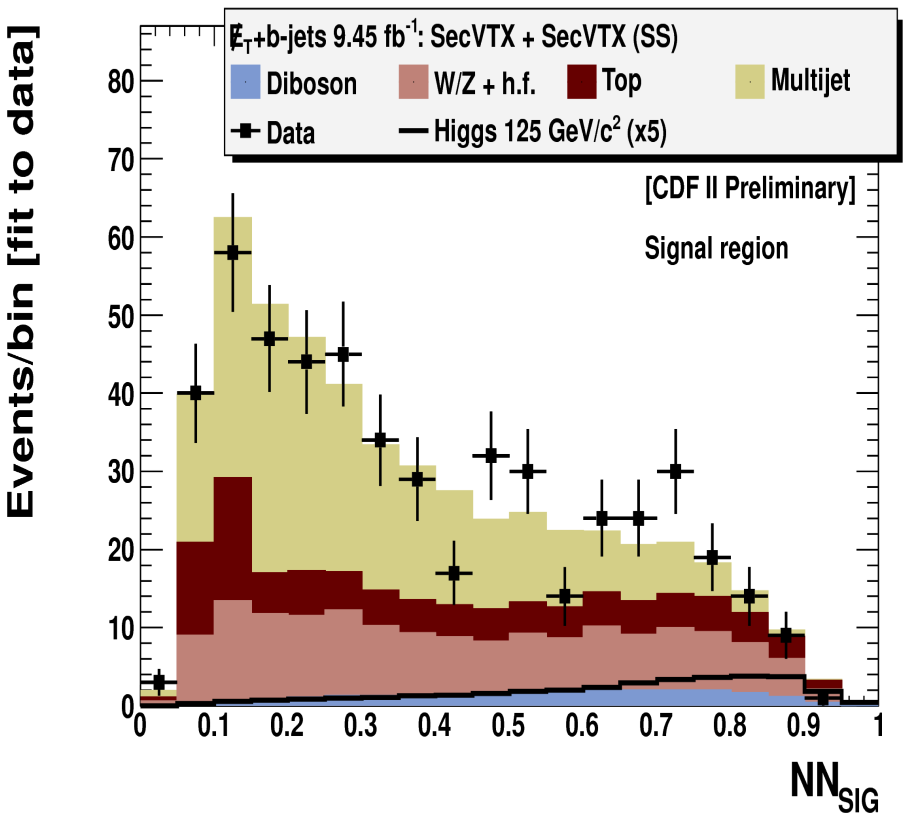


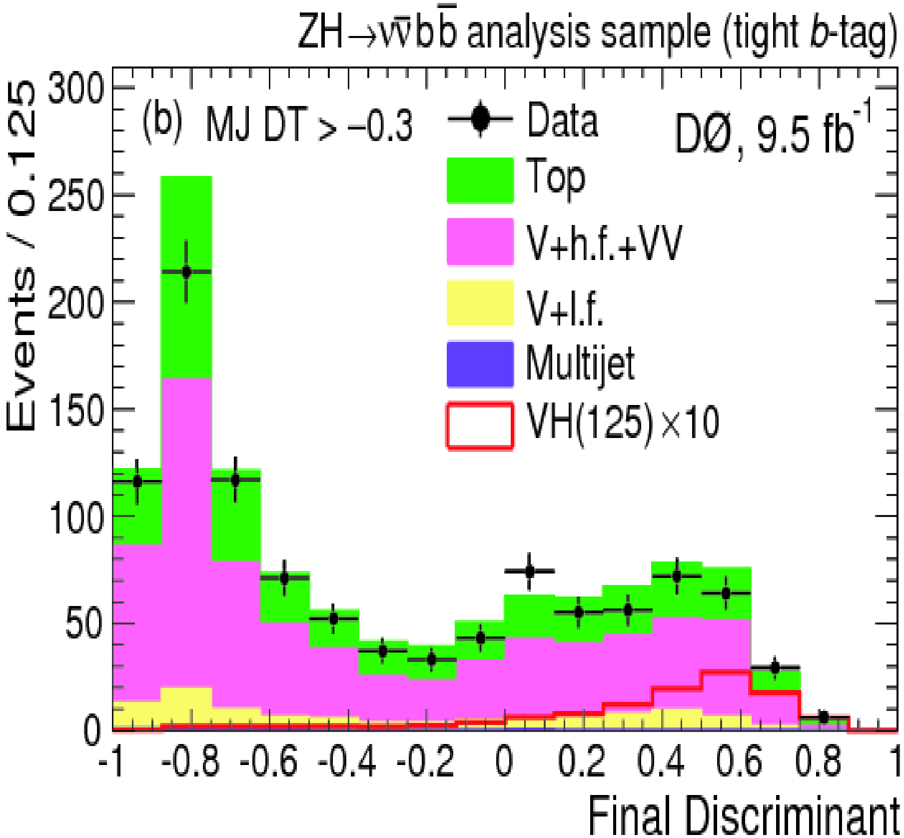
- Set 95% CL limits on obs/exp:7.1/3.9(CDF) and 7.1/5.1(D0) @125 GeV
- PRL 109, 111803,2012(CDF), PRL 109, 121803, 2012(D0)

Search for ZH→vvbb, WH→(l)vbb

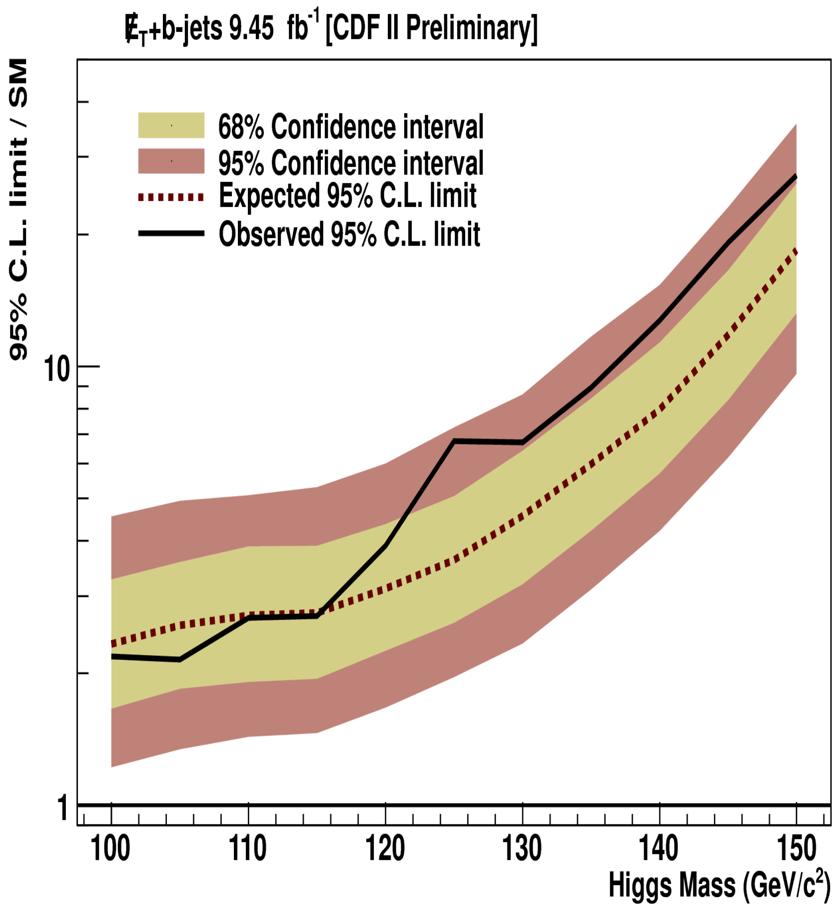
- Large event rate with large QCD MJ, very difficult
- Require met>50 GeV + 2/3 jets, b-tagging.
- Train NN to separate Signal, bckgrnd and QCD.

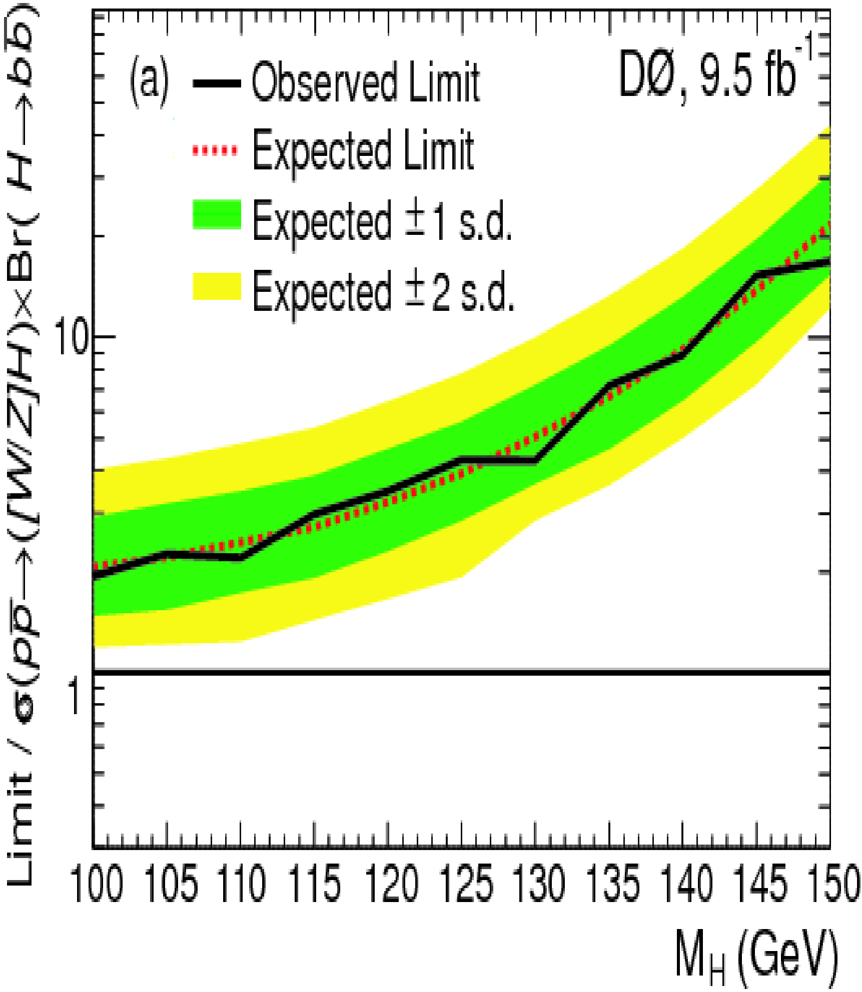






ZH→vvbb, WH→(l)vbb Limits

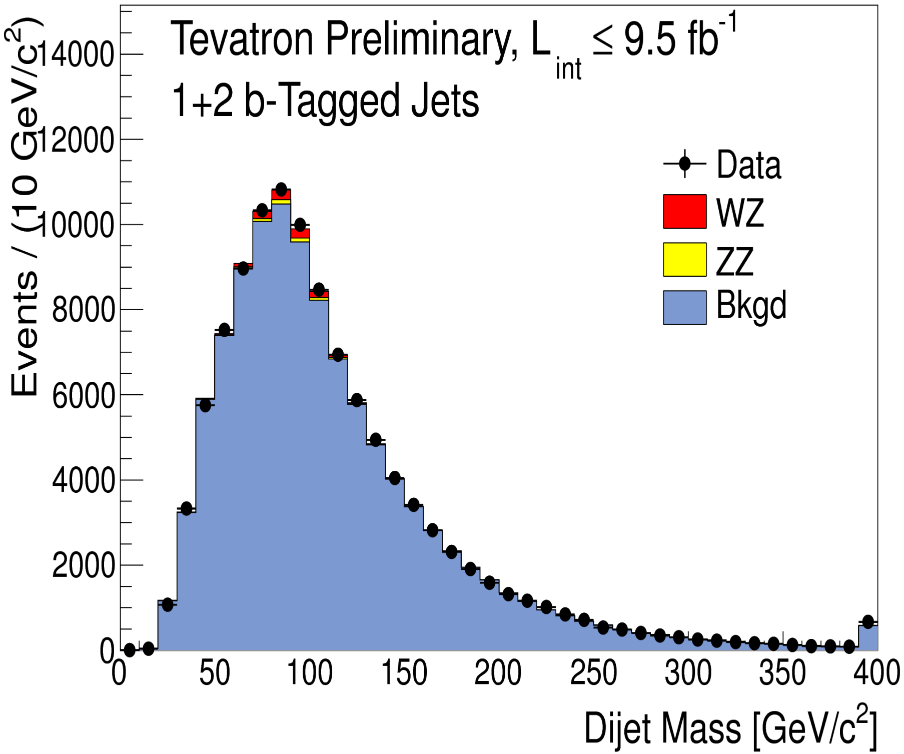


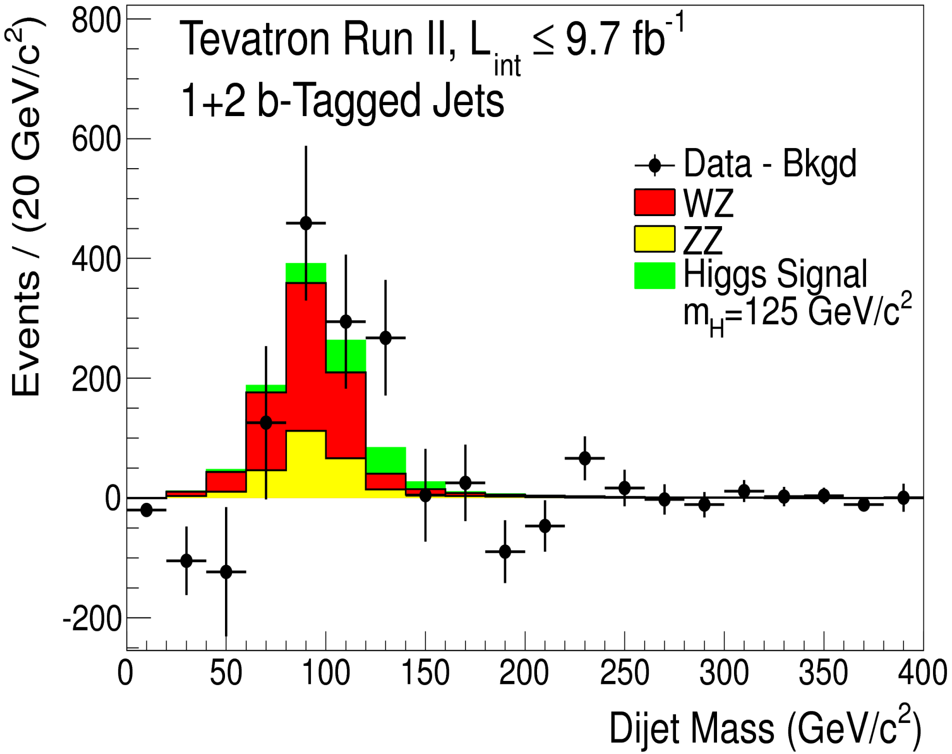


- Set 95% CL limits on obs/exp:6.7/3.6(CDF) and 4.3/3.9(D0) @125GeV
- PRL 109, 111805, 2012 (CDF), PL B716, 285, 2012 (D0)

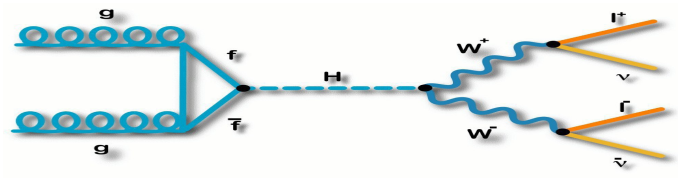
Cross Check with Z→bb Search

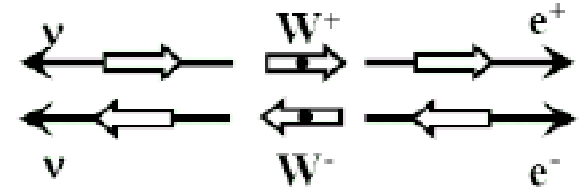
- Validating search strategy by looking for Z→bb in association with W or Z with similar signatures:WZ/ZZ→lvbb, vvbb, and vvbb
- Measured σ_{WZ+ZZ}=(1.01+-0.21)xSM, in good agreement with SM prediction.
- That demonstrated again the background and systematic well understood.



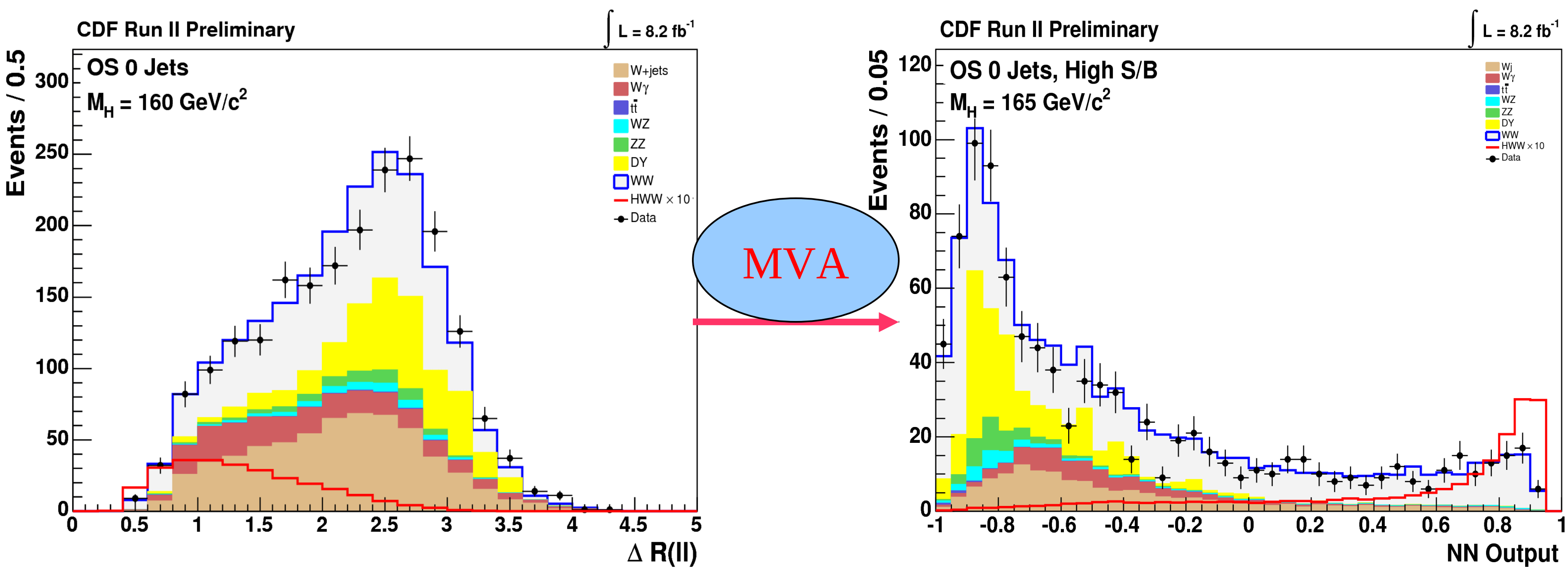


Search for H→WW



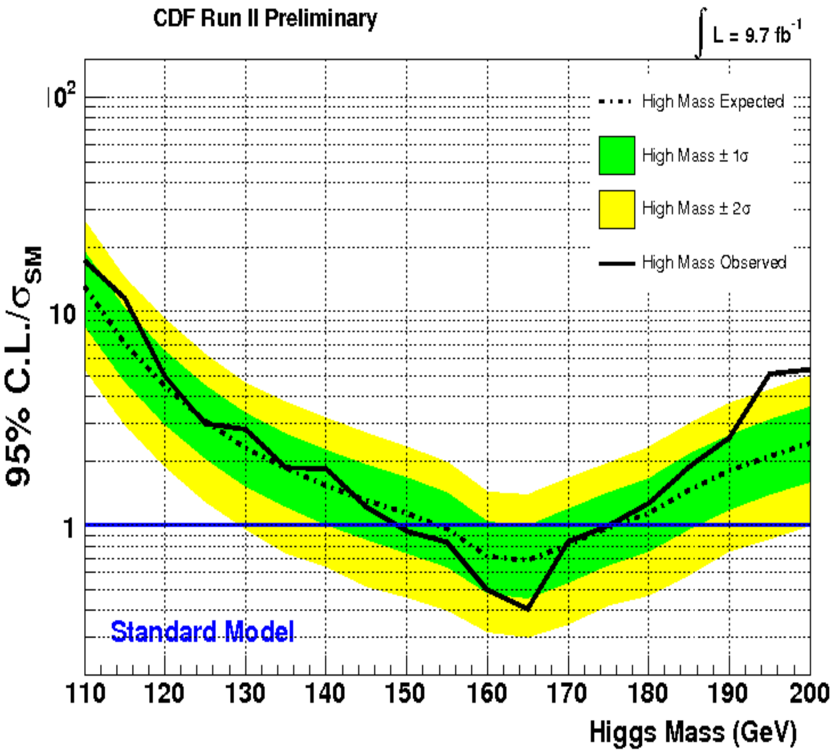


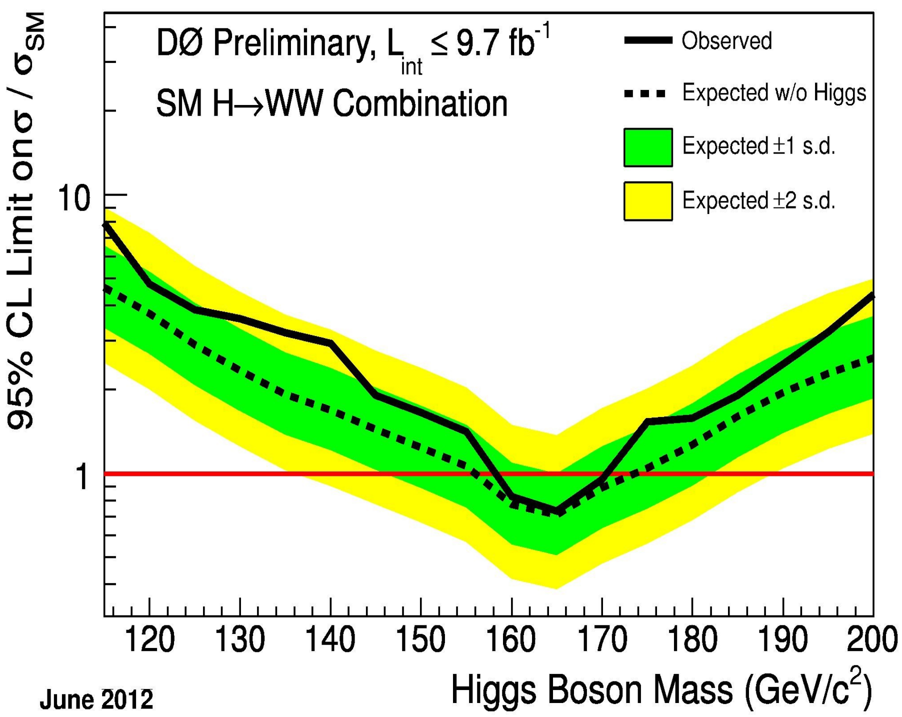
- Search for H→WW inclusively that leads to many interesting final states.
- Most sensitive channels is H→WW→lνlν: OS dilepton+met+0,1,2 jets .
- Use MVA to separate signal from main backgrounds: WW and top.



Limits for H→WW

- H→WW limit after combining all sub-channels(OS,low mll, SS, trileptons)
- CDF/D0 have similar sensitivity and observed limits
- The excess at 200 GeV driven by small event fluctuation in CDF OS 1jet bin.

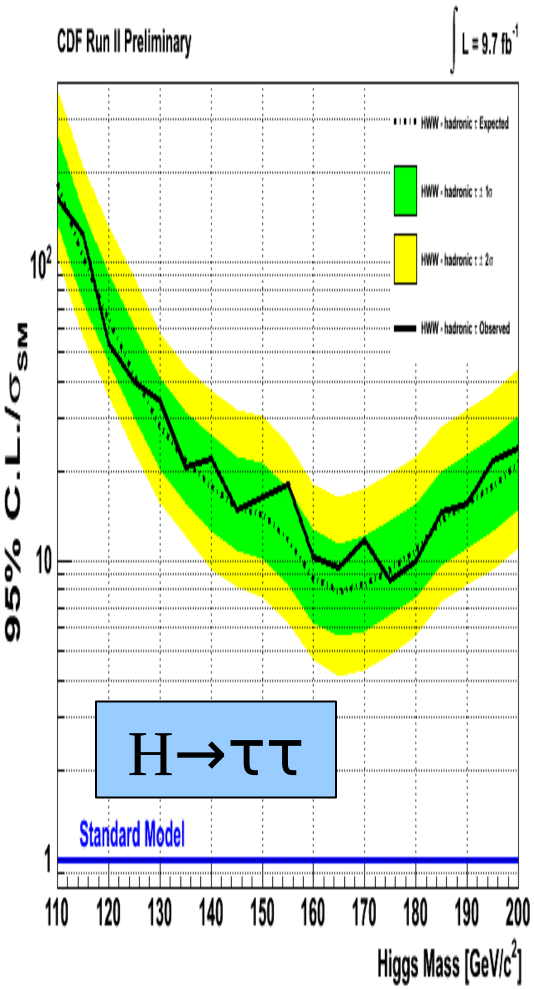


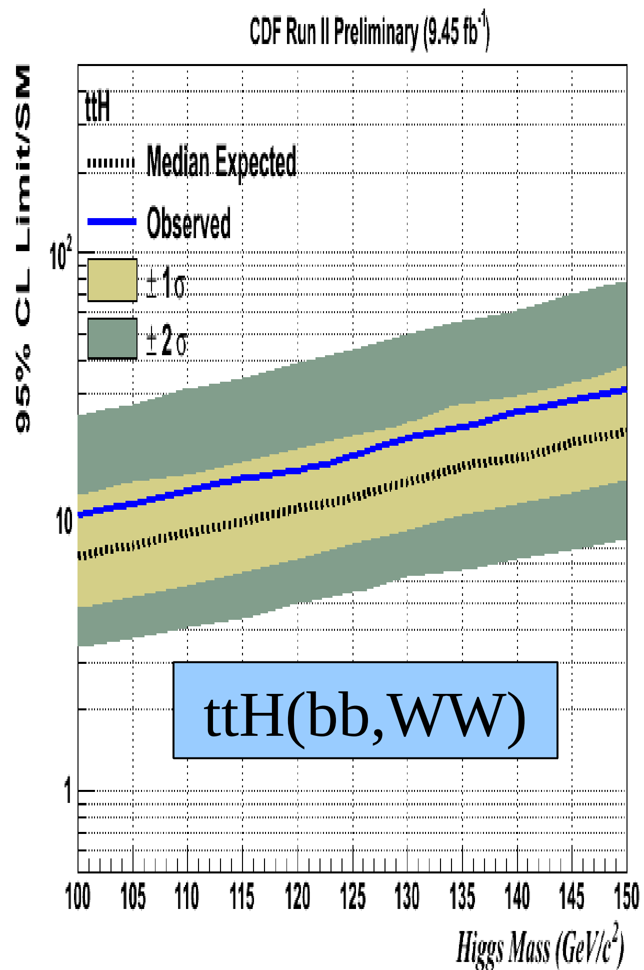


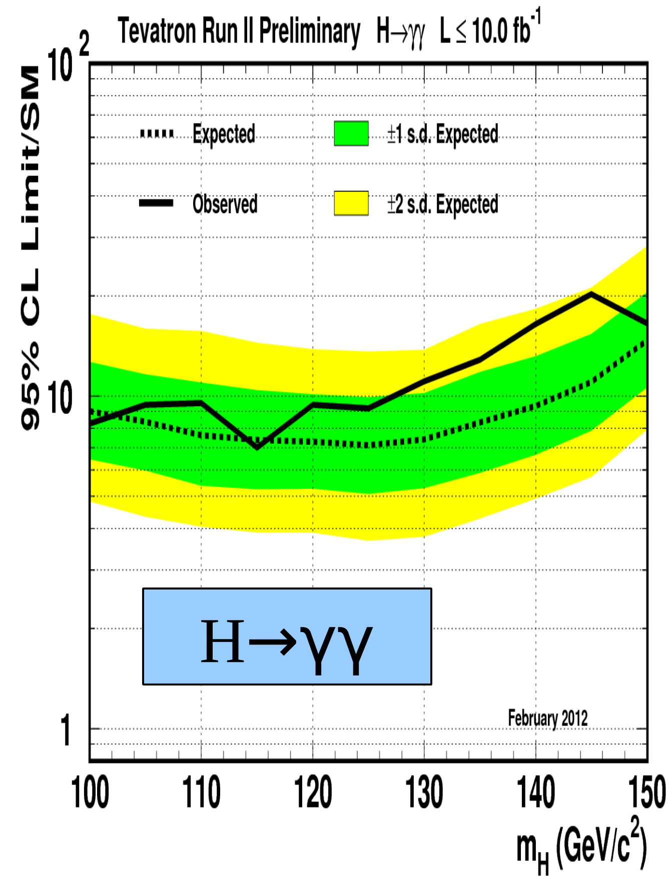
- Set 95% CL Obs/Exp Limits: 0.40/0.67(CDF) and 0.73/0.72(D0) @165 GeV

Other Searches

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



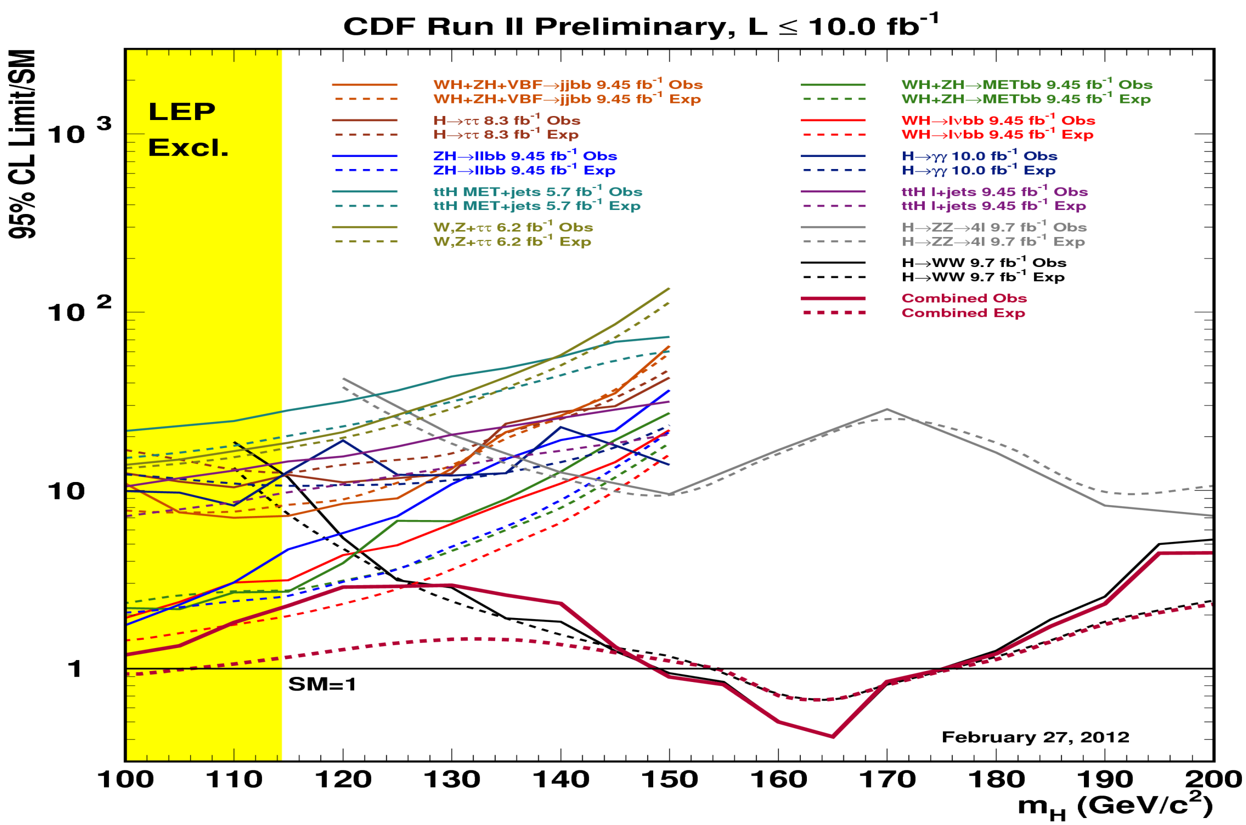




Combined Limits on SM Higgs Production

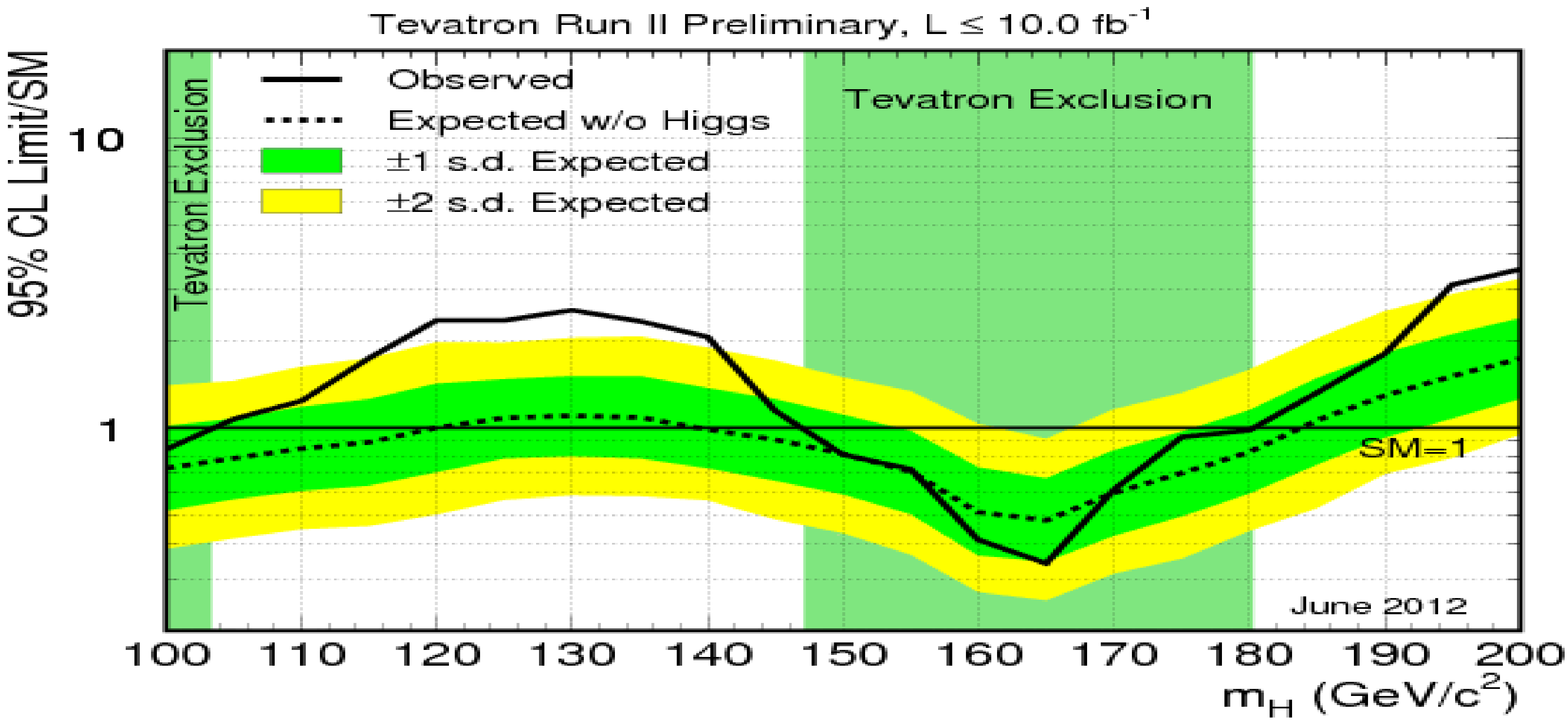
- CDF and D0 have searched for all possible SM Higgs production and decays and set limits with respect to nominal SM predictions.
- Combining all channels to improve the Tevatron Higgs limit.

WH→lvbb
ZH→vvbb
ZH→llbb
H→WW→lvlv
WH/ZH→jjbb
ttH→WbWb bb
H→γγ
H→ττ
VH→(lv,ll)ττ
H→WW→lvjj
VH→VWW
H→ZZ



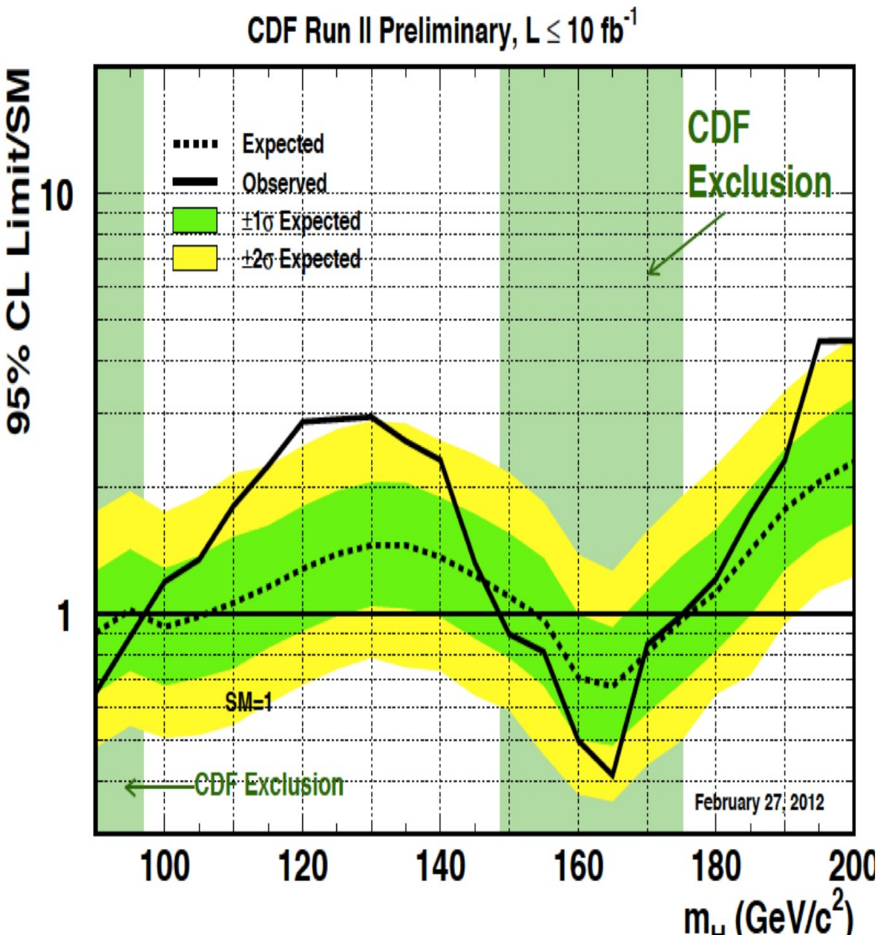
Tevatron Combination

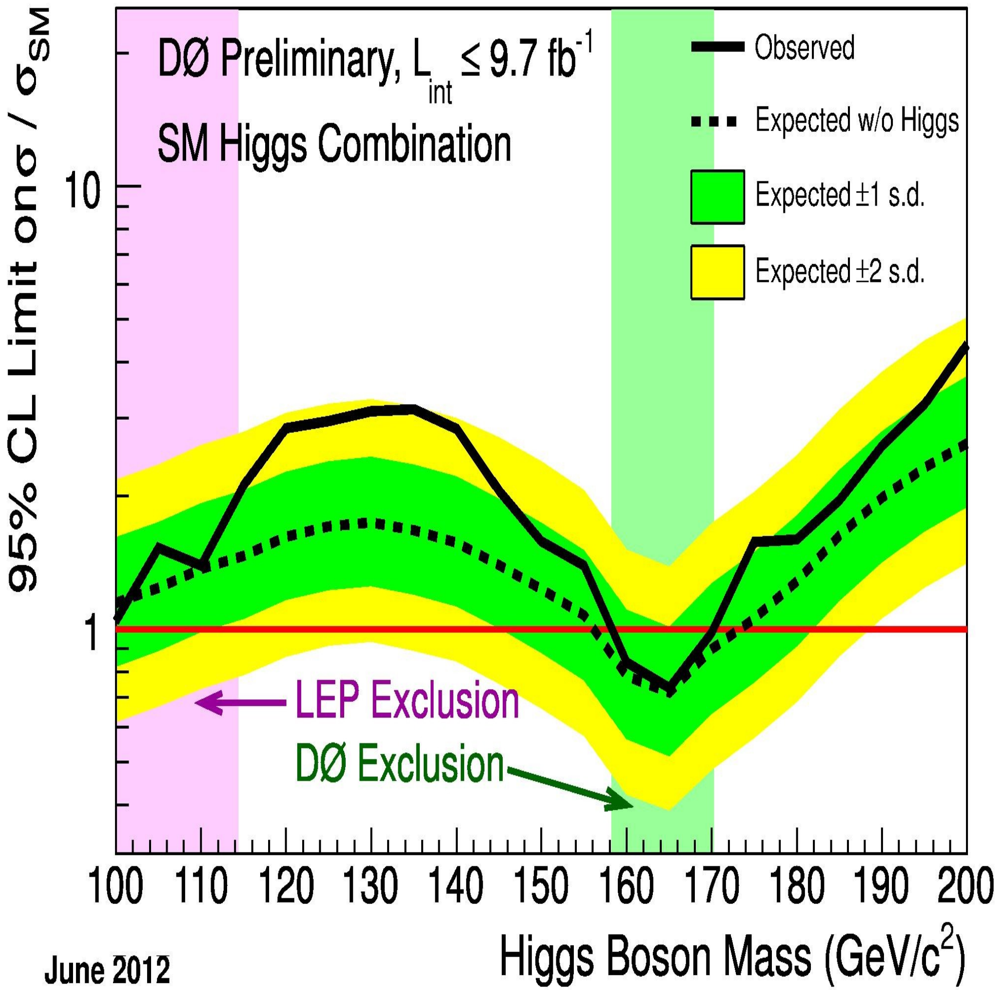
- Exclude high mass: 147-180 with expectation of 139-184 GeV/c2 and low mass: 100-103 with expectation of 100-120 GeV/c2.
- Broad excess(>2σ) observed between 115-140 GeV/c2.



Individual Experiment Results

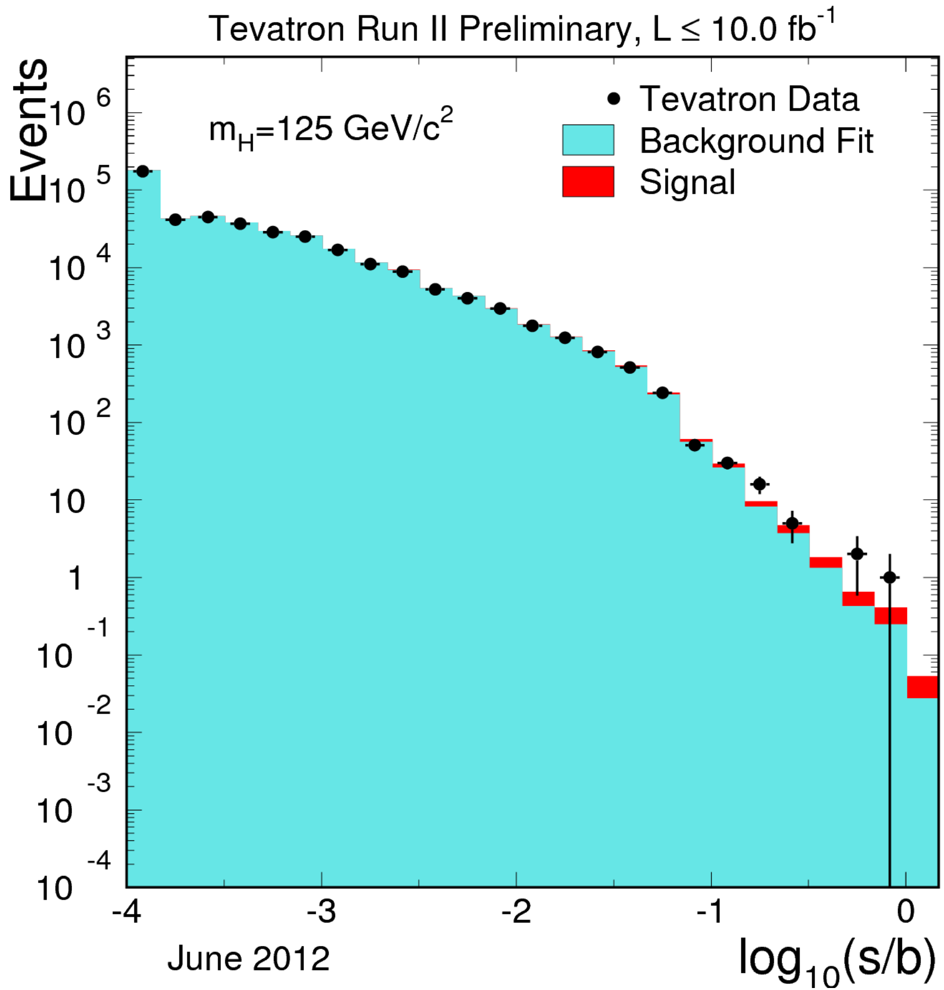
- Provide cross check to each other, have similar sensitivities and results
- Both have a broad excess between 115-140 GeV.

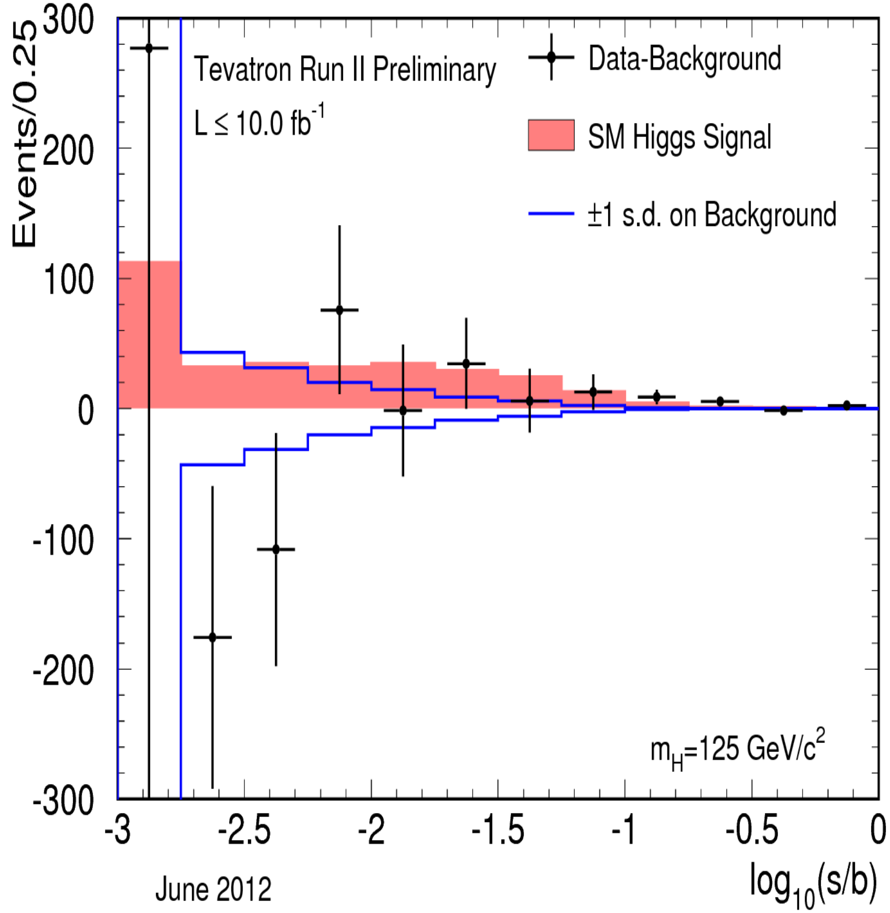




Visualizing Data at M_H=125 GeV

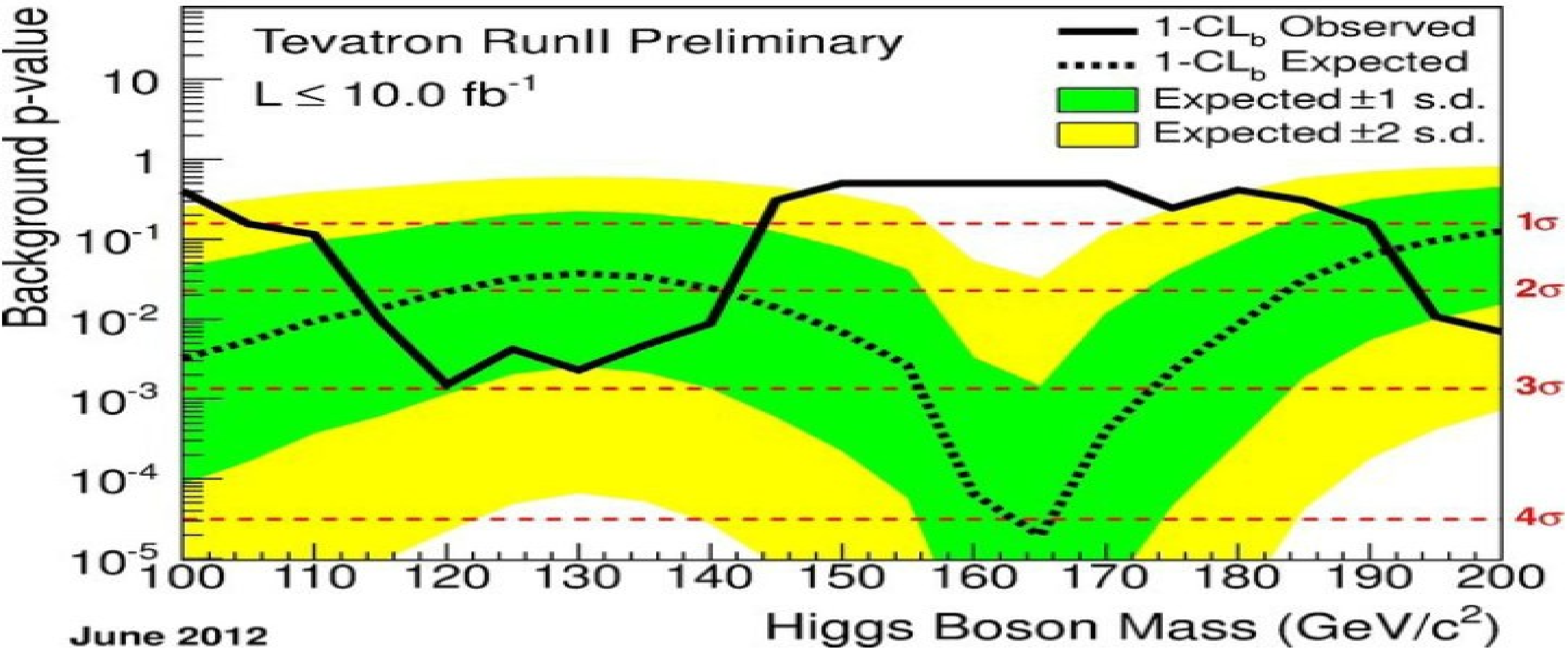
- Display cumulative discriminant from all channels, ordered by S/B.
- Excess events in the high score region consistent with SM Higgs signal.





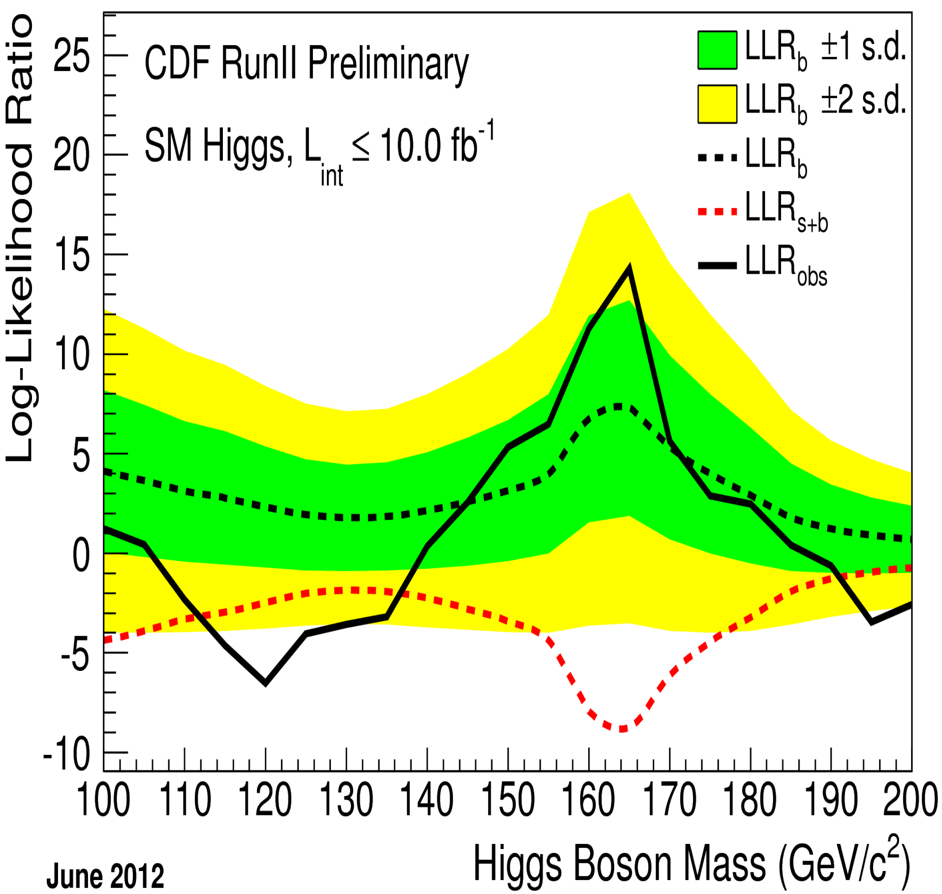
Quantifying the Excess

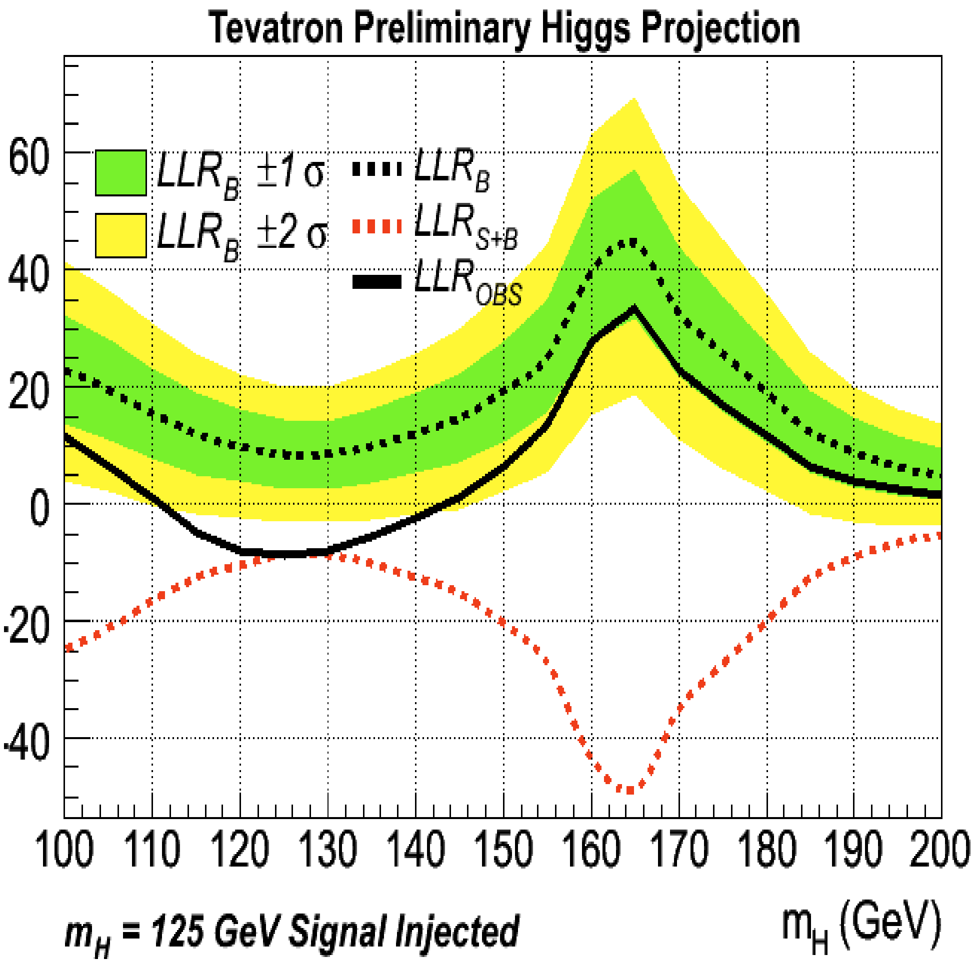
- Calculating local p-value distribution for background-only hypothesis.
- Local p-value =3.0σ at 120 GeV gives global p-value of 2.5σ(LEE=4).
- The excess at 200 GeV is less significant (<2σ) and has excluded by LHC.



Compatible with SM Higgs at 125 GeV

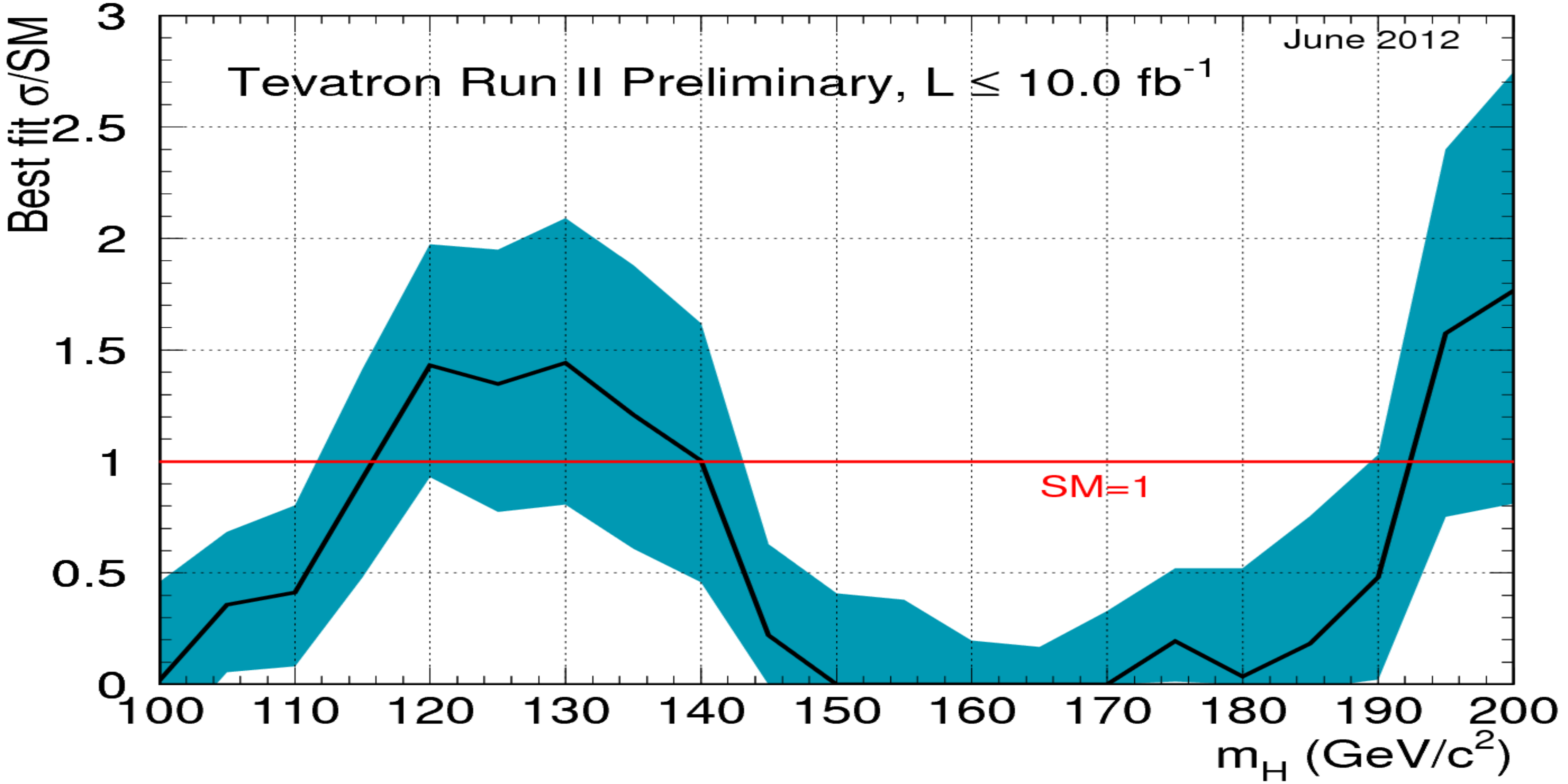
- Compared LLR after injecting Higgs(125) to bkgd-only pseudo-experiments.
- MVA is not optimized for mass, but for S/B separation, expect a broad excess.





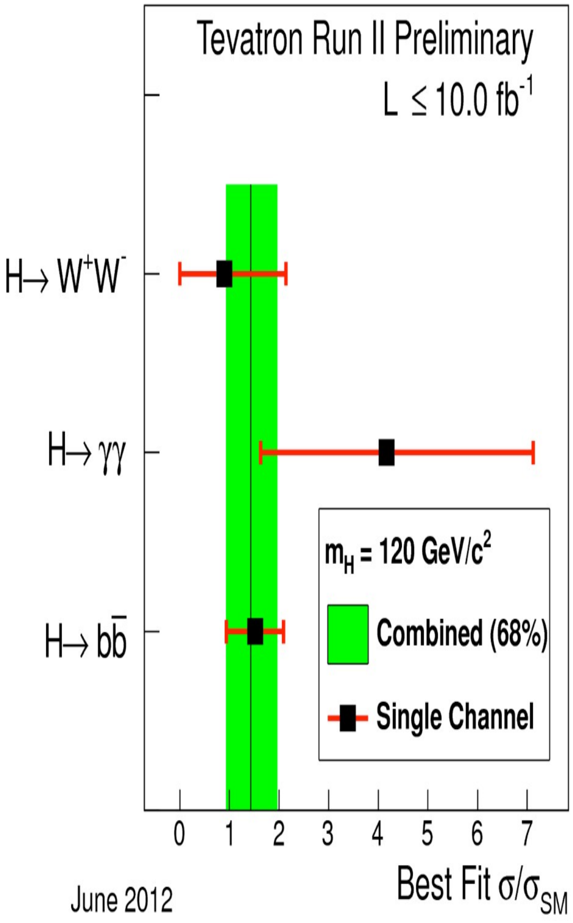
Tevatron Cross Section Fits

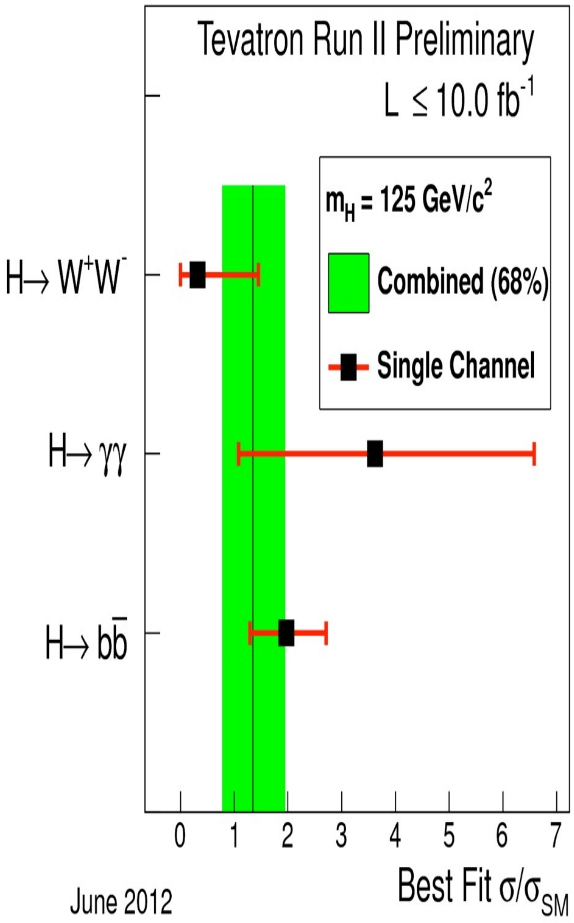
•Fits to cross section strength (1.4+-0.6) @ 125 GeV, consistent with SM Higgs Production.

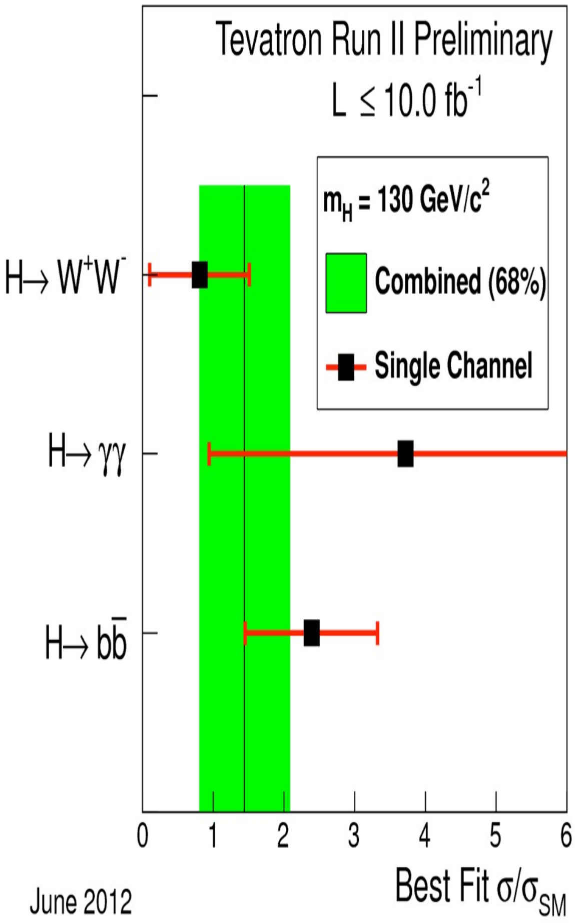


Comparison of Signal Strength

- Fit to data with H→bb, γγ, WW, separately to see where the excess is
- Excess mainly driven by H→bb, consistent with SM higgs@125 GeV.

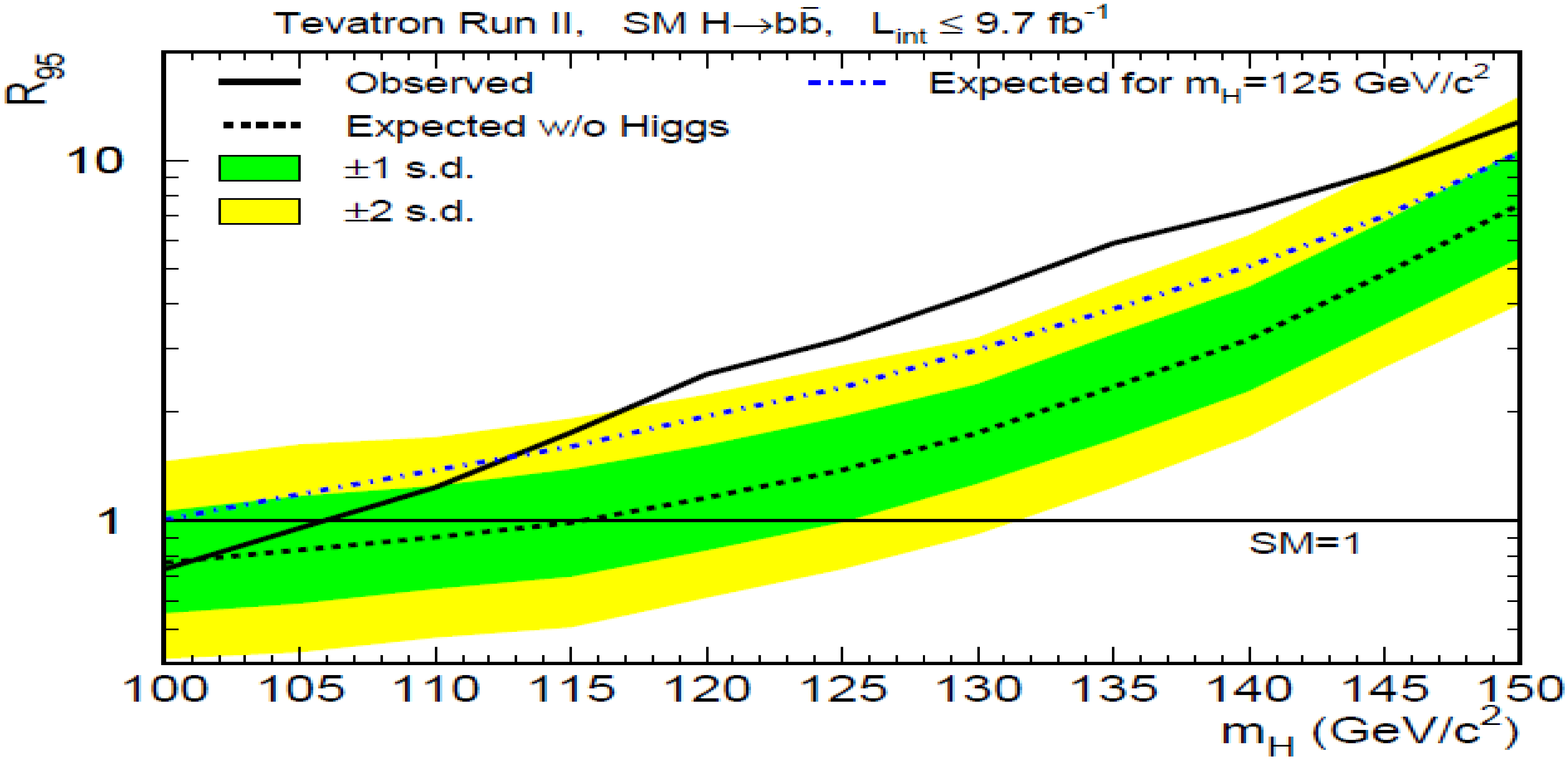






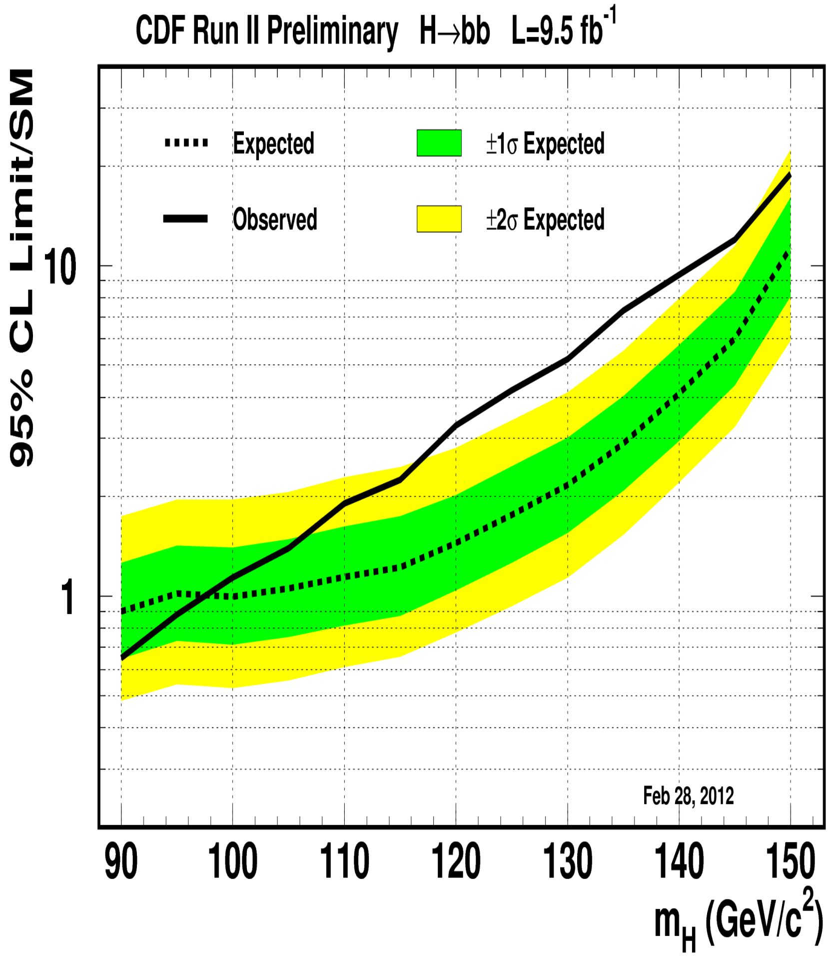
Tevatron H→bb Combination

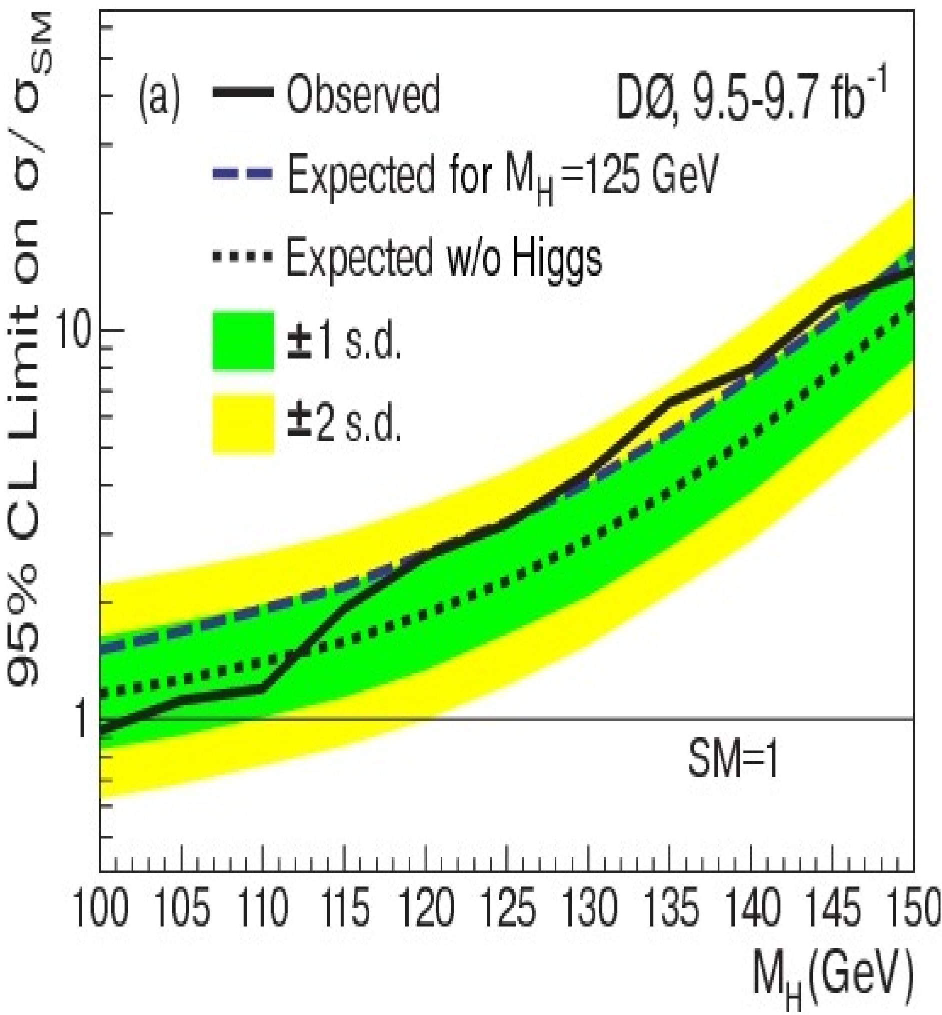
- Combining all H→bb channels together and compared to what expected from a Higgs signal at 125 GeV.
- The broad excess in $120<m_H<140$ GeV seems consistent with SM prediction



Individual Experiment H→bb Results

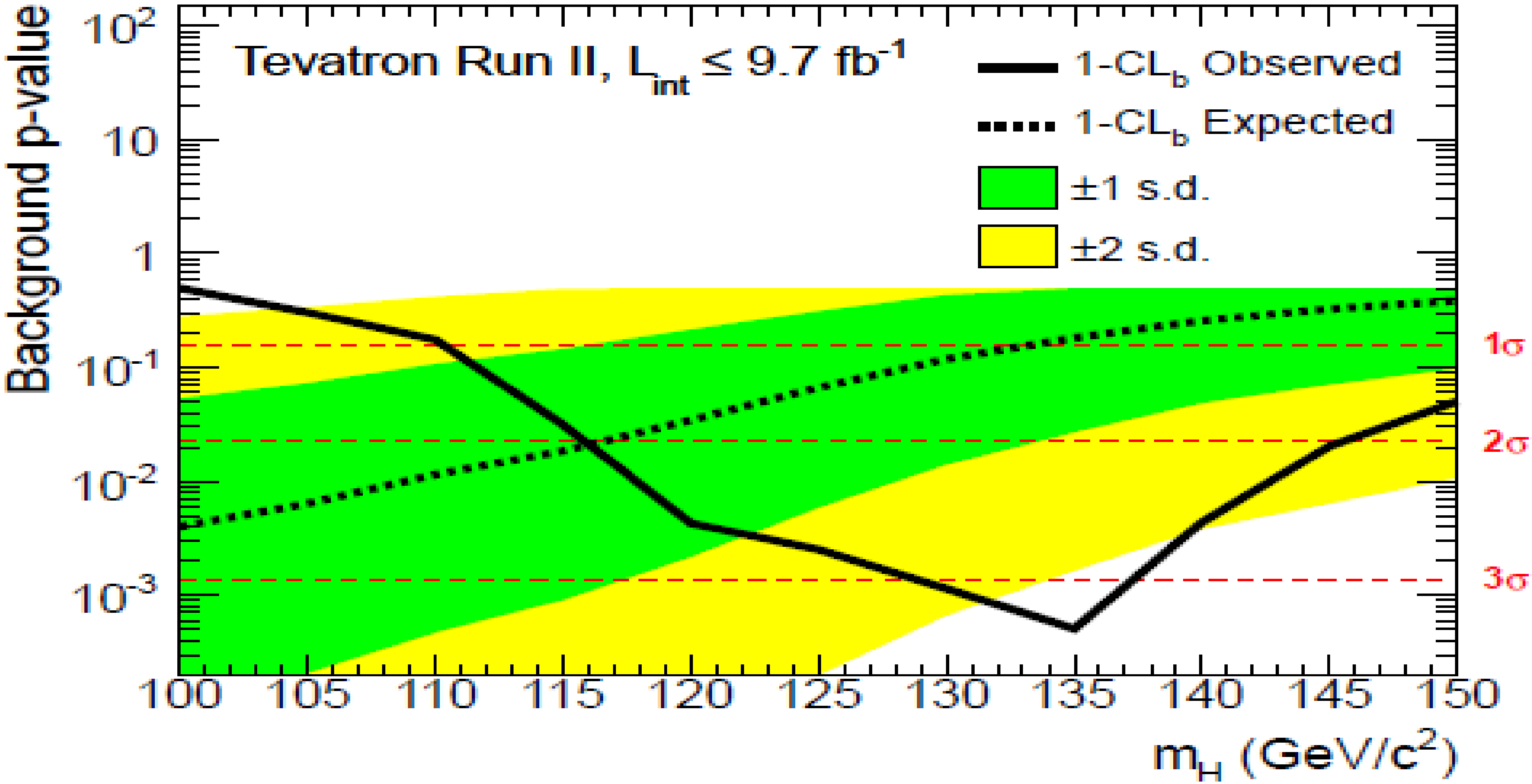
•Similar excess in 120-140 GeV: 2.5σ (CDF) and 1.5σ(D0).





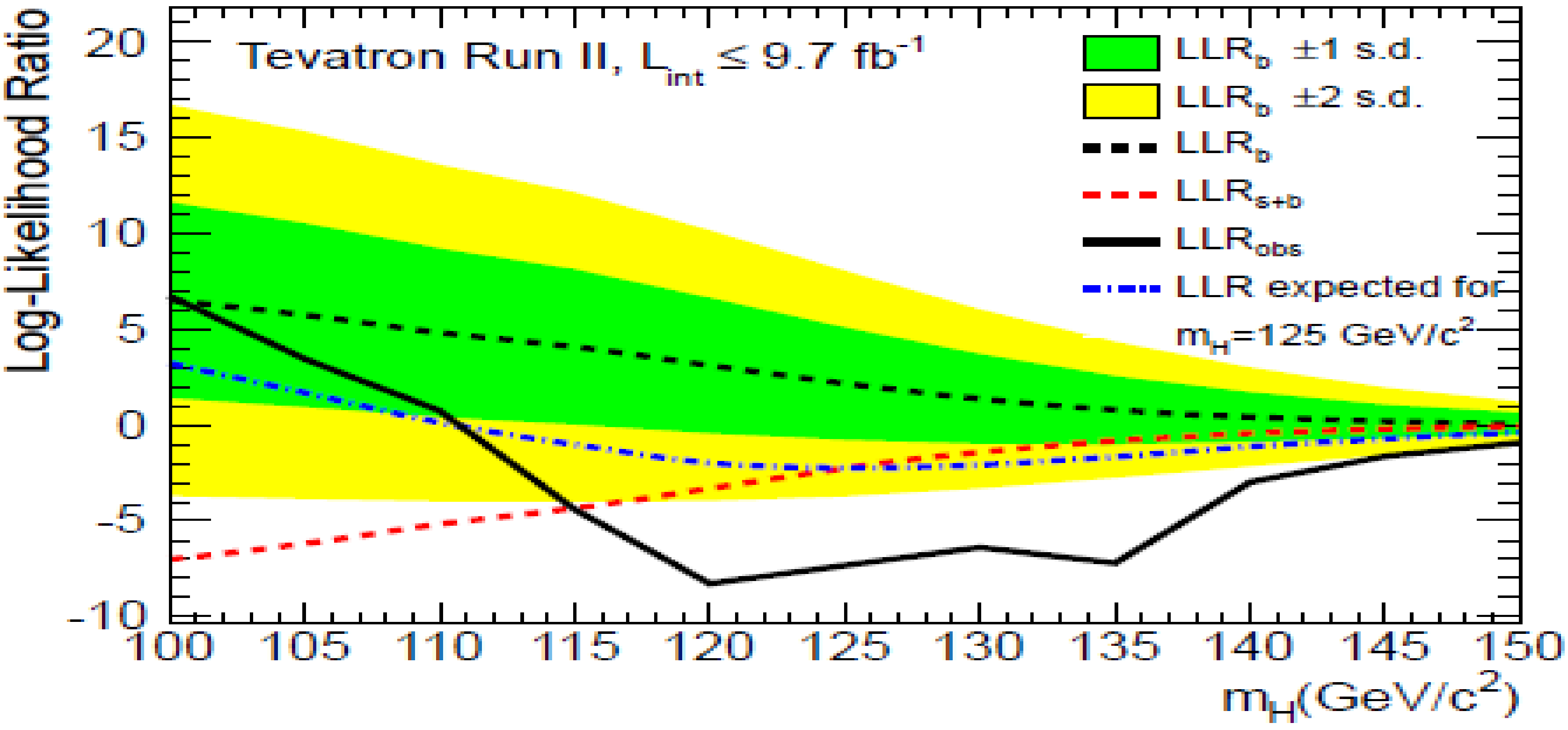
Quantifying H→bb Excess:

- Calculating local p-value distribution for background-only hypothesis.
- Local p-value=3.3σ at 135GeV gives global p-value=3.1σ with LEE factor 2.

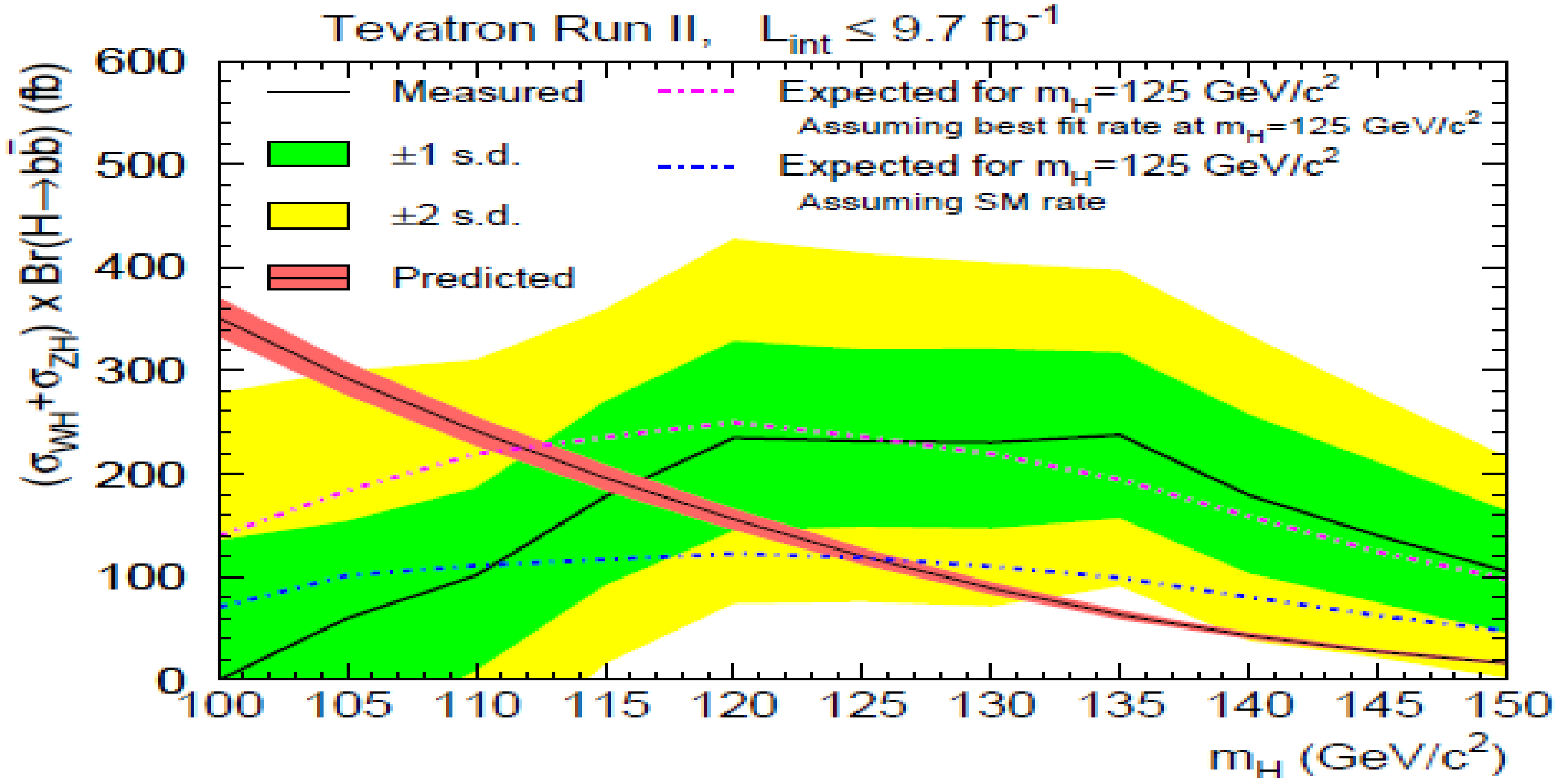


Compatible H→bb with SM Higgs at 125 GeV

- Compared LLR after injecting Higgs (125) to background-only.
- The shape seems similar and data seem prefer higher signal rate than SM prediction.



Cross section * BR measurement



- Measured: $(\sigma_{WH}+\sigma_{ZH})xB(H\rightarrow bb)$=0.23+0.09-0.08(stat+syst) pb, consistent with SM prediction @ 125 GeV: 0.12+-0.01 pb

Conclusion

- With full dataset, many years hard work, we have exceeded our most optimistic sensitivity projection based on 2007 summer results.

- Tevatron reported first evidence for H→bb in the mass range between 120 and 135 GeV with a global p-value of 3.1σ, consistent with the Higgs-like particle newly discovered by ATLAS and CMS.

- This is exciting and looking forward to H→bb discovery at LHC.