SM Higgs Searches at the Tevatron

Weiming Yao (LBNL)

On behalf of the CDF and D0 Collaborations

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Outline

- Introduction
- Overview the Higgs Search Strategies
- Recent Improvements
- Tevatron Results with the full dataset
- Conclusion

More Details:

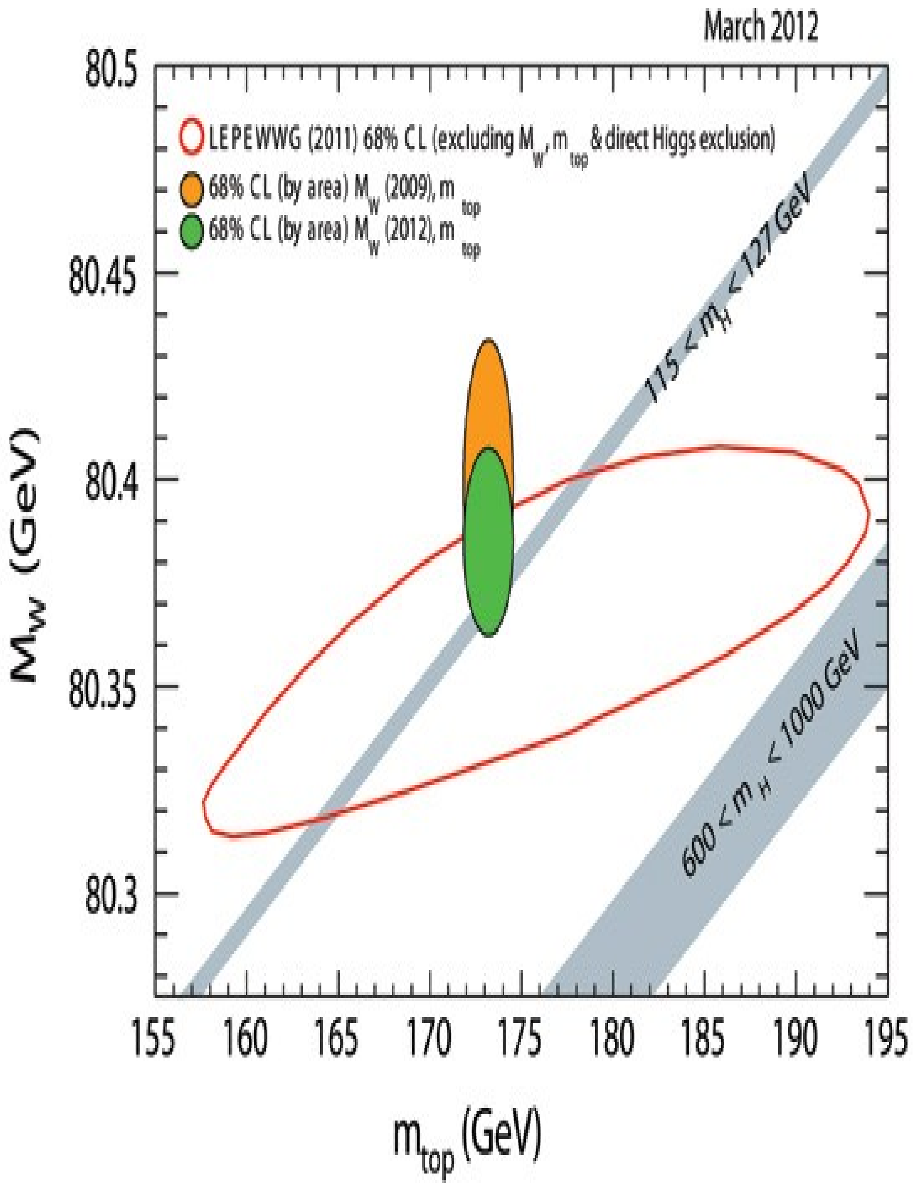
http://www-cdf.fnal.gov/physics/new/hdg/Results.html

http://www-d0.fnal.gov/Run2Physics/D0Winter2012.html

http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_12/

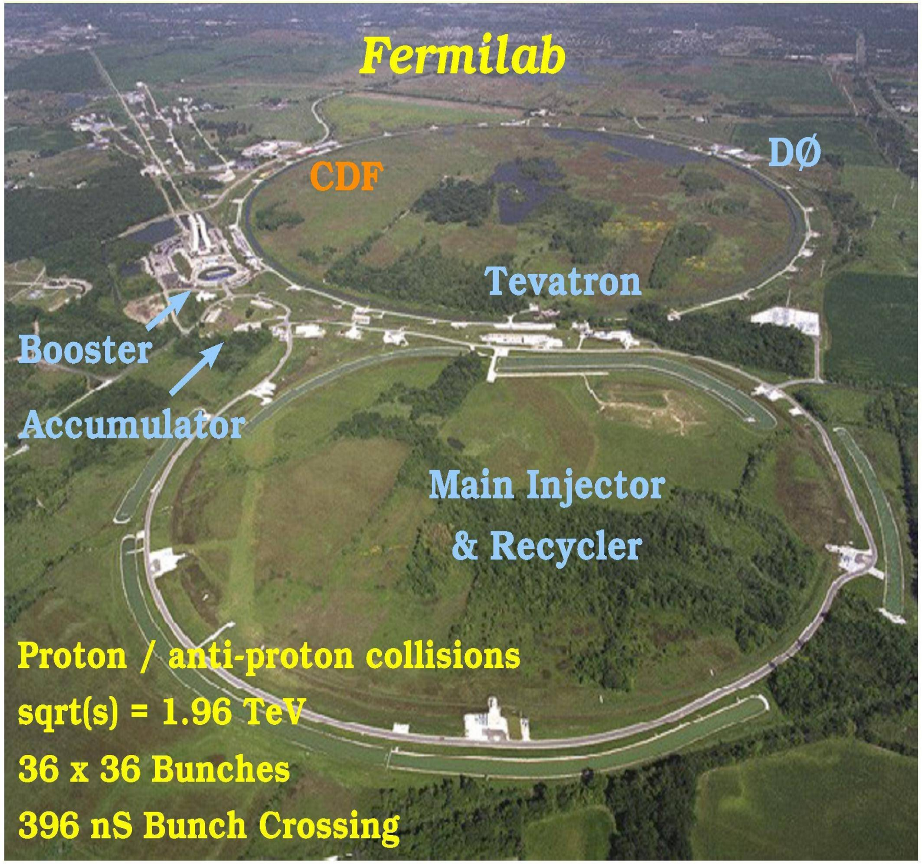
Introduction

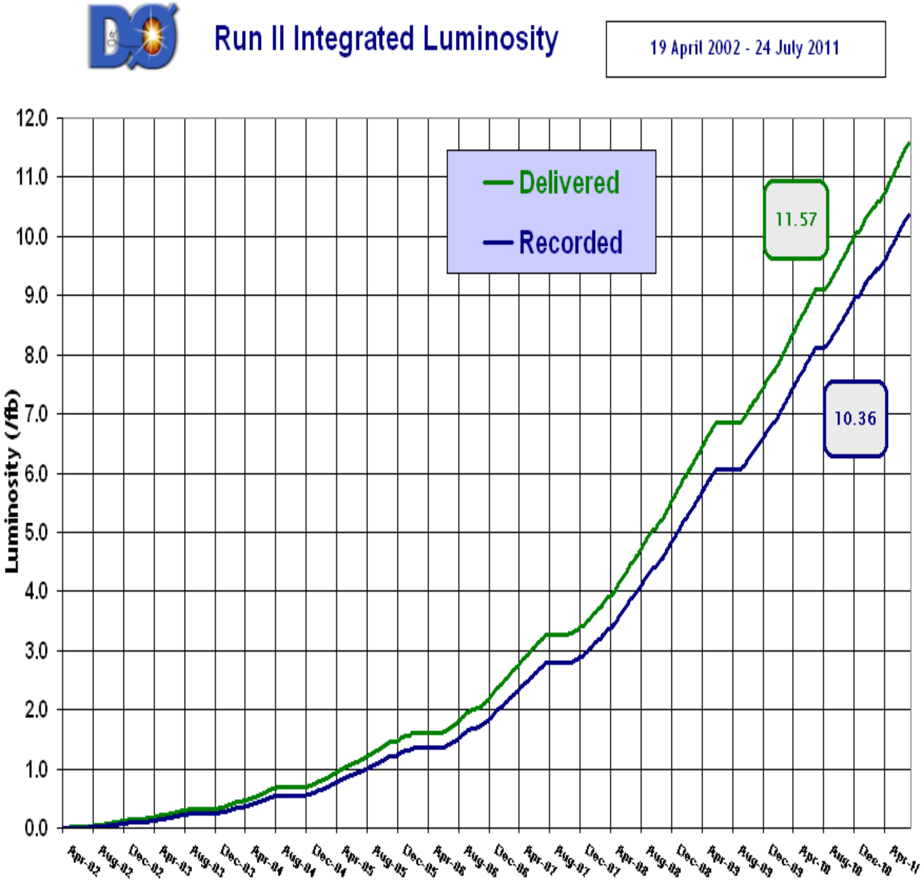
- Higgs boson is the remnant of the Higgs field that responsible for the electroweak symmetry breaking.
- Higgs Mass Limits@95% CL:
  - Indirect: M_H<152 GeV
  - Direct: 116<M_H<127 GeV
- While LHC continue to improve their Higgs reach, Tevatron search of H→bb decay is still competitive and will provide a crucial test on the existence and nature of the Higgs boson.



The Tevatron

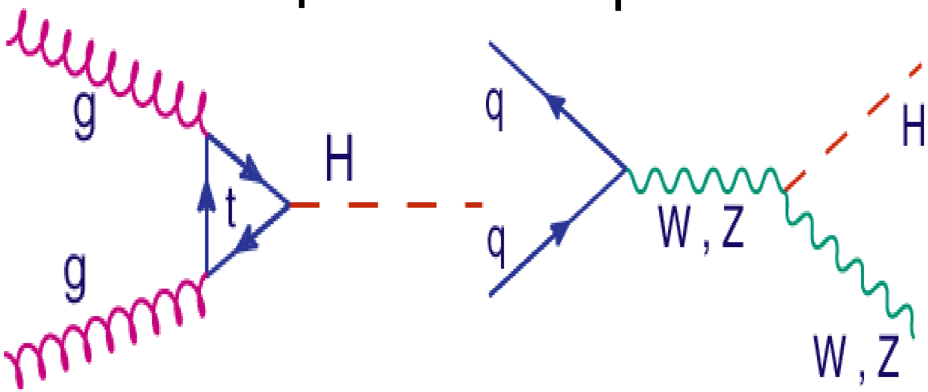
- Tevatron: p-pbar collision@1.96TeV, $L_{peak}=4.3x10^{32}\ cm^{-2}s^{-1}$
- Delivered ~12 fb^{-1} data before shutdown on 9/30/2011.
- Most results presented are based on the full dataset (~10 fb^{-1})

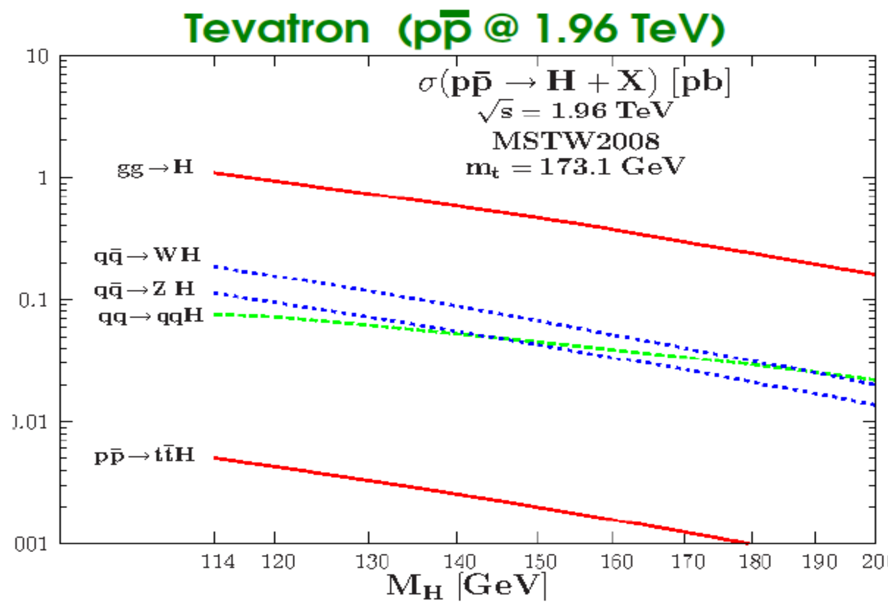




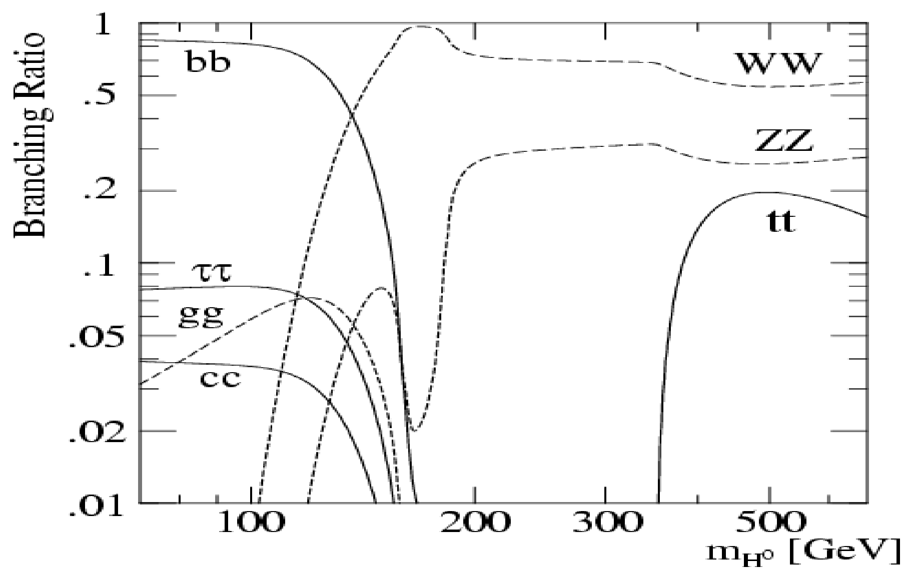
SM Higgs Production and Decay @ Tevatron

- 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):

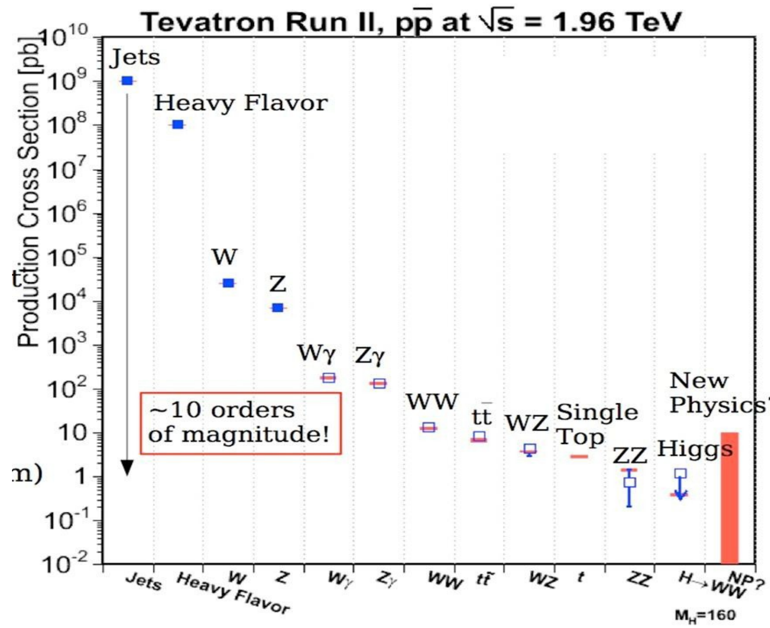
  Mainly decays: gg→H→WW,ZZ

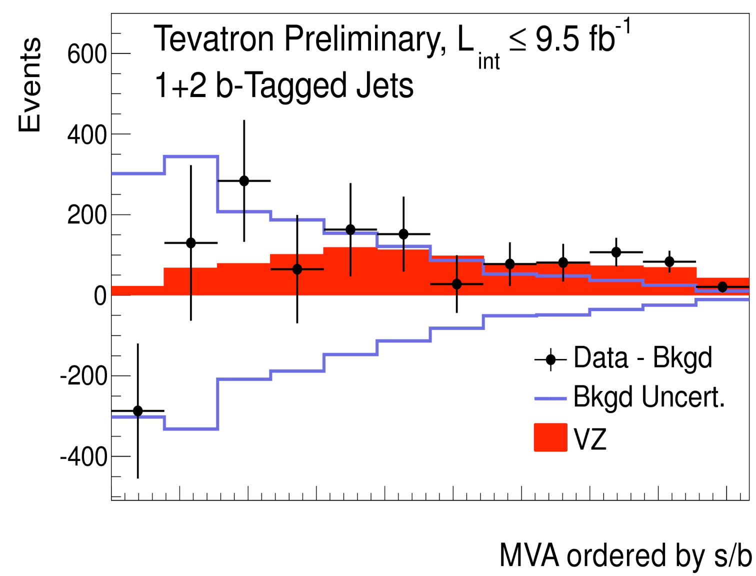
- Other decays: H→ττ,γγ, and ttH.

The Challenge

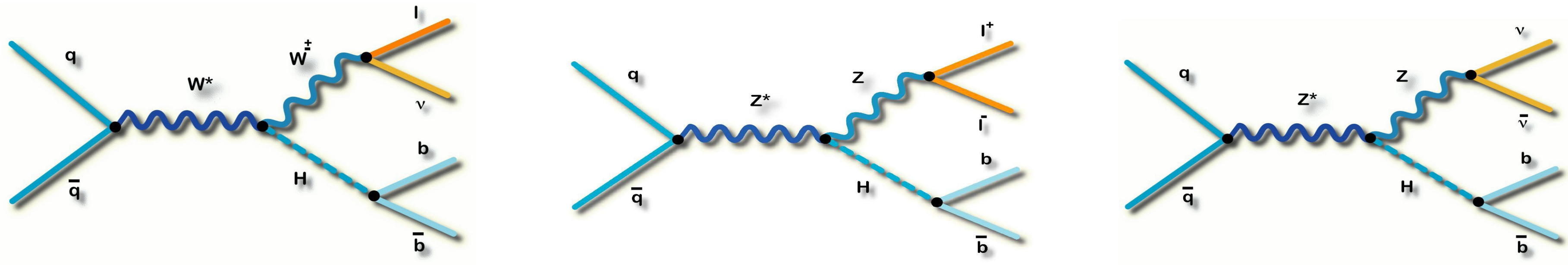
- The Challenge is due to that Higgs signal is so tiny compared to other SM process with the same final states.
- Search Strategy has evolved over years:
  - –Maximizing signal acceptances using efficient triggers, lepton ID, and b-tagging that improves S/B to ~1/100.
  - –Using multivariate analysis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

Observation of single top, diboson provide solid ground for strategy. Measured σ_{WZ+ZZ}= 1.01±0.21xσ_{SM} in VZ→lvbb,llbb,vvbb search.

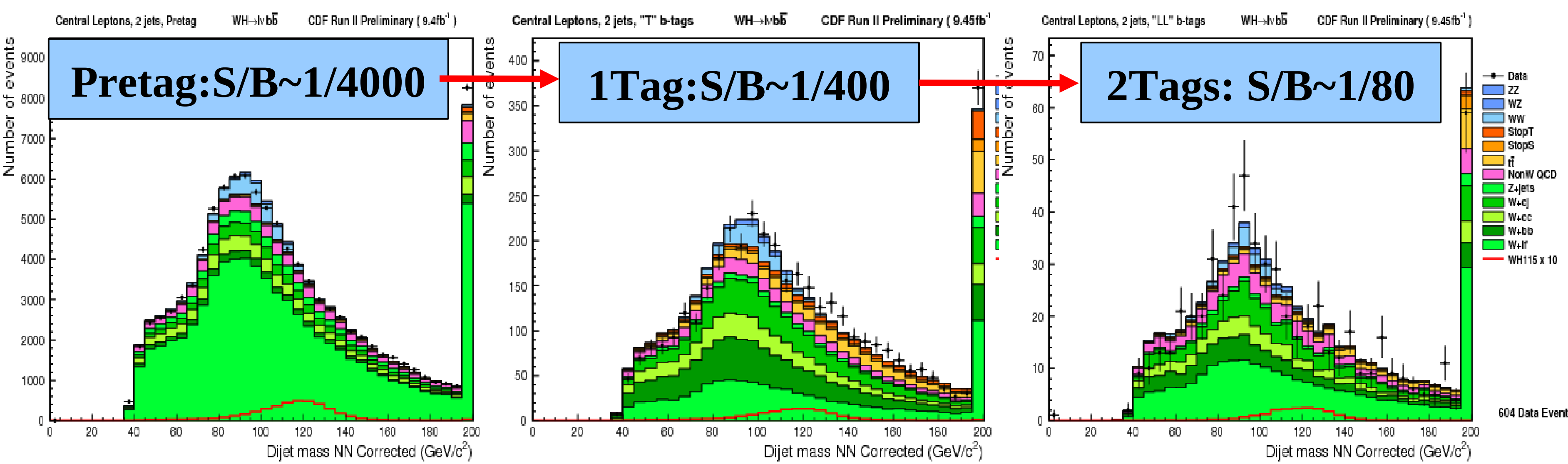




Low Mass Signatures

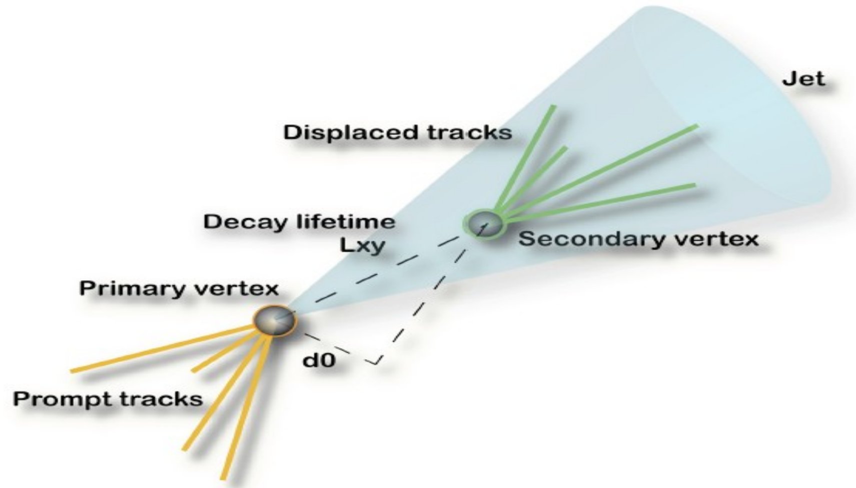


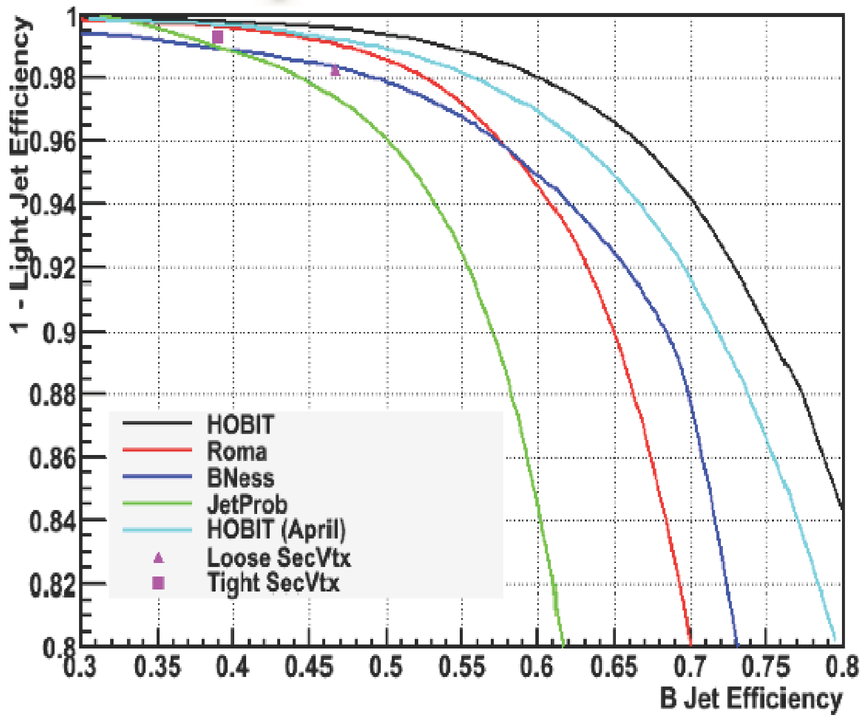
- Search for H→bb resonance in association with W or Z.
- WH→lνbb, most sensitive low-mass channel: one lepton+MET+ 2jets
- Requiring b-tag improves S/B significantly



Improvement of b-tagging

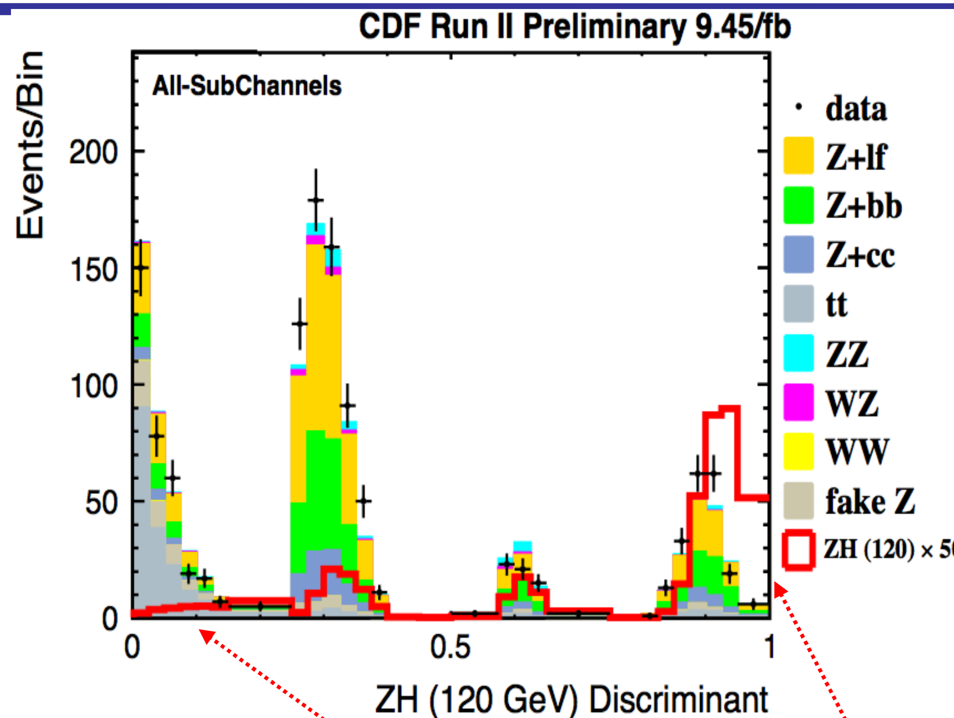
- CDF and D0 use MVA techniques to improve b-tagging that exploits the decay of long-lived B hadron as displaced tracks/vertices. Typical eff:40-70% with mistag rate:1-5%.
- Recently CDF combined existing b-tags into a Higgs optimized b-tagger (HOBIT), which improves eff by 20% while keeping mistag rate same.
- Eff and mistag rate calibrated using W+1jet, W+3 or more jets(ttbar), and b-enriched inclusive electron data samples.

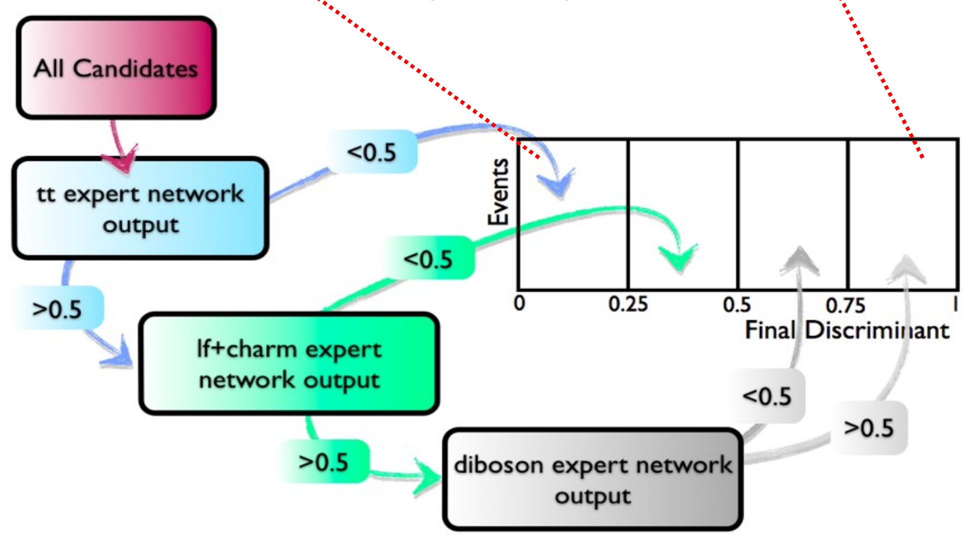




Improving Multivariate Discriminant

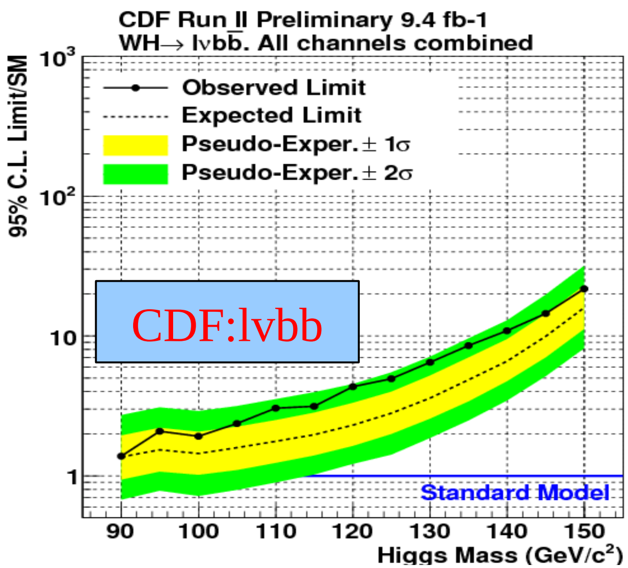
- Most Higgs Analysis uses MVA to improve bkgd rejection with a sensitivity gain of 25%, compared to single variable alone, e.g. dijet mass.
- We can further improve MVA by training against multiple bkgds, splitting analysis into subchannels based on S/B, e.g. lepton type, number of jets.
- CDF trained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

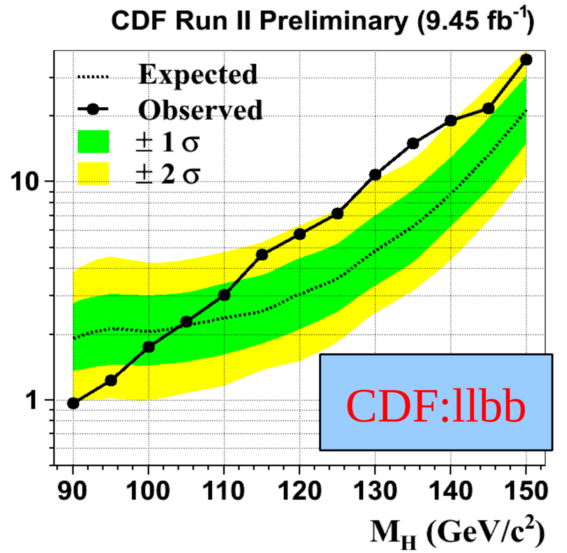


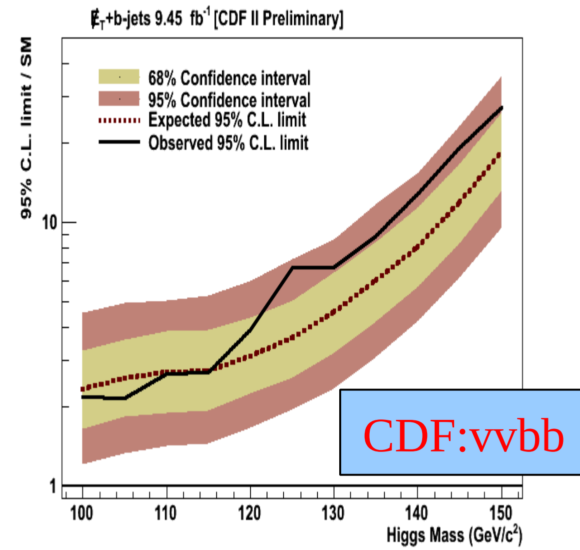


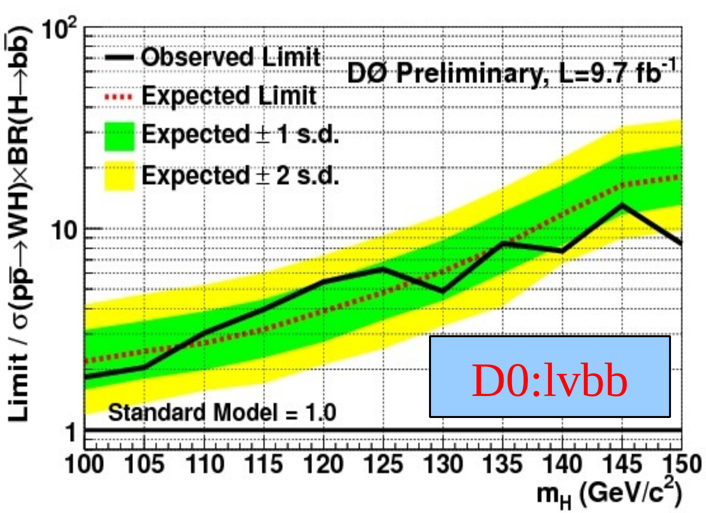
Limits for H→bb

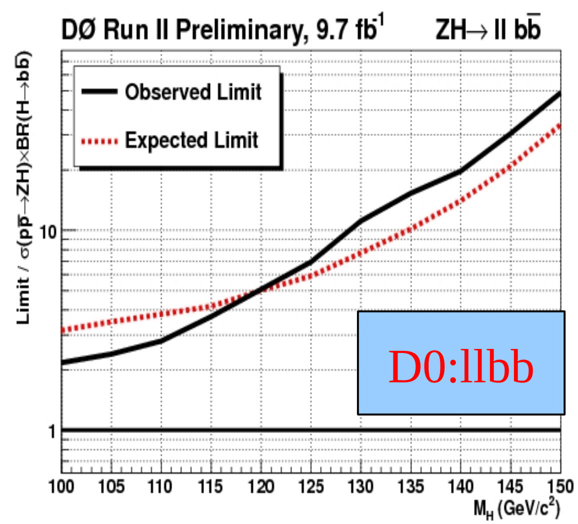
- Obtained individual Higgs limits for three main low-mass channels.
- Some excess events in CDF data while D0 continues improving their analyses.

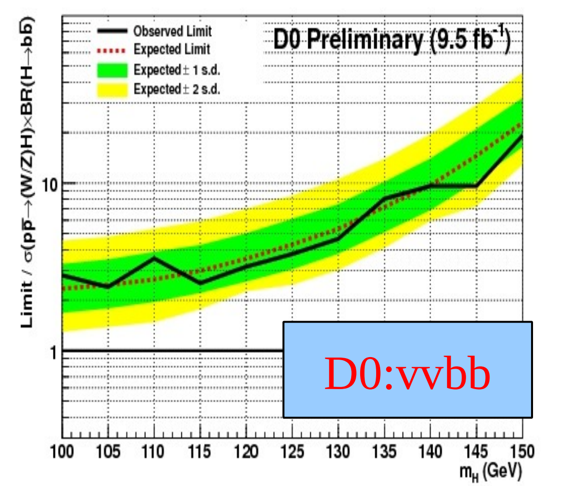




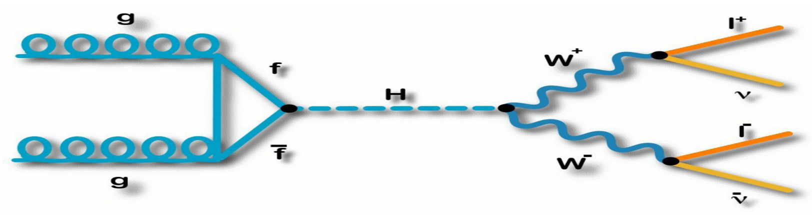


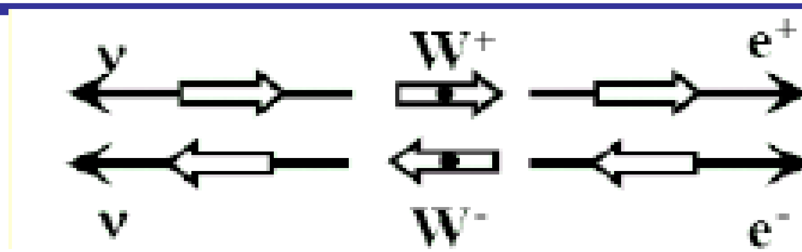




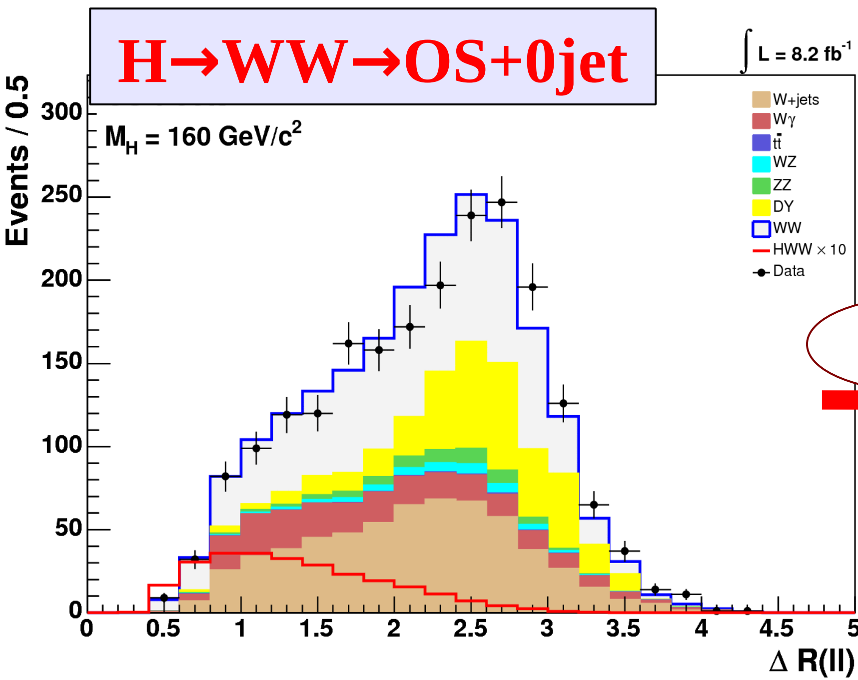


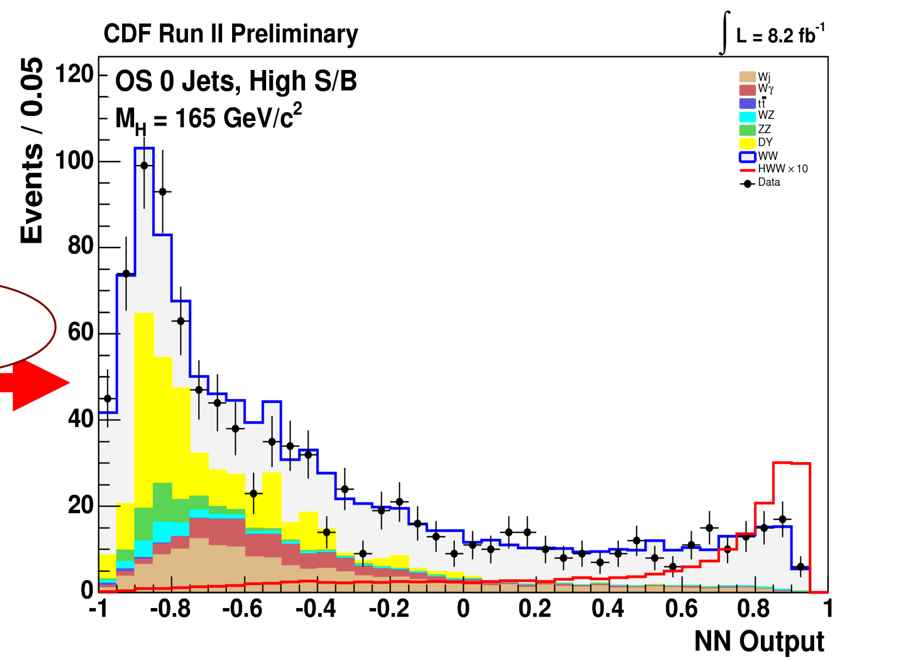
High Mass Signatures





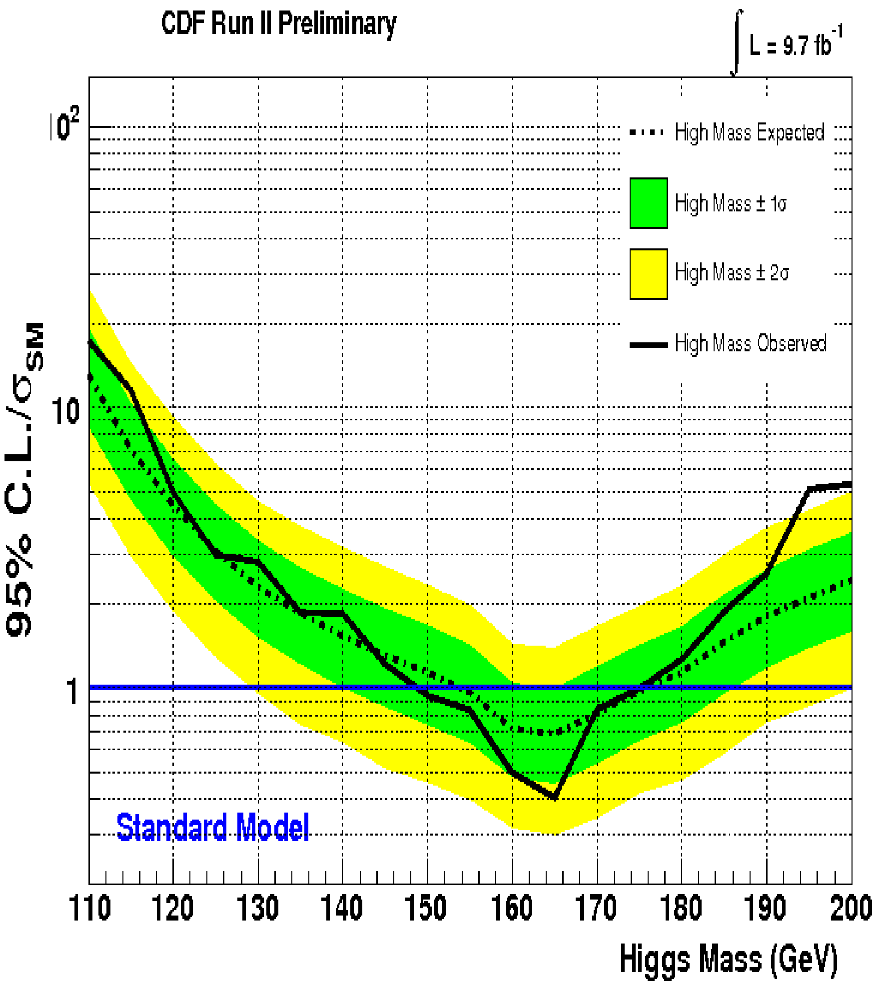
- Search for H→WW inclusively that leads to many interesting final states.
- Most sensitive channel is H→WW→llυυ: OS Dilepton + MET + 0,1,2 Jets.
- Requiring MVA to separate signal from main backgrounds(WW and top).

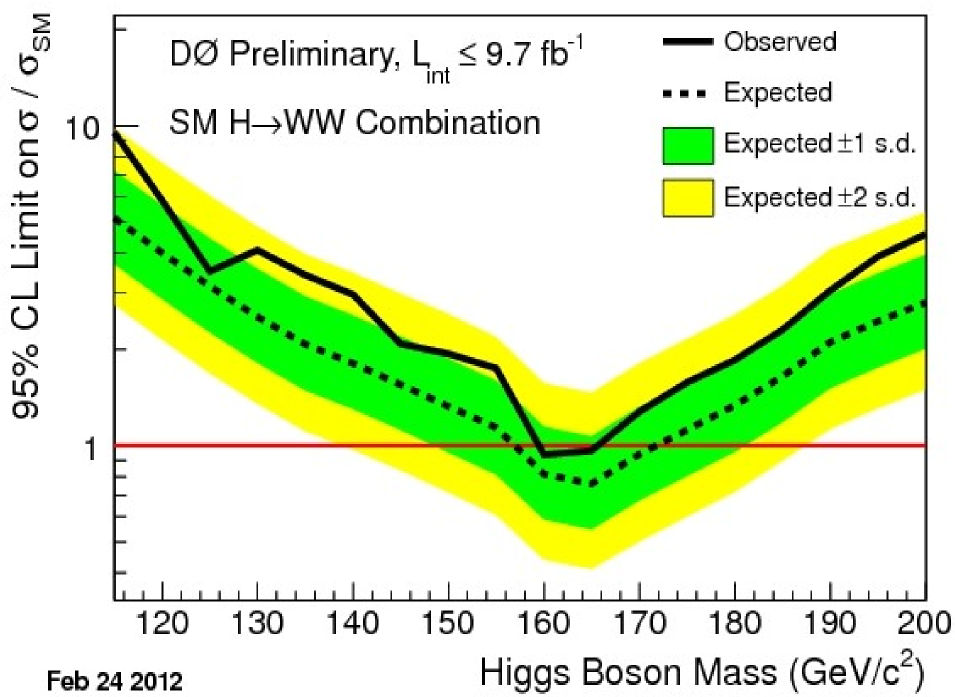




Limits for H→WW

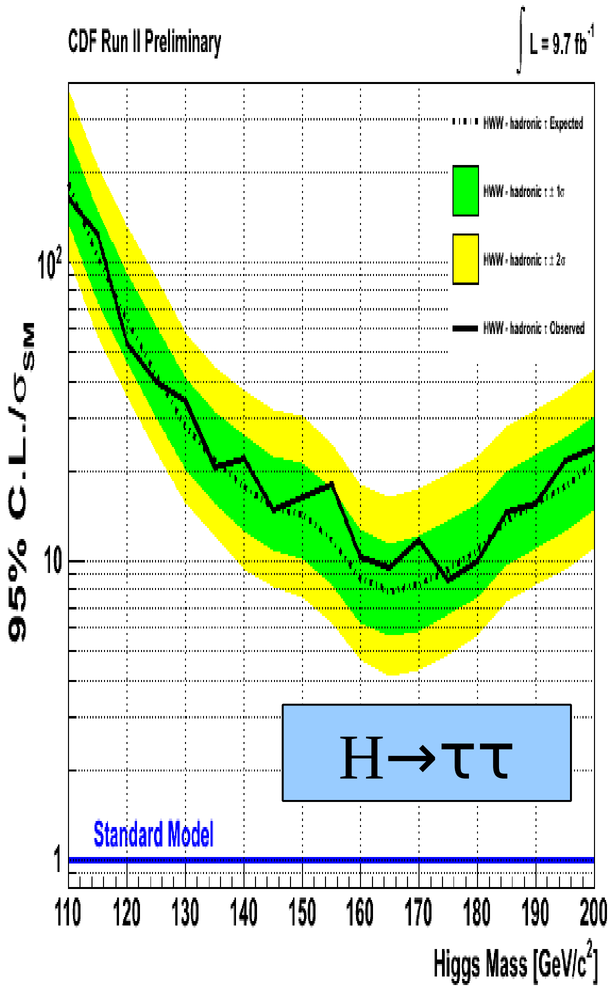
- H→WW Limit after combining all subchannels(OS+njet, low m_{ll}, SS, trileptons).
- CDF/D0 have similar sensitivities while its observed limit fluctuated differently.

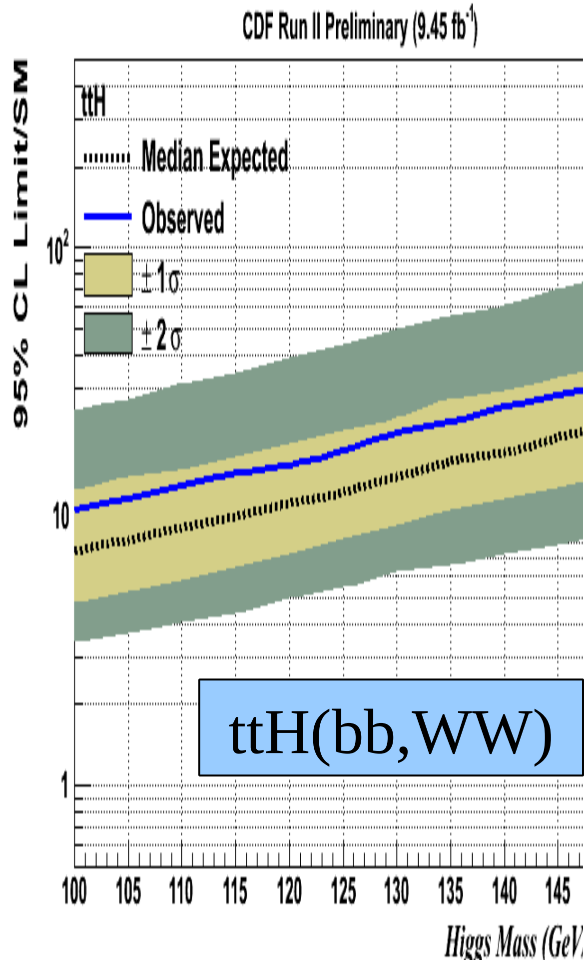


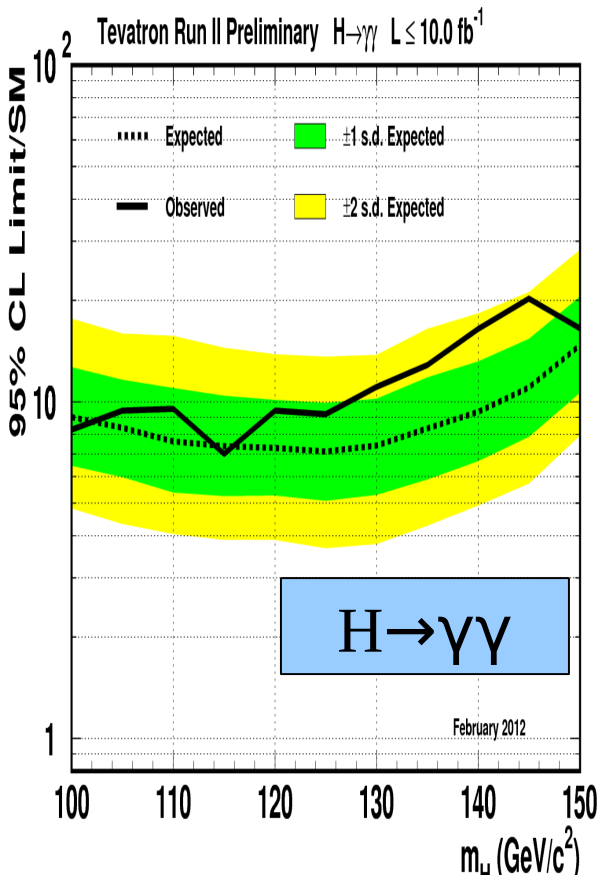


Other Searches

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



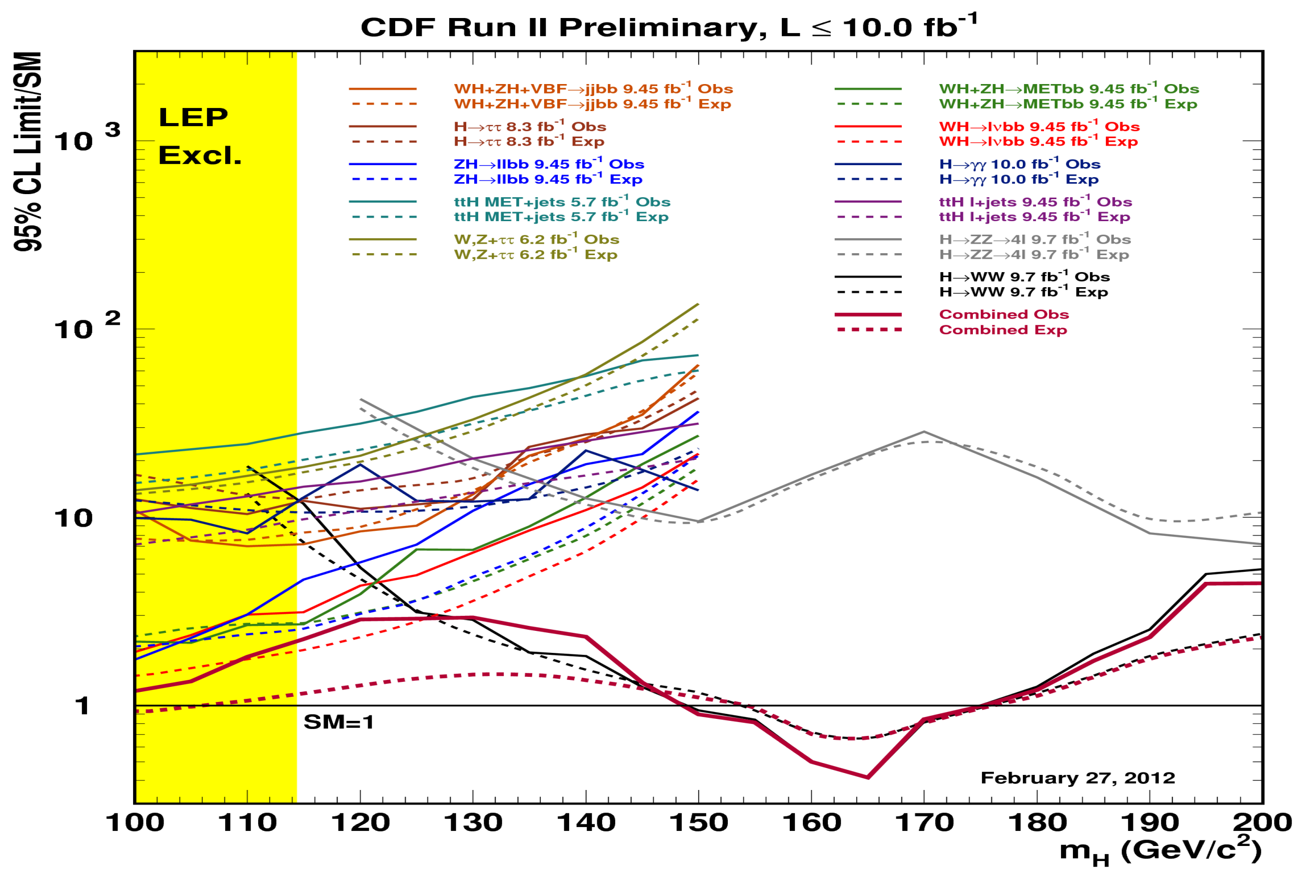




Combined Limits on SM Higgs Production

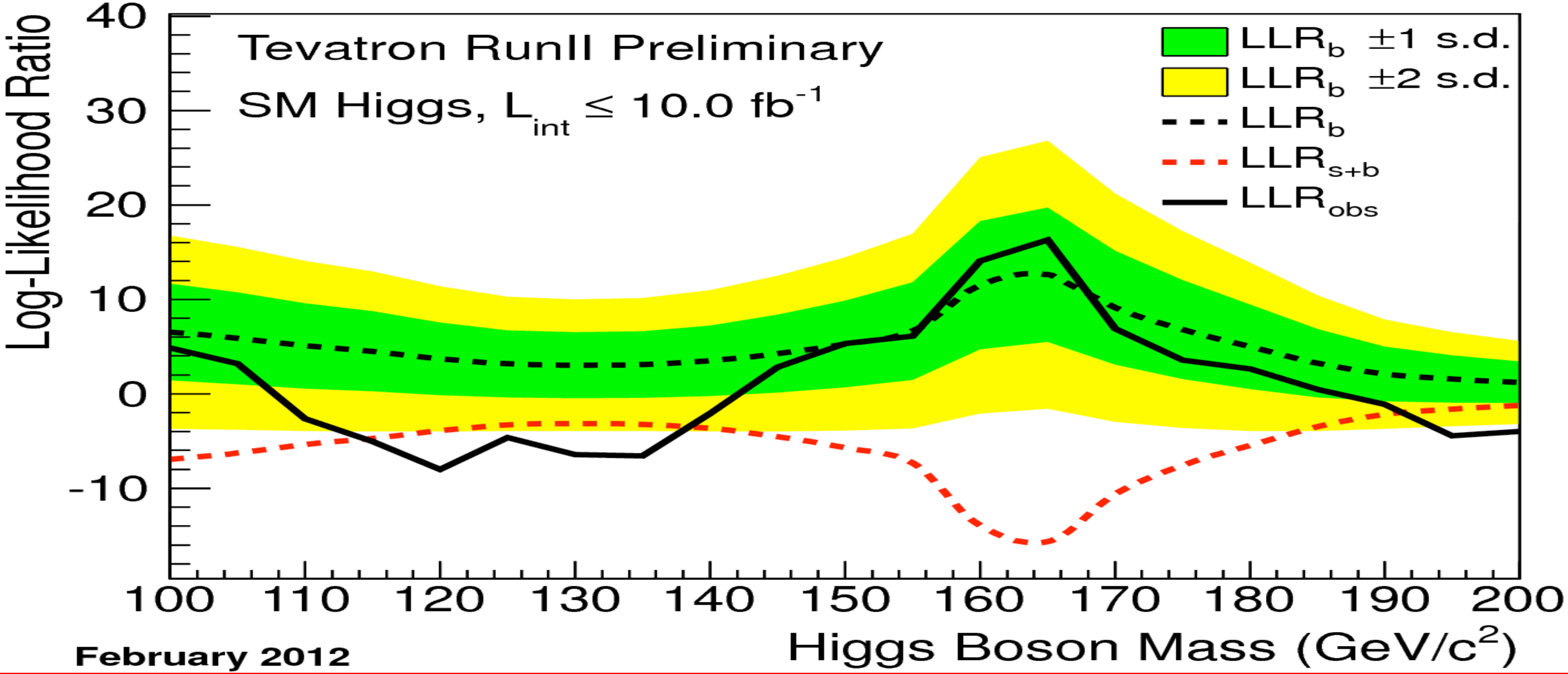
- Have searched for all possible SM Higgs production and decays and set limits with respect to nominal SM predictions.
- CDF and D0 in good agreement, combining to improve Tevatron limit.

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 Sensitivity

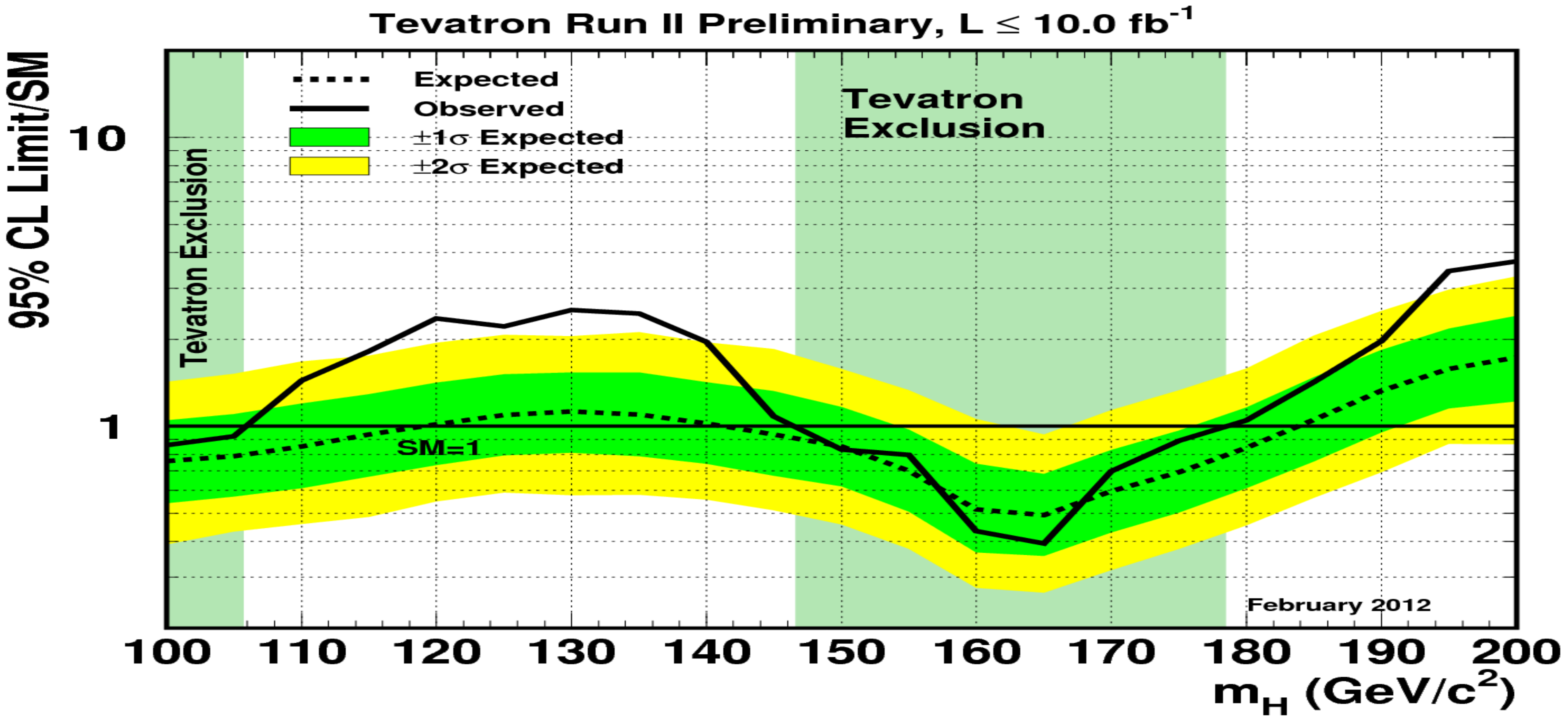
- Log-likelihood Ratio help to test data with different signal hypotheses
- LLR Separation between B and S+B provides a measure of search sensitivity.



Expect to see ~ 2 σ excess for Higgs mass at 125 GeV.
Data consistent with S+B hypothesis in $115<m_H<135$ GeV.

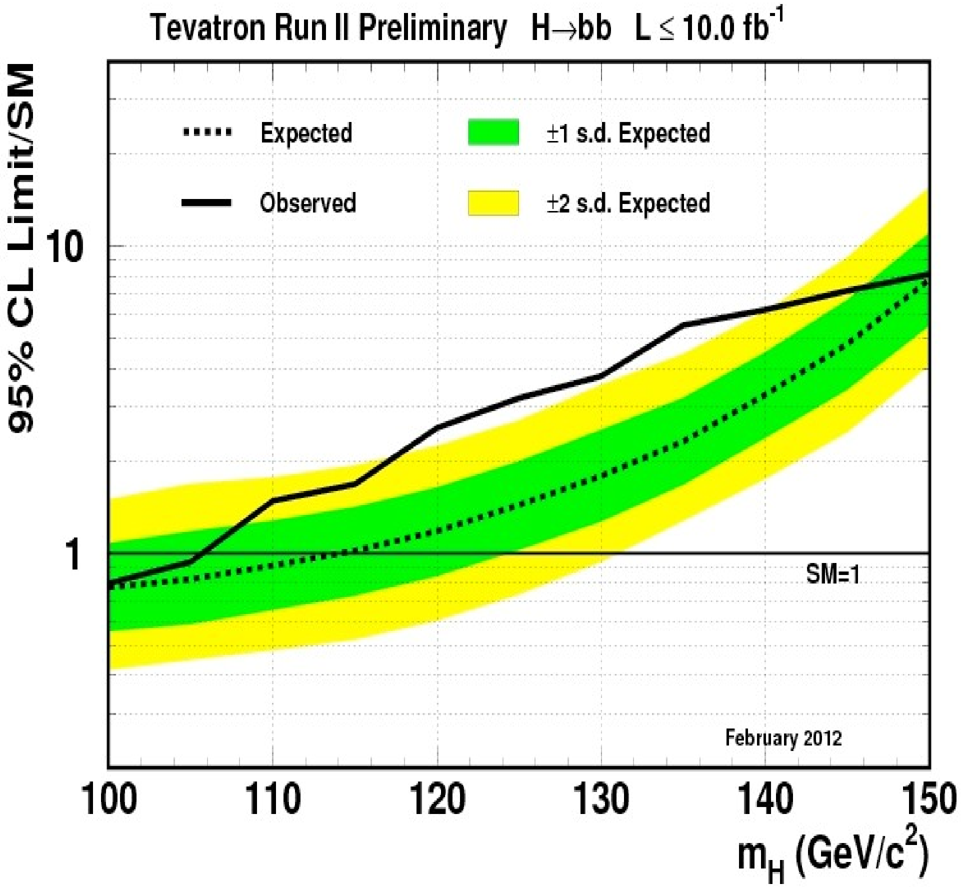
Tevatron Combination

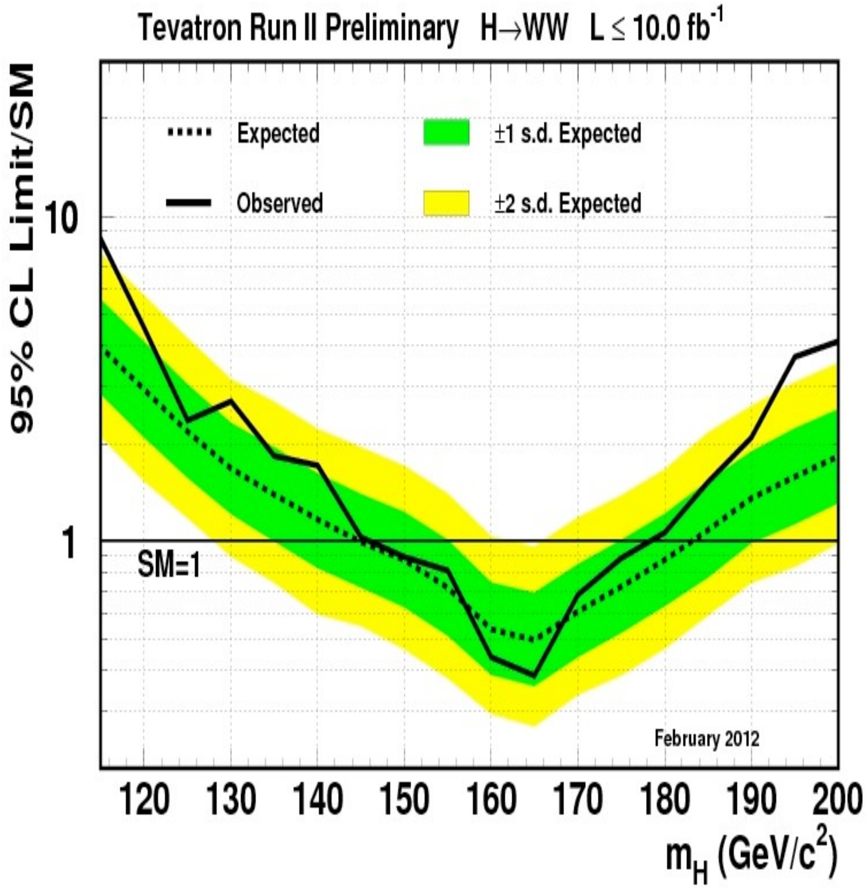
- Observed Exclusion: $100<M_H<106$ & $147<M_H<179$ GeV/c^2 @95%CL.
- Expected Exclusion: $100<M_H<120$ & $141<M_H<184$ GeV/c^2@95%CL.
- There are >2σ excess of events in $115<m_H<135$ GeV



Tevatron H→bb, WW Combination

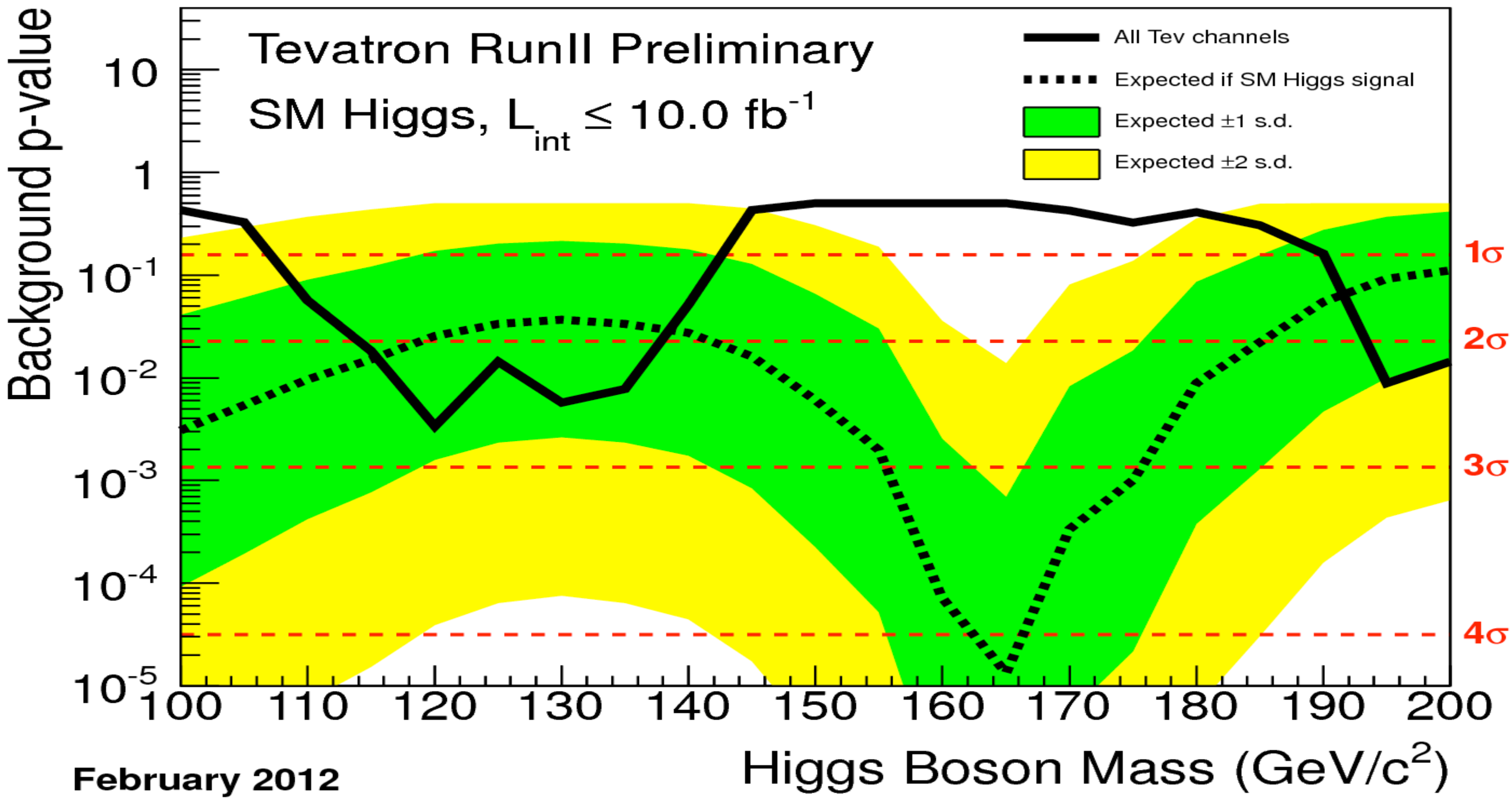
- Combining H→bb, WW channels separately to see where excess comes from.
- Excess is mainly driven by H→bb which has >2σ excess in same mass region.





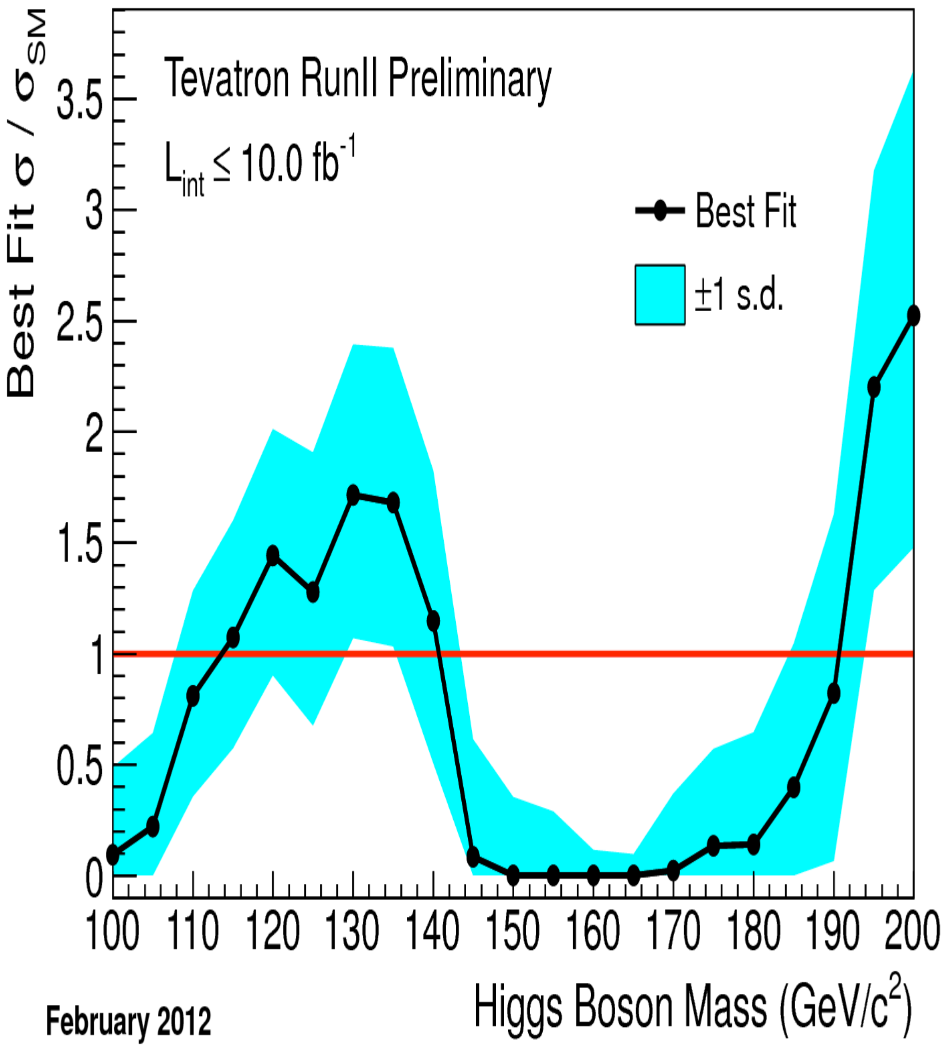
Quantifying the Excess:

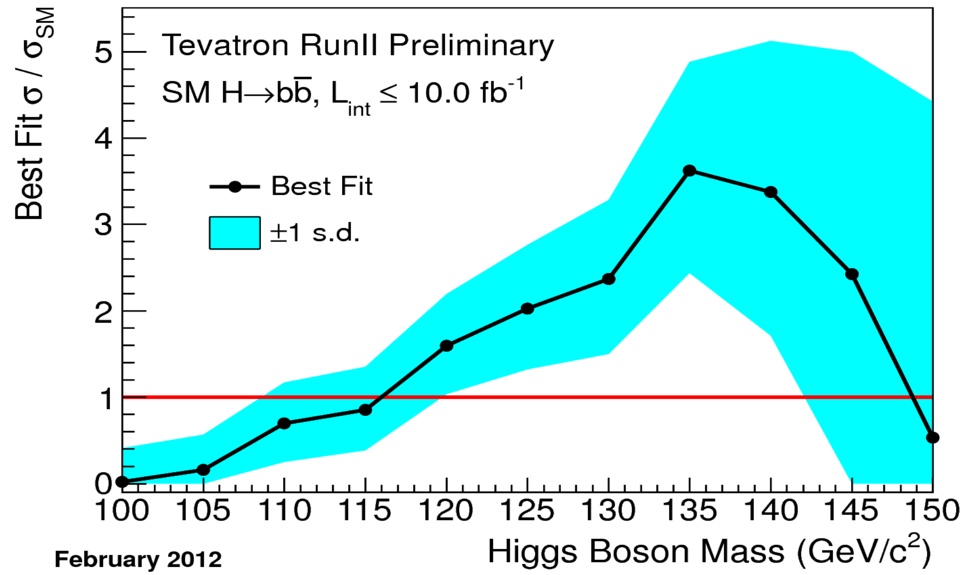
- Calculating local p-value distribution for background-only hypothesis.
- Local p-value=2.7σ at 125GeV gives global p-value=2.2σ with LEE factor 4.

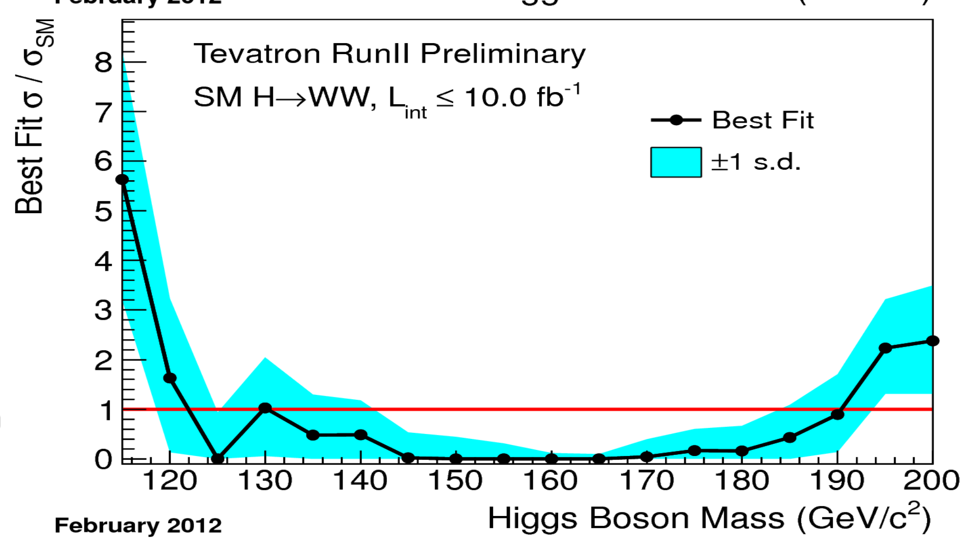


Fitted Signal Rate

- Fit to data and separately for bb, WW with signal as free parameter.

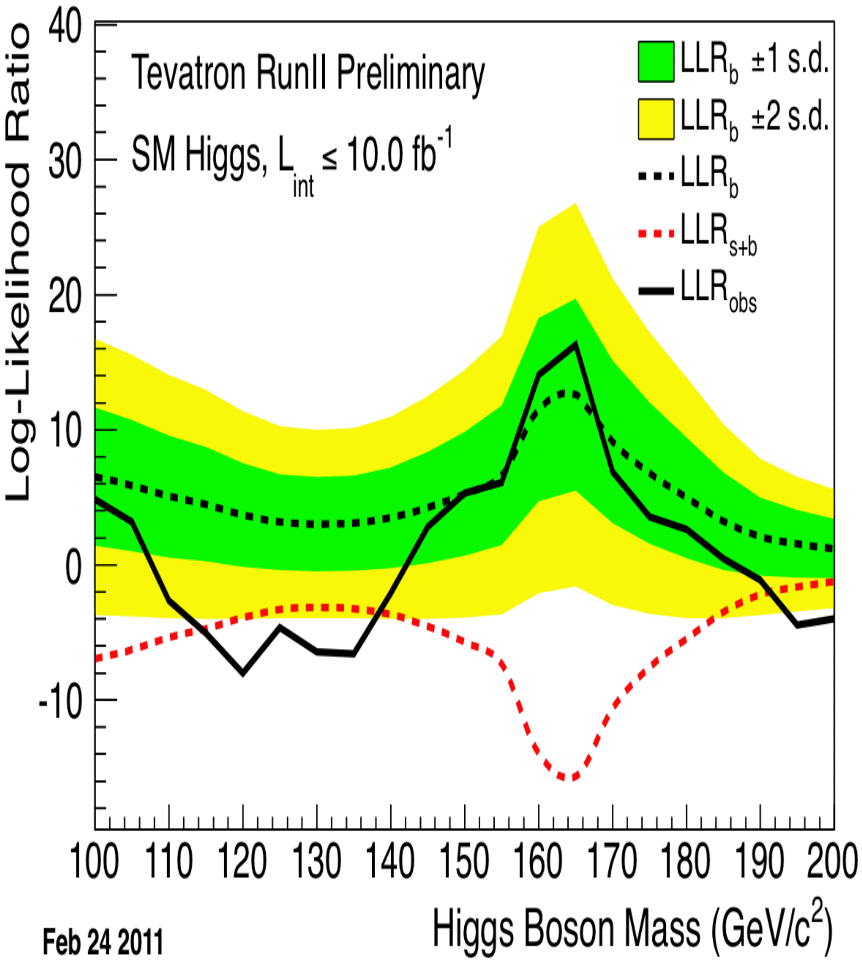


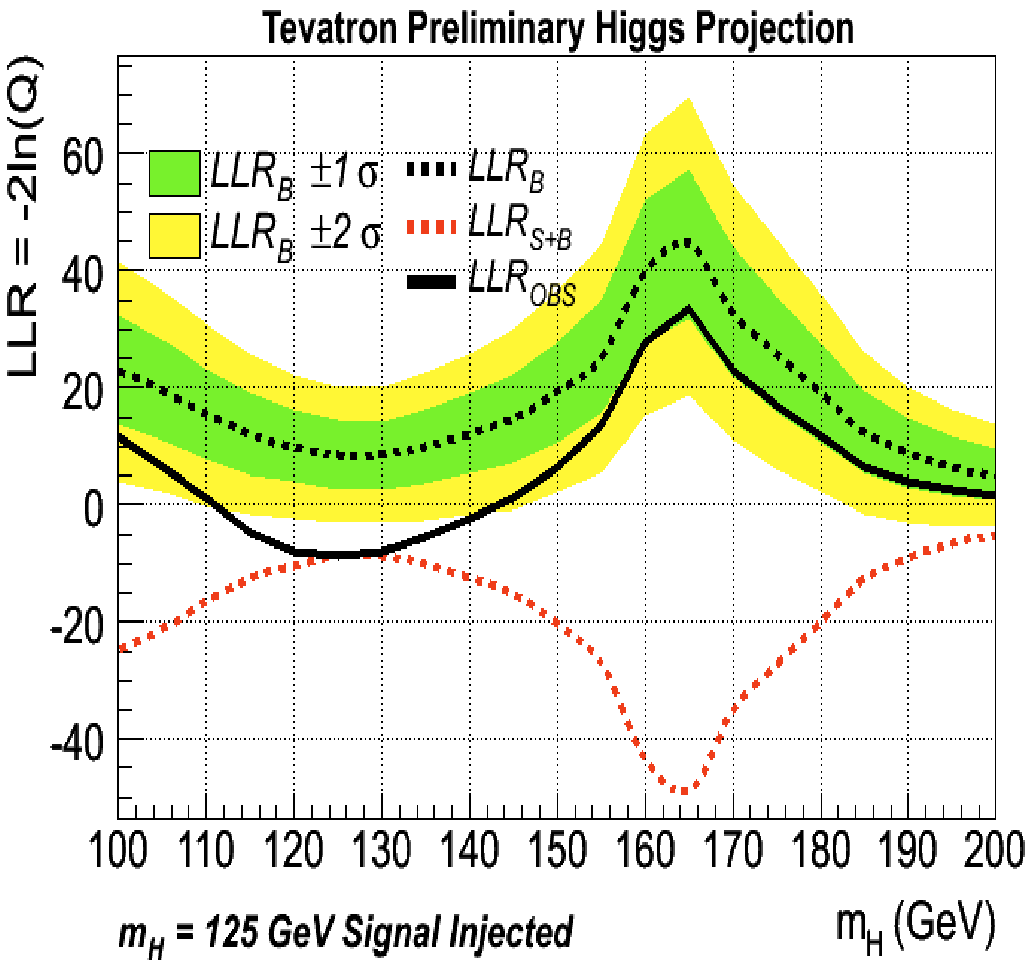




Compatible with SM Higgs at 125 GeV

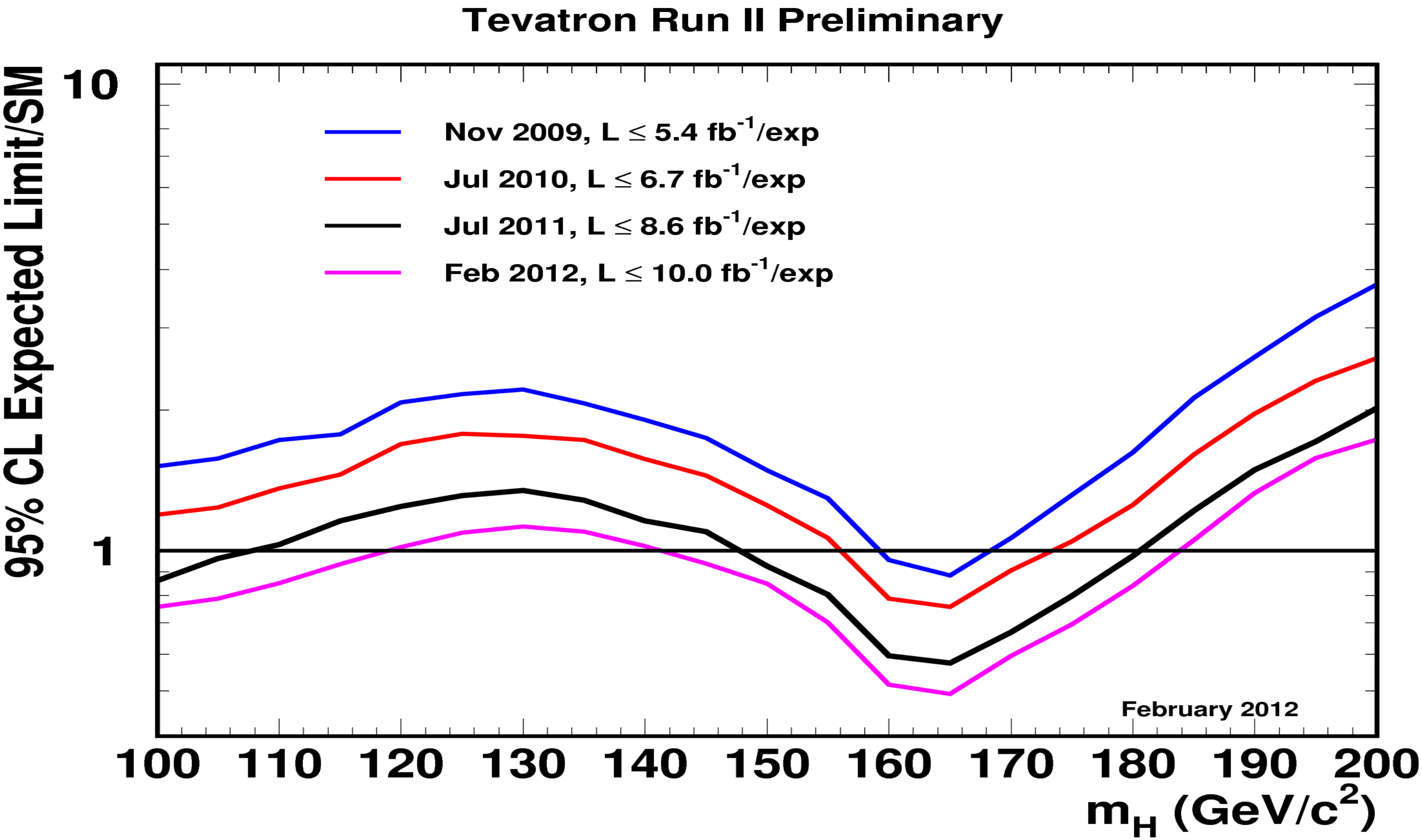
- Compared LLR after injecting Higgs(125) to bkgd-only pesudo-experiments.
- MVA is not optimized for mass, but for S/B separation, expect a broad excess.





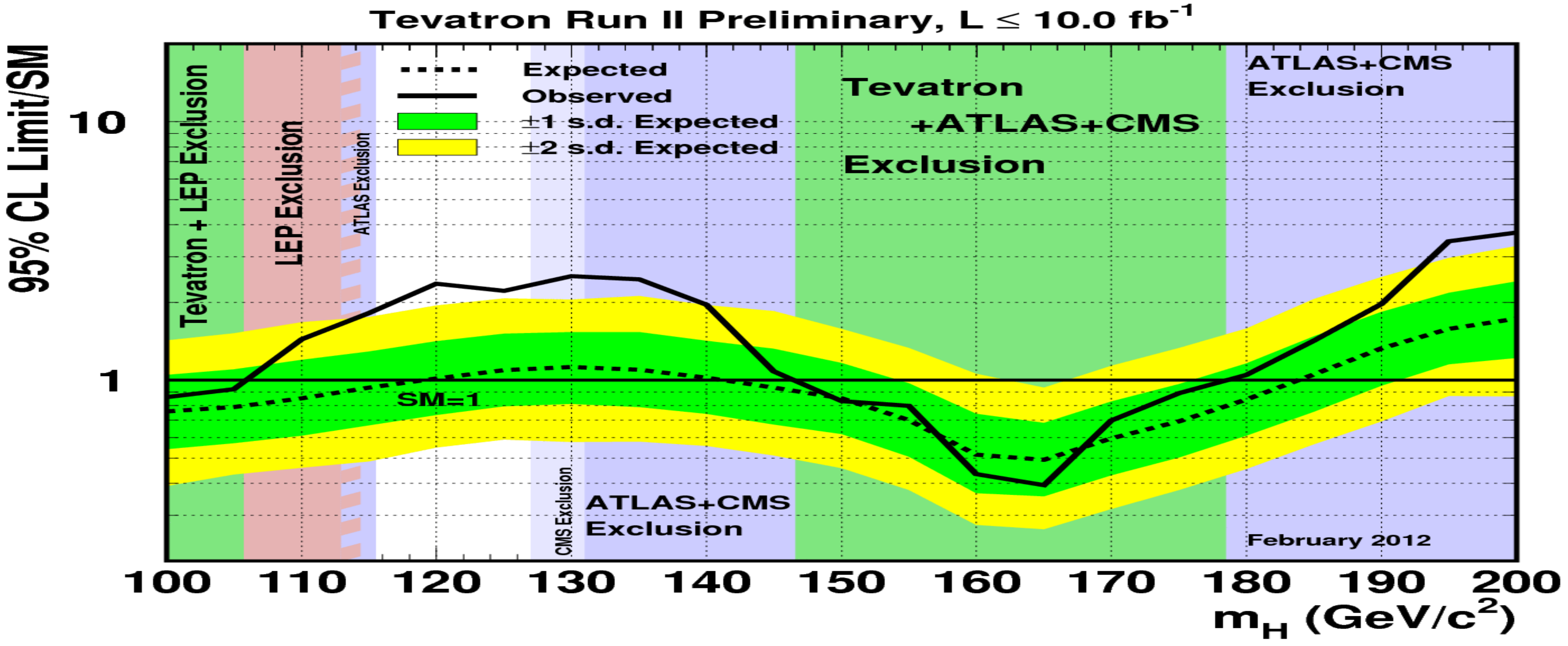
Improvements of Higgs Sensitivity

- Achieved Higgs sensitivity over time is close to 1/L, instead of 1/sqrt(L).



Conclusion

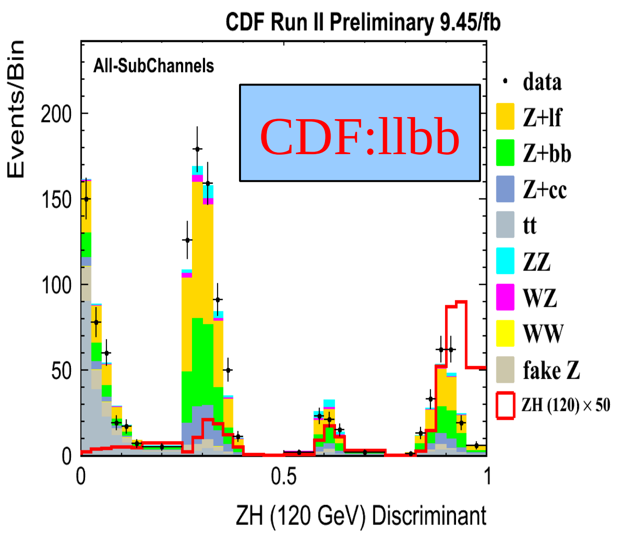
- With full dataset and many years hardwork, Tevatron has finally reached SM Higgs sensitivity over most of mass range up to 185 GeV.
- Observed small excess in $115 < m_H < 135$ GeV with global p-value~2.2σ
- Further improvements are expected and have final results at ICHEP.

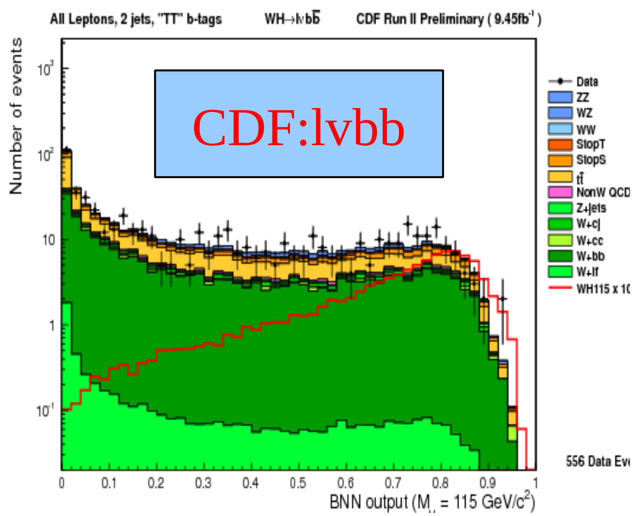


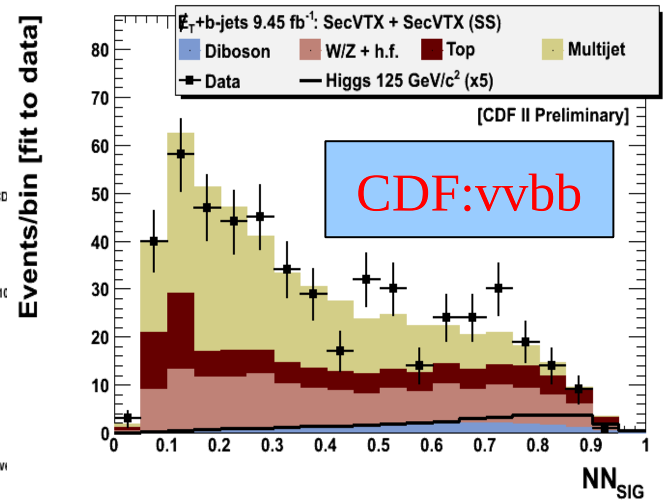
BACKUP

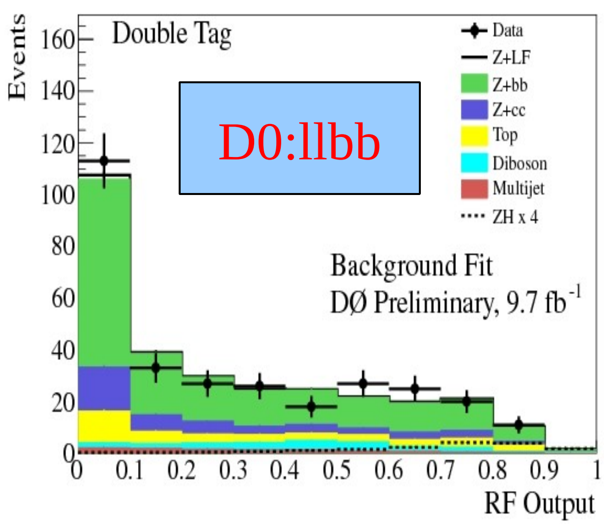
Searching for H→bb

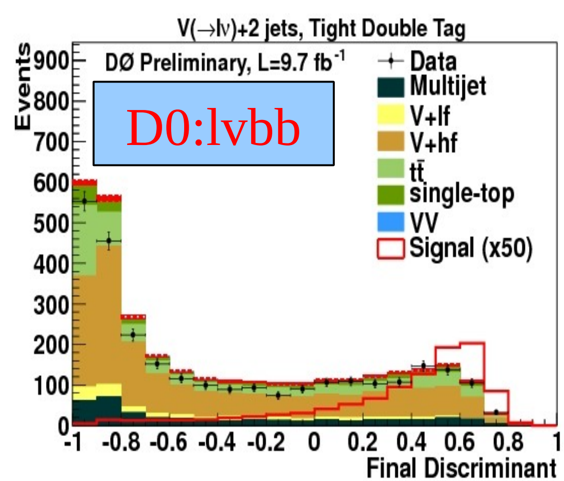
- Some examples of the final discriminant in three main low-mass channels.
- Overall agreements between data and bkgd predictions are excellent.

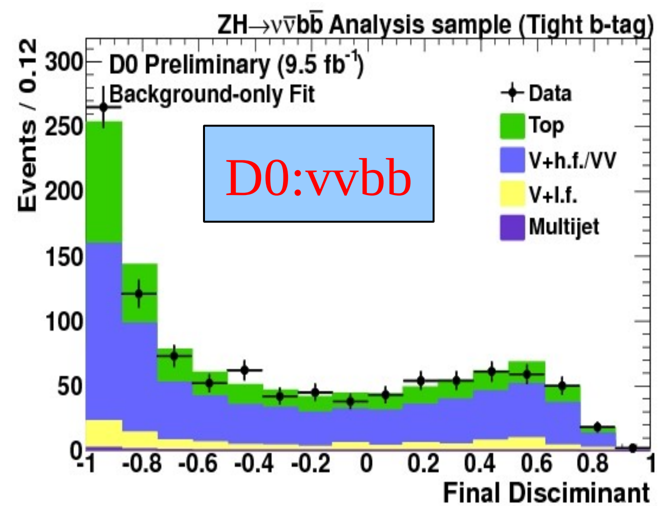






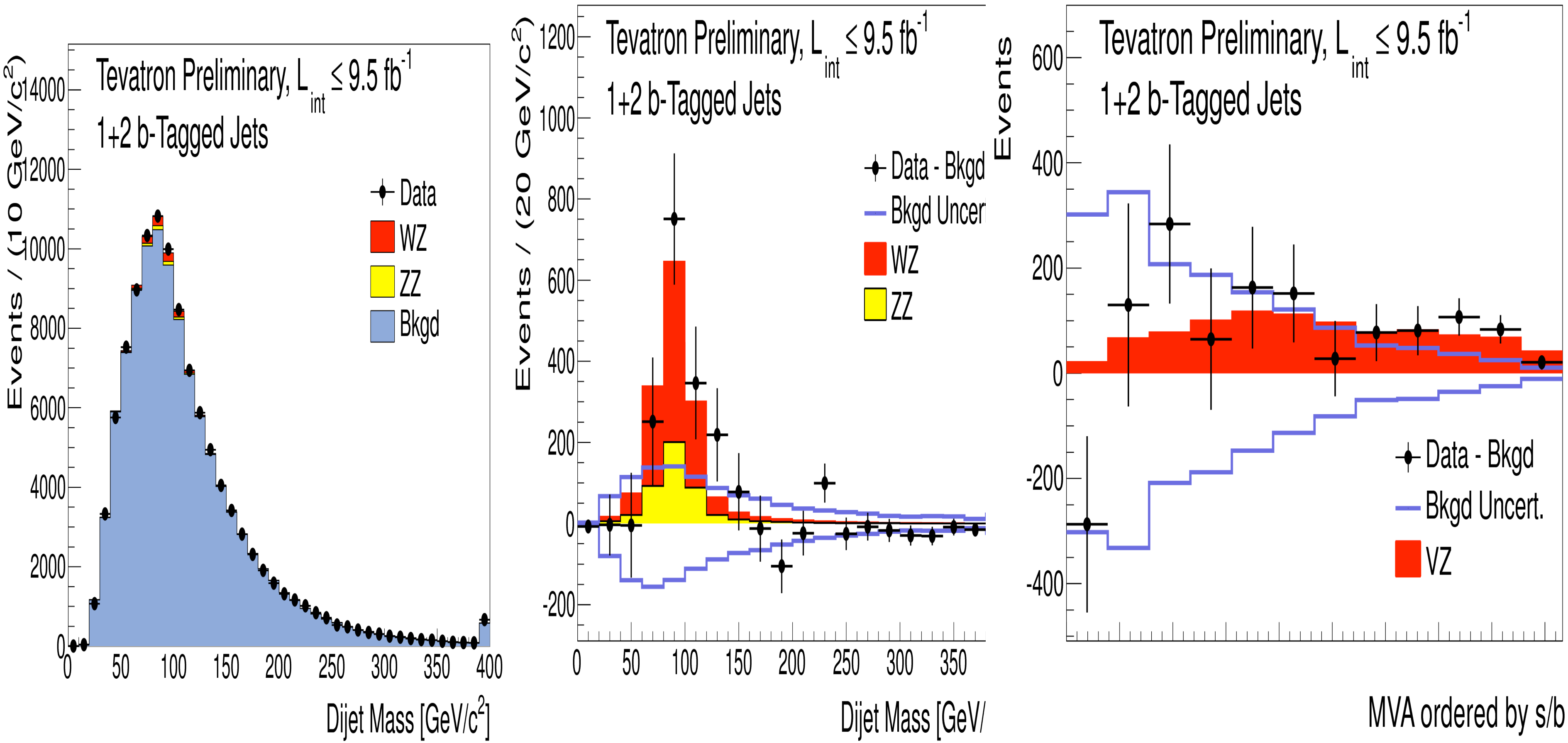






Searching for Z→bb: Validation of Analysis Tools

- Validating search strategy by looking for WZ and ZZ with similar signatures.
- Combination of CDF and D0 searches for WZ/ZZ →llbb, lνbb, and ννbb
- Measured σ_{WZ+ZZ}=(1.01+-0.21) x SM, in good agreement with SM



Theoretical Uncertainties

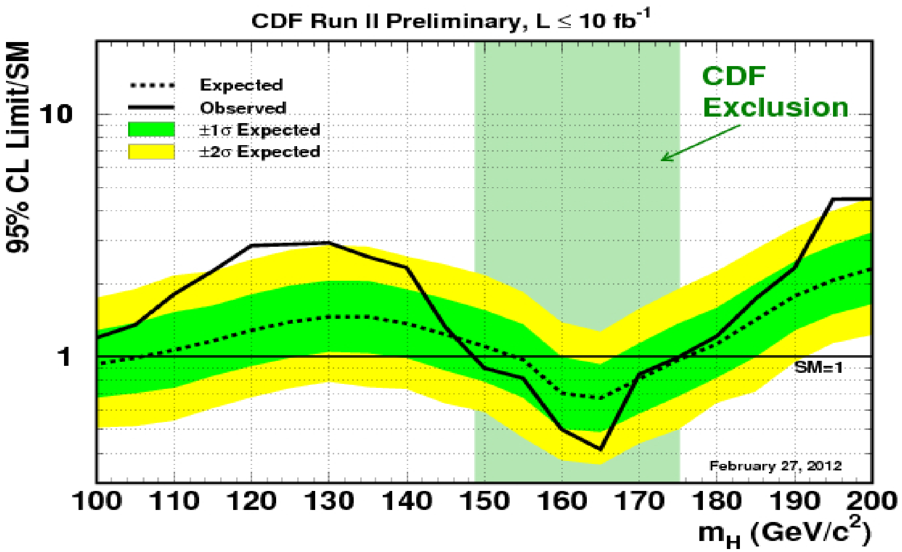
- Since we combine searches in different Higgs production/decay modes, cross section limits are given with respect to nominal SM predictions.
- This requires to incorporate latest theoretical predictions and uncertainties for signal cross section and branching ratios.
- Changes in each iteration to reflect the progresses made in theory and development of MC generators over many years, for example:
  - the new prescription of PDF by LHC Higgs cross section WG
  - BNL accord to estimate $H \rightarrow WW$ uncertainties in each jet bin.
  - the interference between $H \rightarrow WW$& WW needs to be included next time.

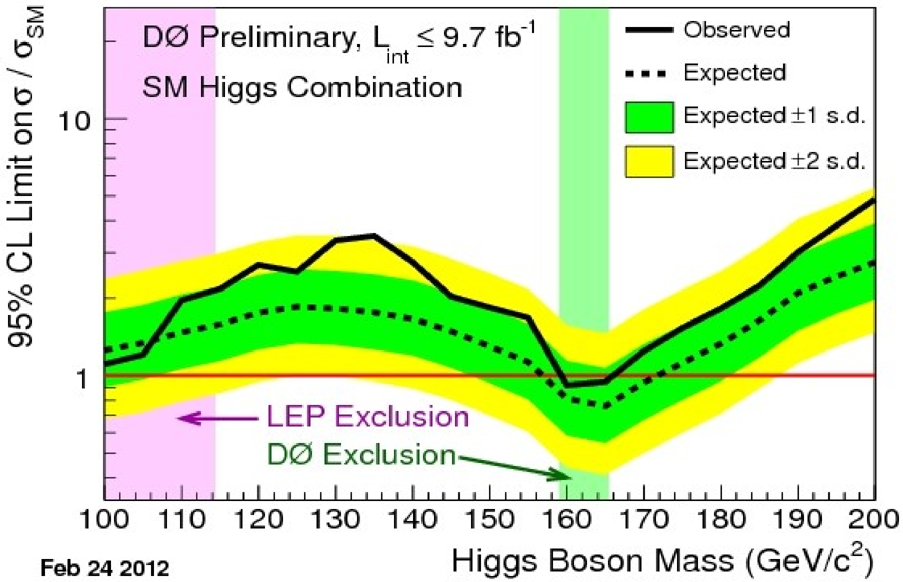
Combination Methods

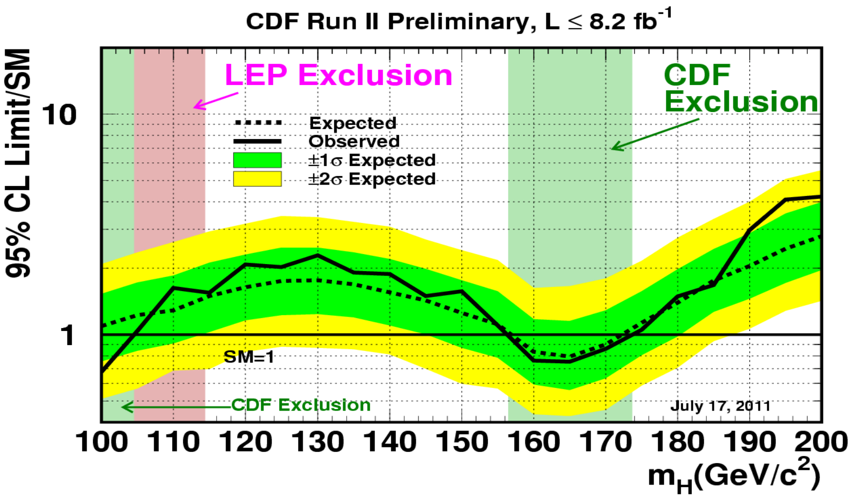
- Two limit setting methods used and provide cross check.
  - Using distributions of final discriminant, not just event yields.
  - Using Poisson statistics for all bins.
  - Systematic as nuisance parameters with truncated Gaussian.
- **Bayesian Method (CDF), integrating over likelihoods:**
  - based on credibility, uses a prior
  - “How likely is the real value below limit?”
- **Modified Frequentist Method (DØ), CLs test statistics:**
  - comparing 'b-only' & 's+b' hypotheses
  - based on coverage, using pseudo-experiments
  - “How likely is the limit above the real value?”

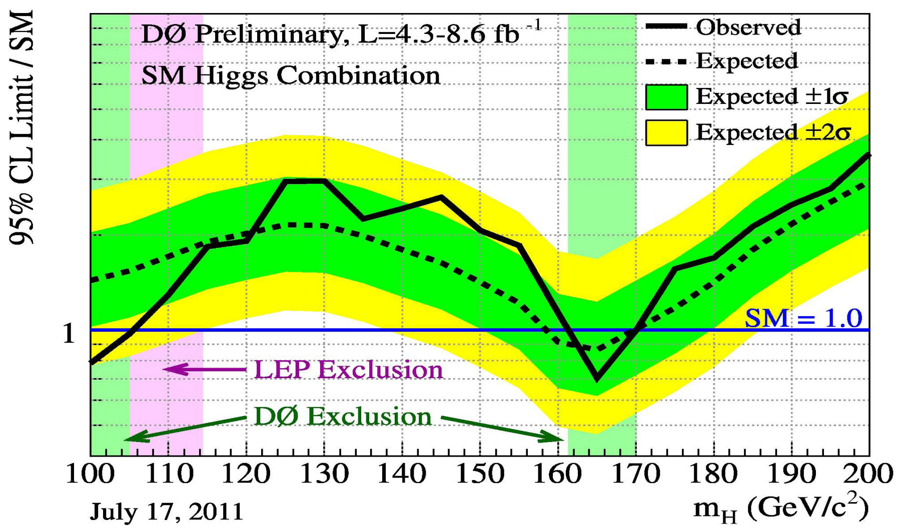
CDF/D0 Limits

- Comparable sensitivity and Consistent results



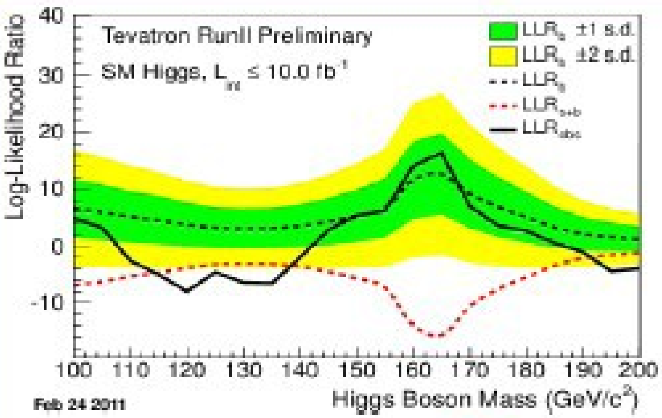




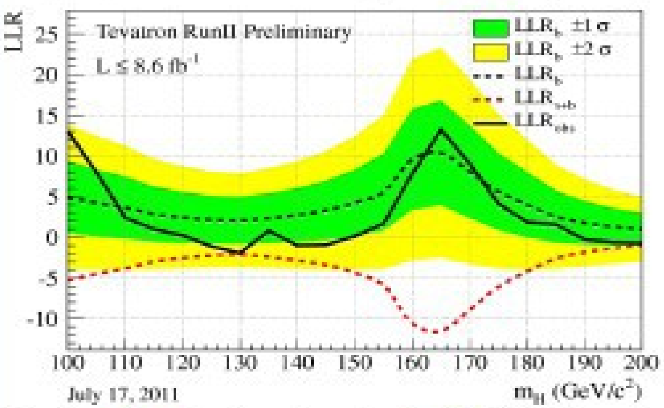


History of Log Likelihood Ratios

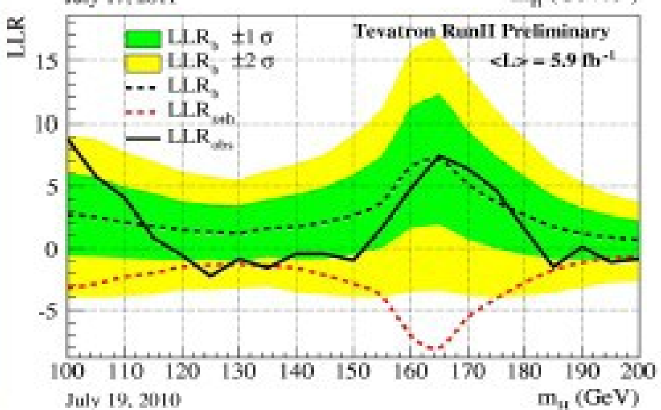
2012



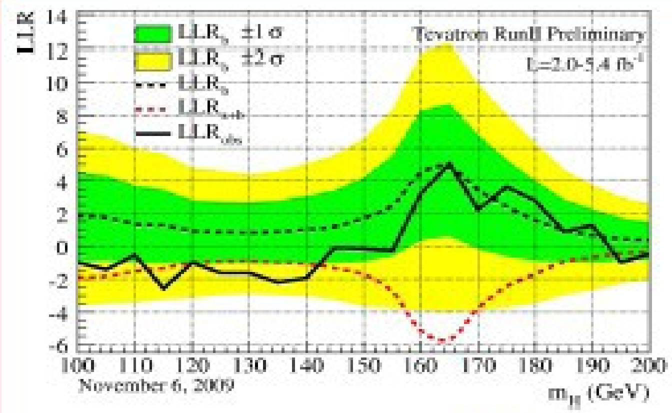
2011



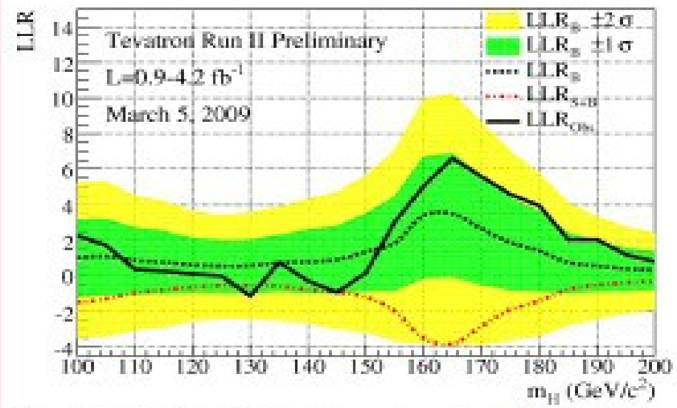
2010



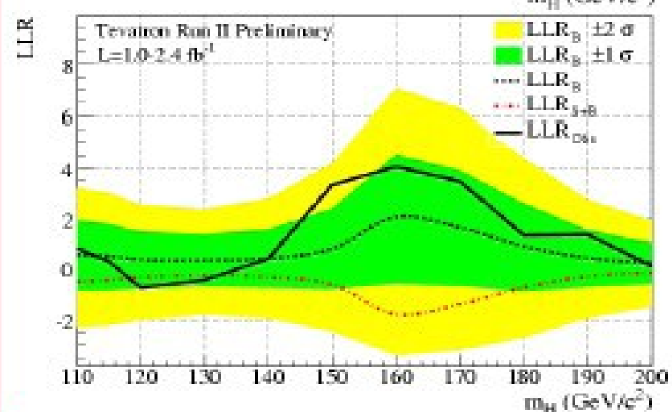
2009



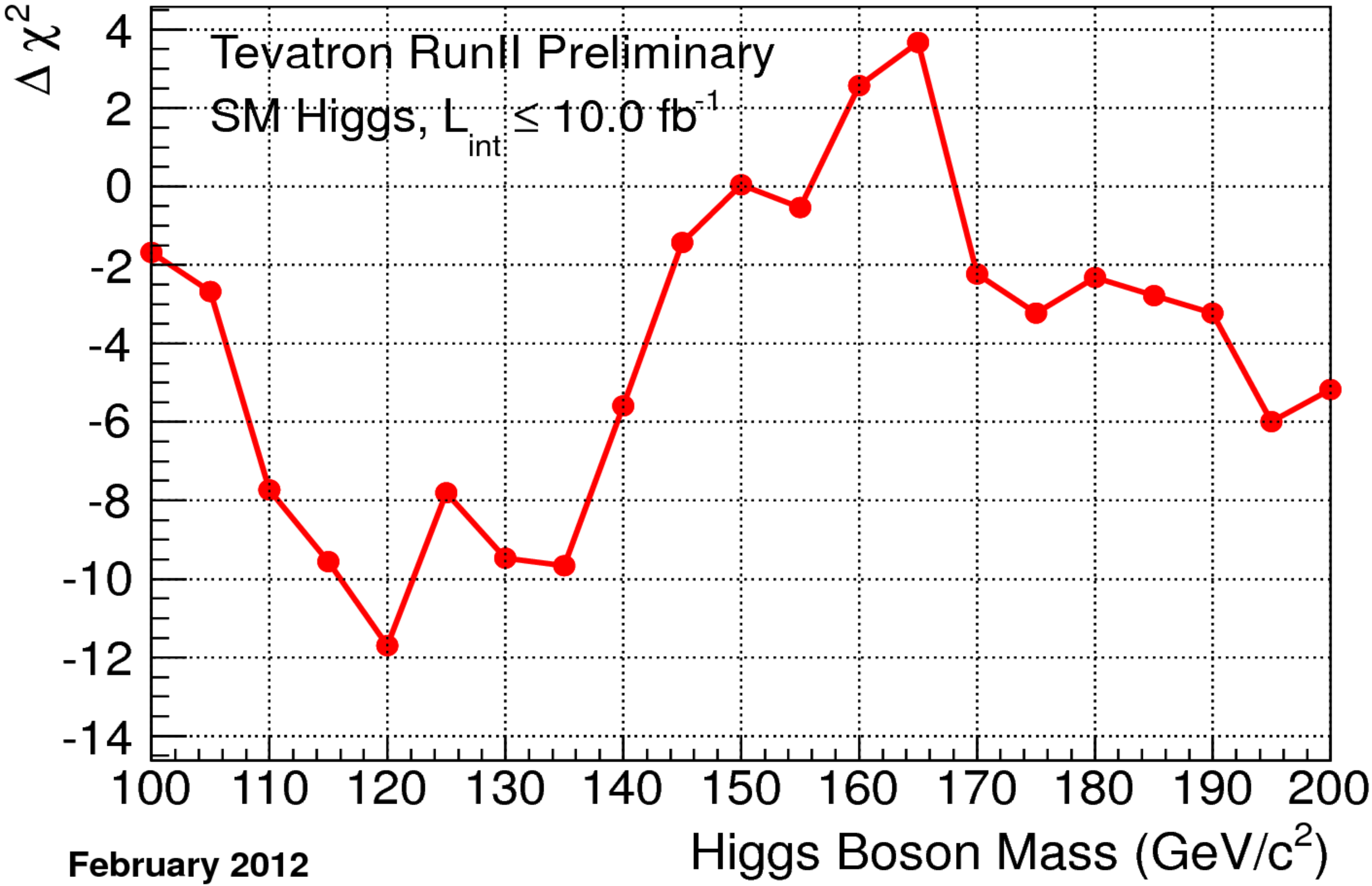
2008



2007

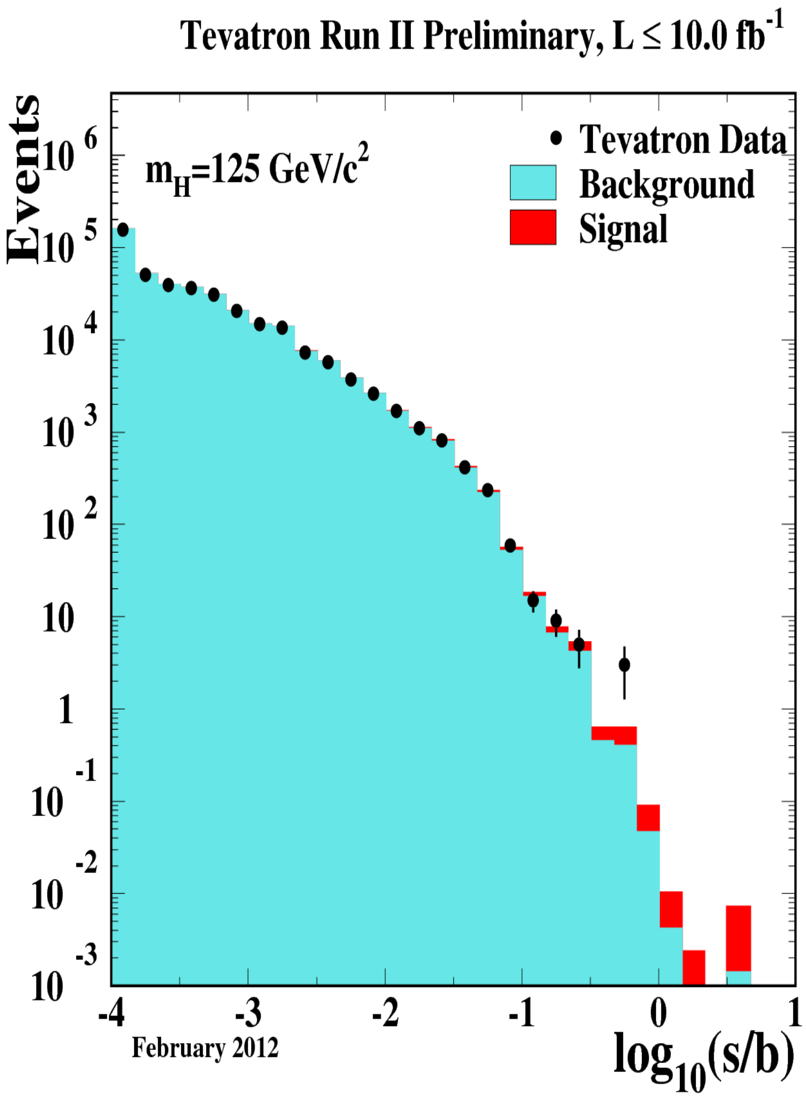


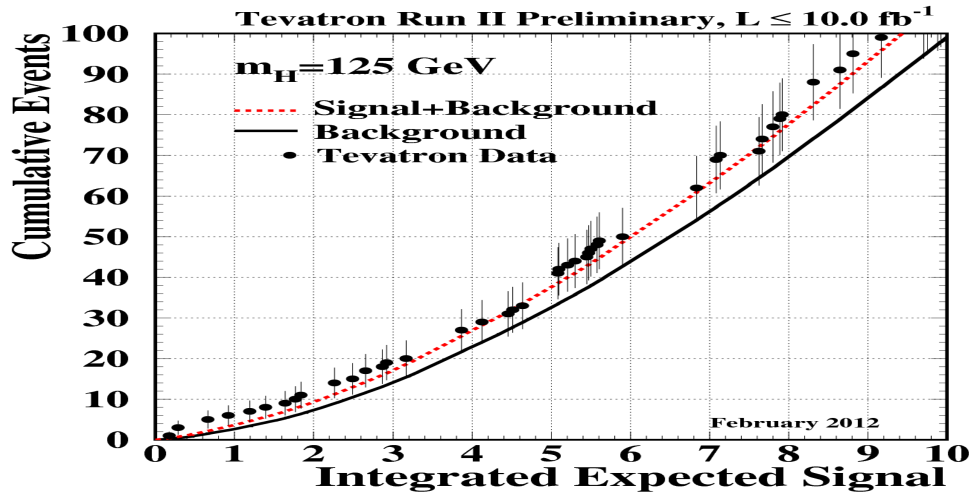
$\Delta\chi^2$

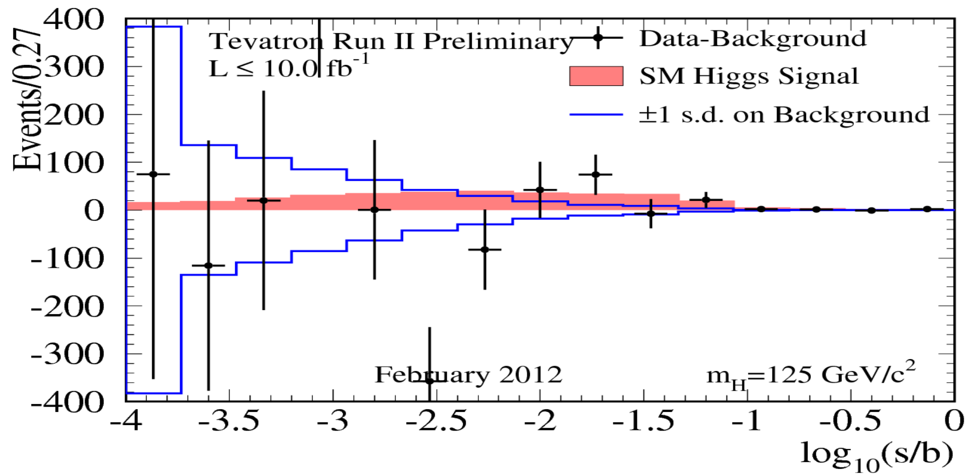

Tevatron RunII Preliminary
SM Higgs, $L_{int} \leq 10.0\ fb^{-1}$
$\Delta\chi^2$
4
2
0
-2
-4
-6
-8
-10
-12
-14
100
110
120
130
140
150
160
170
180
190
200
Higgs Boson Mass (GeV/c^2)
February 2012

Cumulative Discriminant at M_H=125 GeV

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

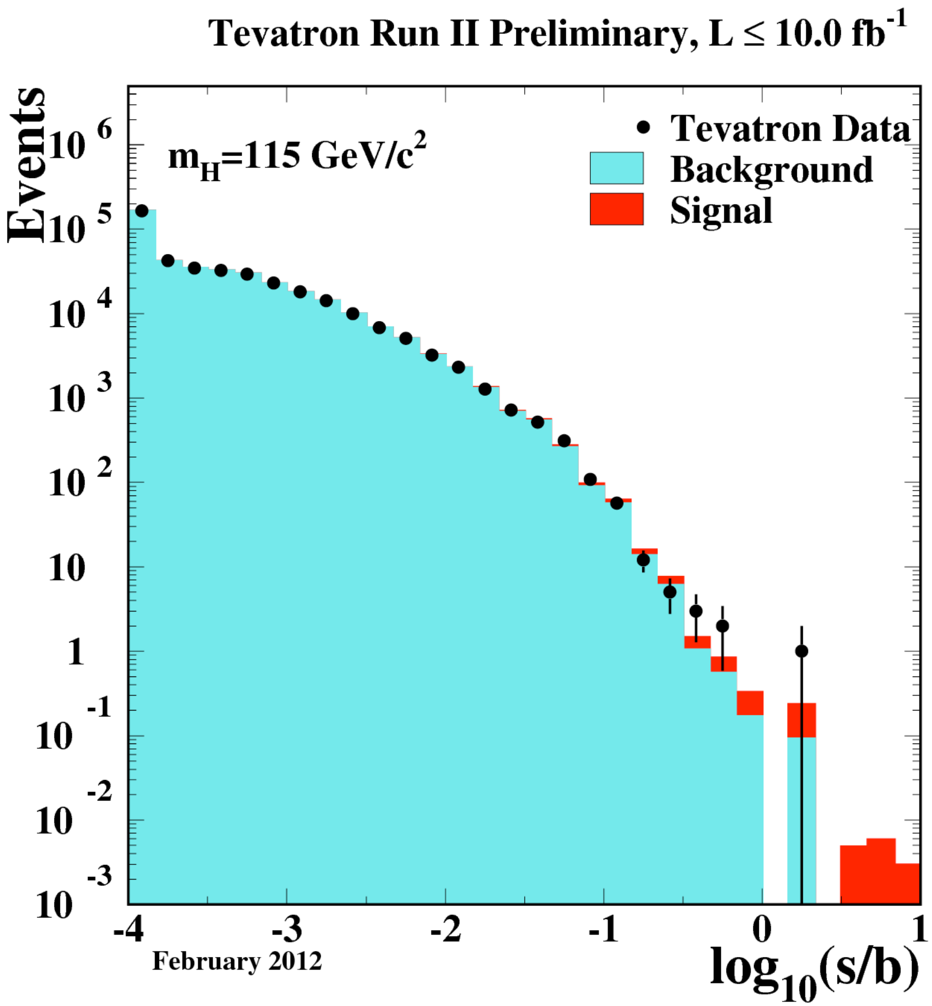


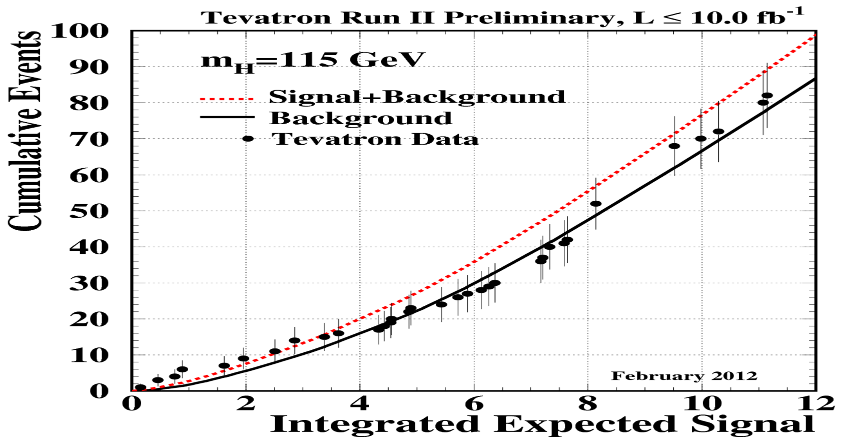


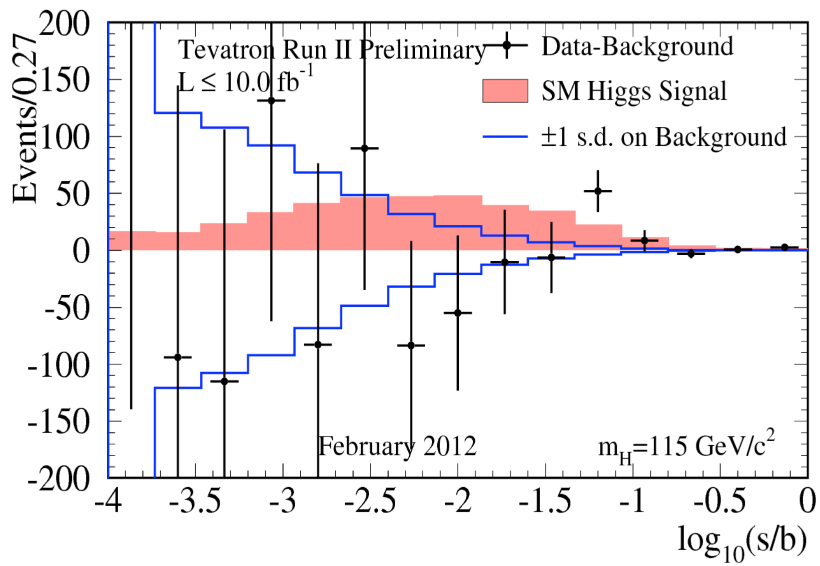


Cumulative Discriminant

- Sum events from all channels, ordered by S/B for M_H=115 GeV.

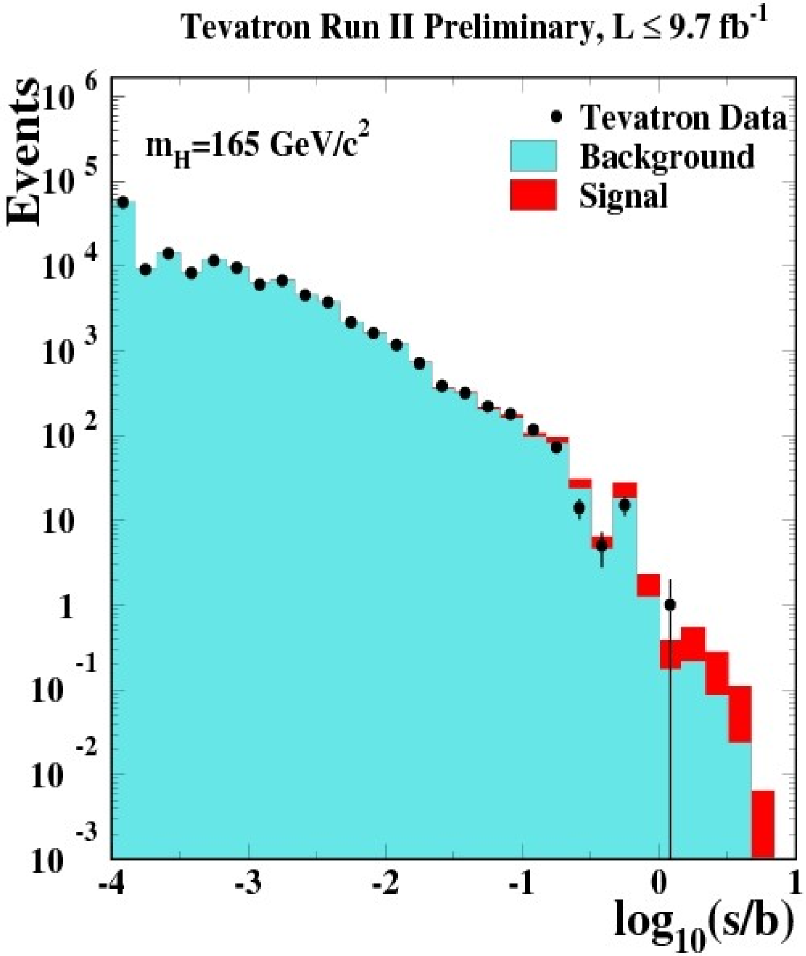


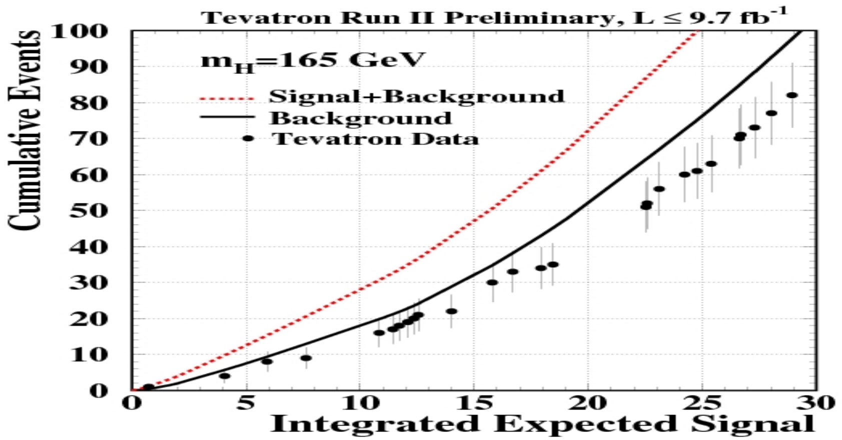


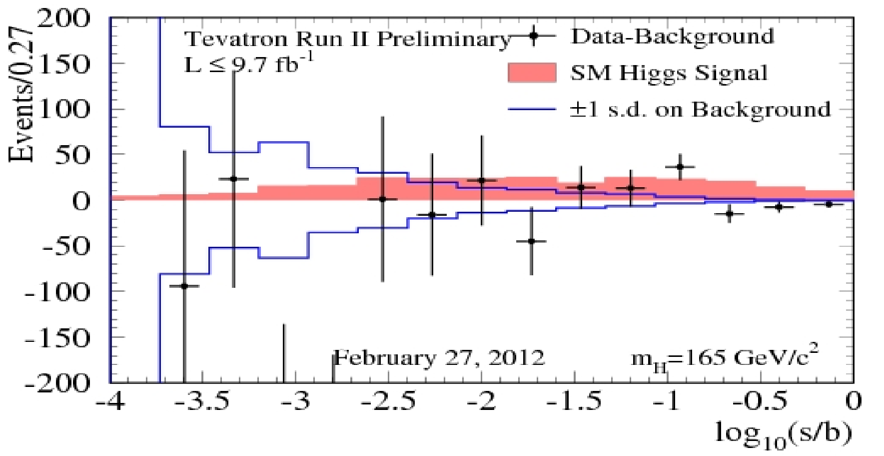


Cumulative Discriminant

- Sum events from all channels, ordered by S/B for M_H=165 GeV.







ZH→llbb

- Comparison of ZH→llbb between summer 11 and winter 12.