Search for Low Mass Higgs Boson at the Tevatron

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On behalf of the CDF and D0 Collaborations

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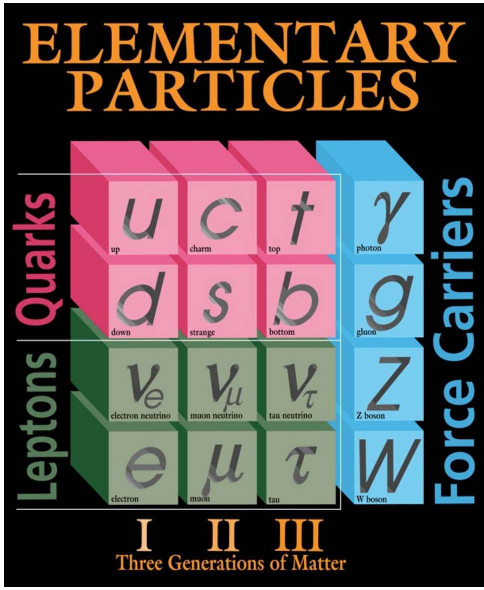
Outline

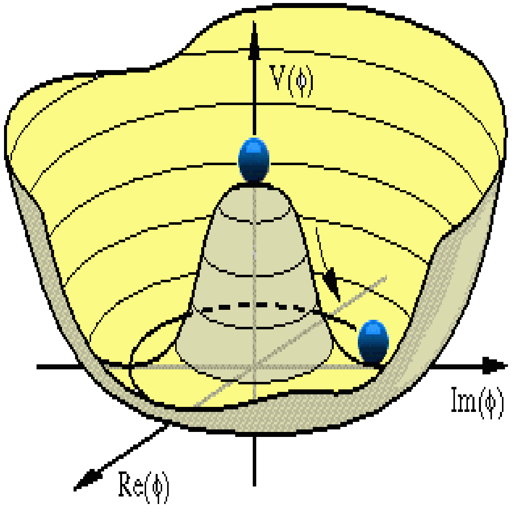
- Introduction.
- Higgs Search Strategies.
- Analysis Techniques.
- Highlights of Low Mass Results.
- Future Prospects and Conclusion.

- Details:
  - http://www-cdf.fnal.gov/physics/new/hdg/Results.html
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

Introduction

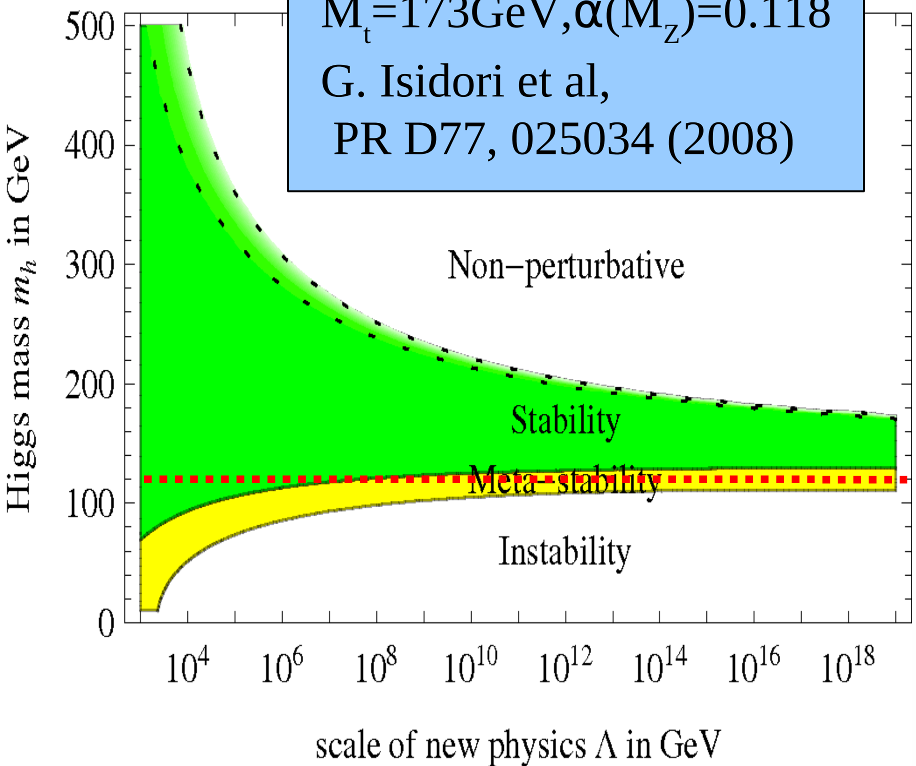
- The Higgs boson is the last unobserved particle postulated in SM to explain the origin of mass in the universe.
- Observation of the Higgs boson or like is a longstanding key objective to probe the mechanism of electroweak symmetry breaking(EWSB).
- Window of opportunity: With full dataset and improved analysis Tevatron could add crucial information H→bb that is more difficult to detect at LHC.
- Not seeing a low mass Higgs guarantee's new physics waiting to be found at LHC.

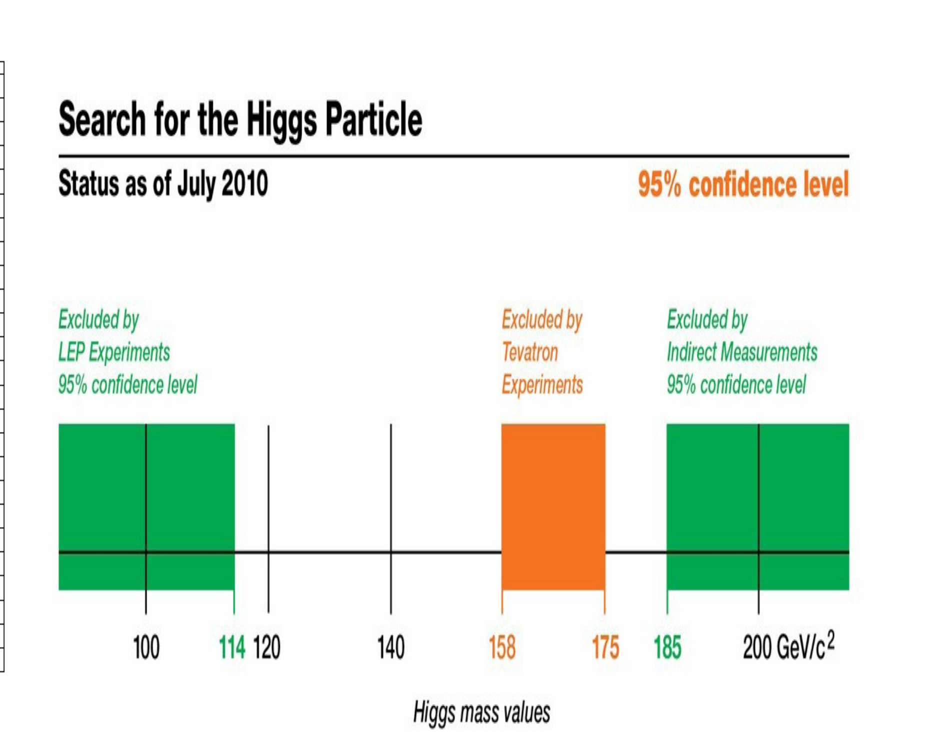




State of the Art Higgs Mass

M_t=173GeV,α(M_Z)=0.118
G. Isidori et al,
PR D77, 025034 (2008)

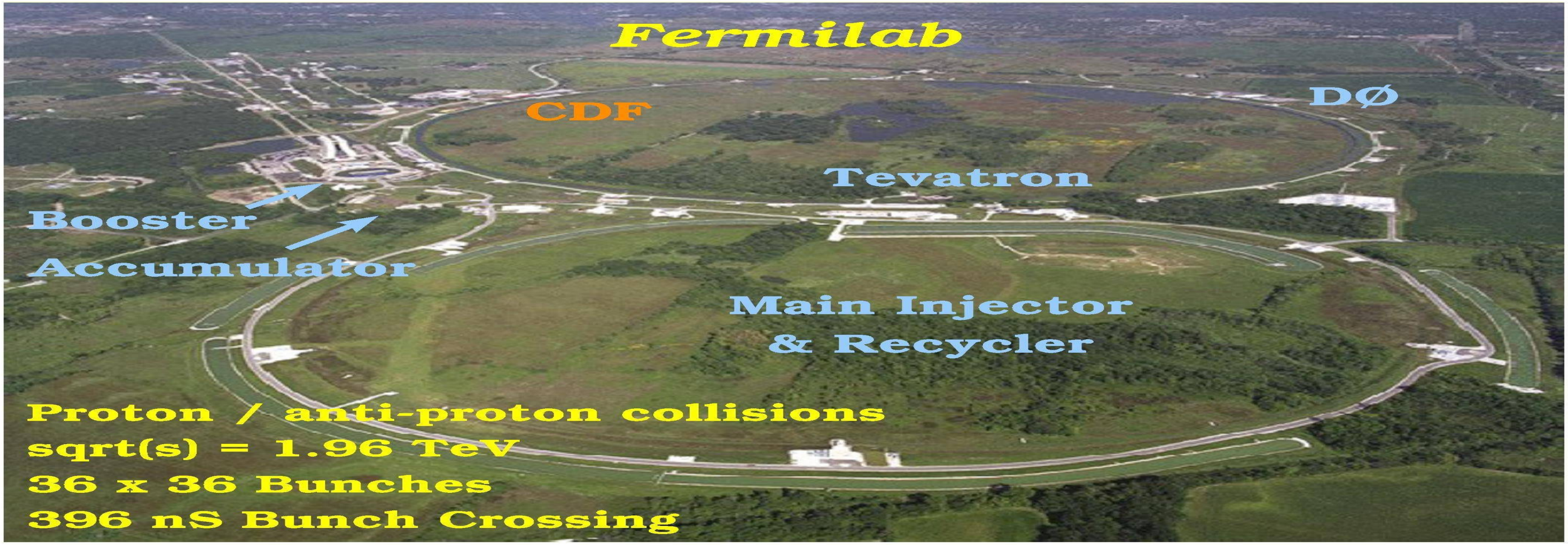




- Theoretical Limits: vacuum stability and perturbativity.
- Direct from LEP+Tevatron:M_H>114.4 & Not[158,175] GeV/c^2
- Indirect from EW data: M_H<158 GeV/c^2 @ 95% CL
- The low mass bound sets scale of new physics at Λ>10^6 GeV.

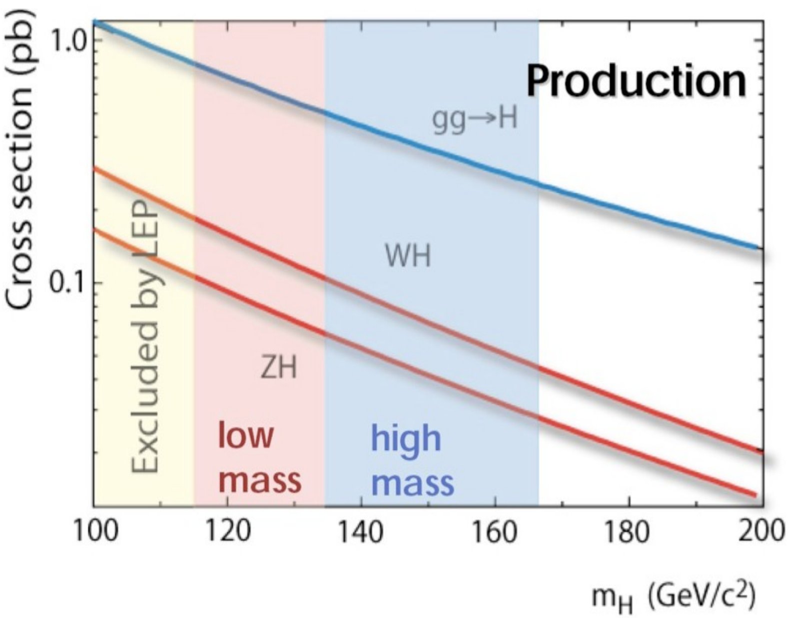
The Tevatron

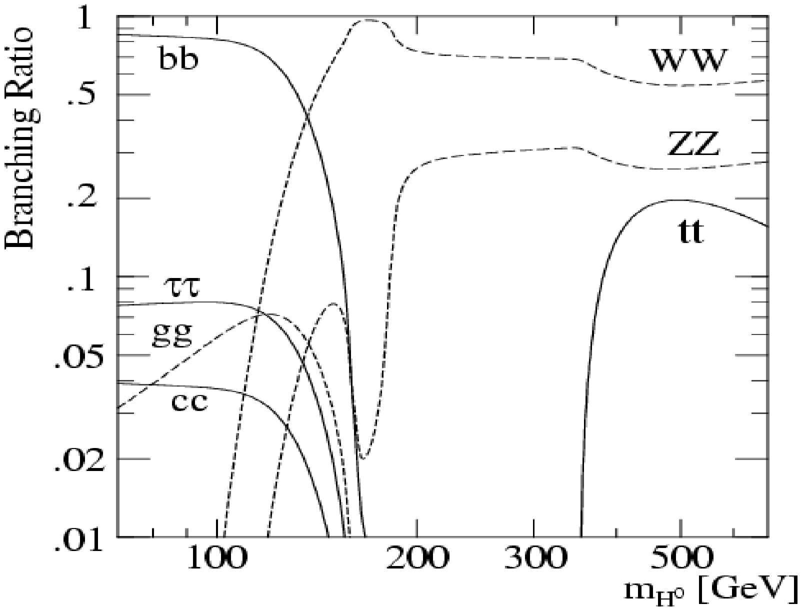
- Tevatron: p-pbar collision@1.96TeV, L_{peak}=4.1x10^{32} $cm^{-2}s^{-1}$
- Delivered > 10 fb^{-1} to each experiment
- Expect 12 fb^{-1} delivered by end of FY11.
- Most results presented here are based on ~6 fb^{-1}.
- Major updates for low mass search are coming in the summer.



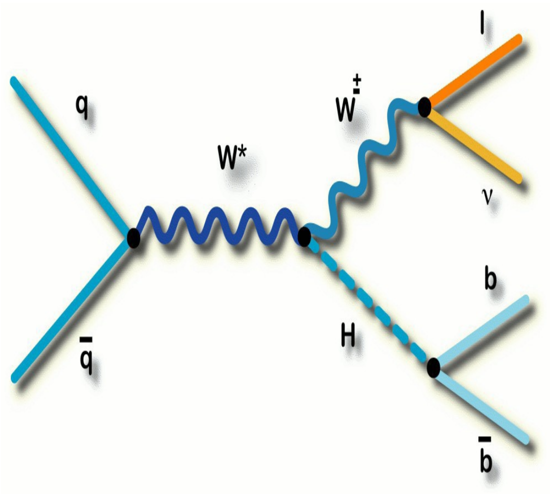
SM Higgs Production and Decay@Tevatron

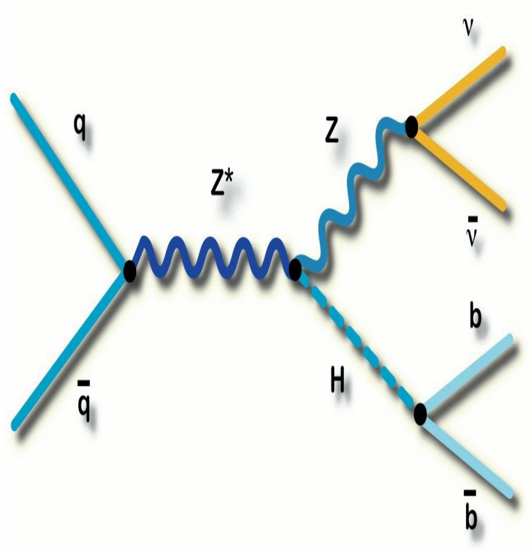
- Primary production modes are:
  - Direct production($gg \rightarrow H$)
  - Associated production (WH,ZH)
- For higher mass(M_H>135 GeV)
  - Mainly decays to W pairs: $H \rightarrow WW$ (see talk by M. Buehler)
- For lower mass(M_H<135 GeV)
  - Main decay: $H \rightarrow bb$
  - Rely on WH/ZH
  - Direct production $gg \rightarrow H$ is limited by multi-jet QCD background
  - Difficult at LHC, due to large ttbar bkg, needs to rely on $H \rightarrow \gamma\gamma$, $\tau^+\tau^-$.

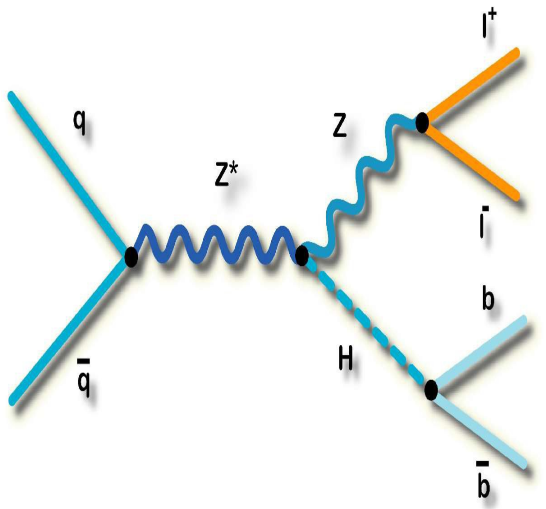




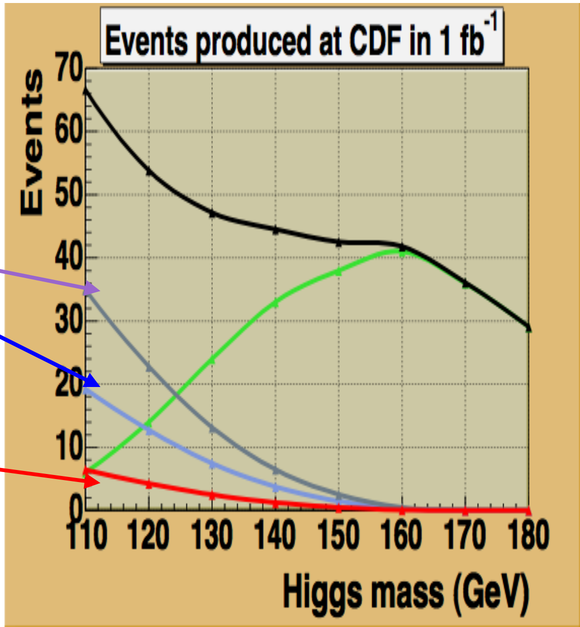
Main Tevatron Search Channels





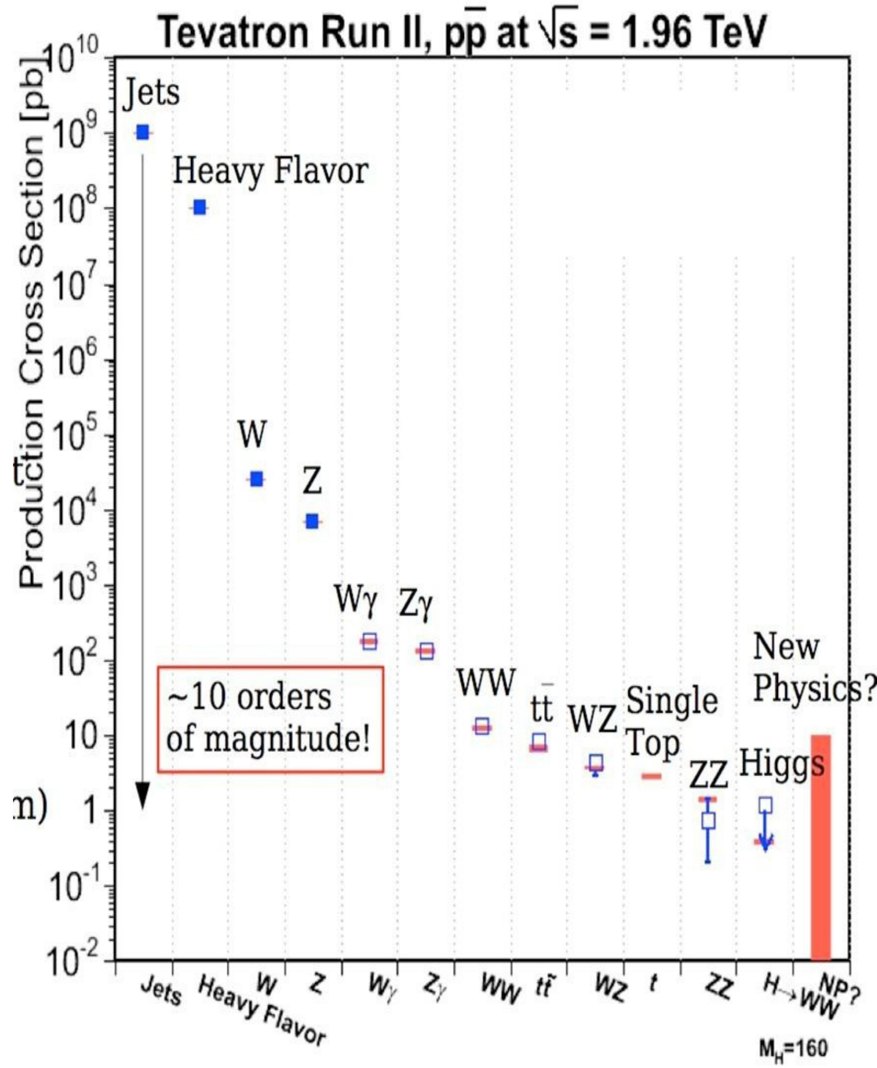


- Search for a dijet resonance H→bb in associated production.
  - WH→lvbb: 1 lepton + met + 2b
  - ZH→vvbb, WH→(l)vbb: 0 lepton + met+2b
  - ZH→llbb: 2 lepton + 2b
- Expect ~30 per fb^{-1} WH→lvbb @115 GeV before detector acceptances.



The Challenges

- While Higgs events are rare, backgrounds are many orders of magnitude large.
- The challenge is how to separate small signal from huge backgrounds using advanced multivariate techniques.
- Observations of single top and diboson provide solid ground that these tools do work to separate small signal from large background.

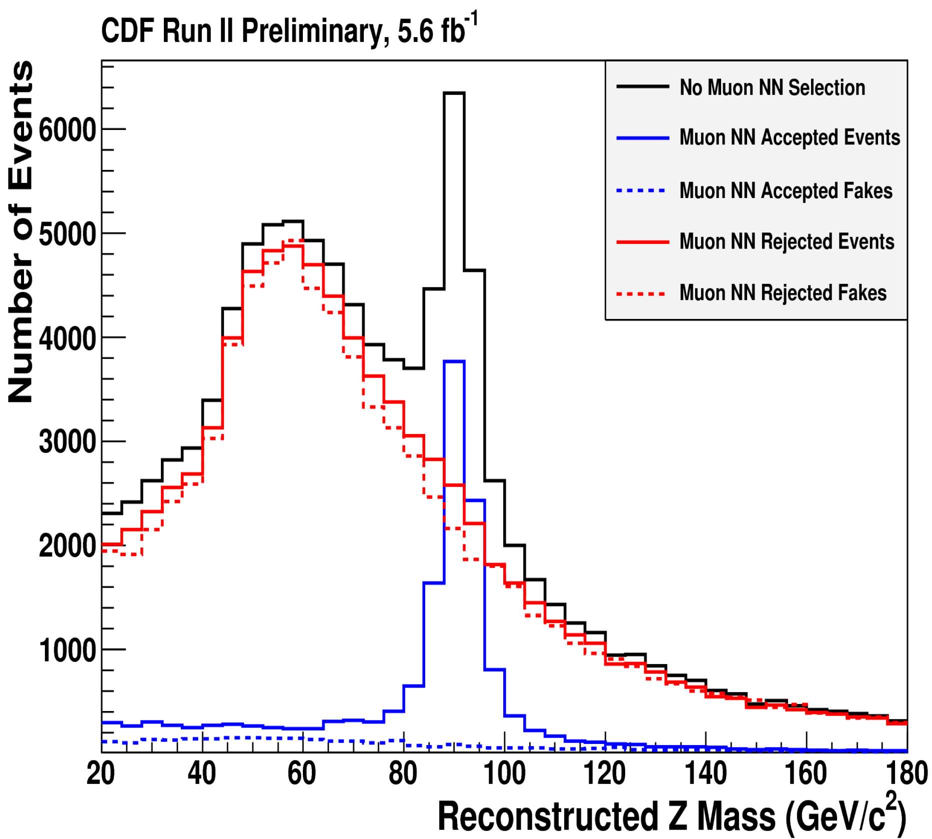


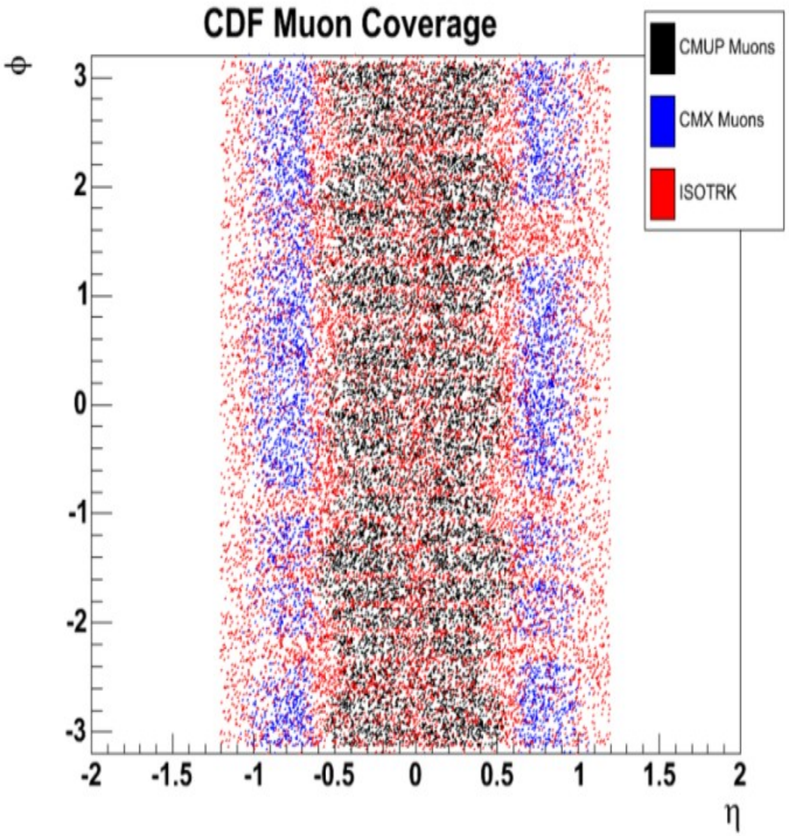
Low Mass Higgs Search Strategies

- Maximize Signal Acceptance:
  - Utilize as much of detector as possible
  - Improving lepton ID and additional triggers
- Reduce W/Z+jets background with b-tagging
  - Improving btag efficiency for b-jet while reducing the mistag for charm and light jets
- Improving $H \rightarrow bb$ dijet mass resolution
- Multivariate discriminant:
  - Combining many kinematic variables to discriminate S/B
  - Validation the modeling of SM backgrounds using many control samples.
  - Fit the output of MV discriminant to extract Higgs signal.
- The procedures are iterated until achieving the best sensitivity.

Maximizing Lepton ID & Triggers

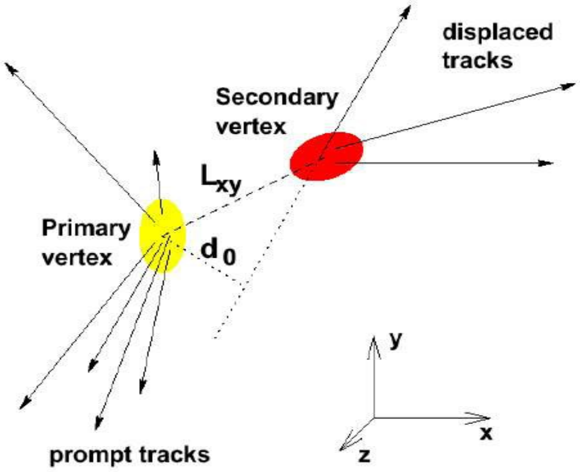
- Selecting high Pt leptons with multivariate lepton identification could gain 20% more Z's than cut-based selections.
- Including loose muon as isolated high Pt track from Met Triggers.

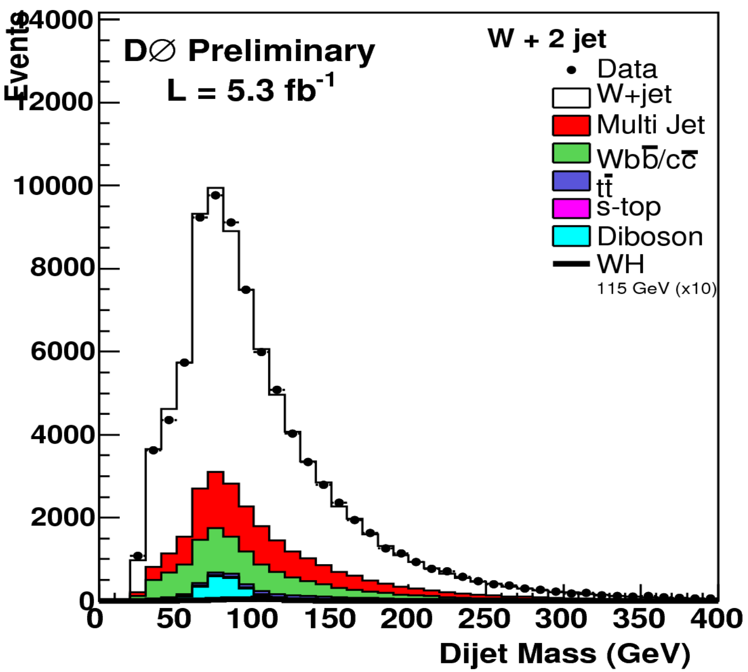


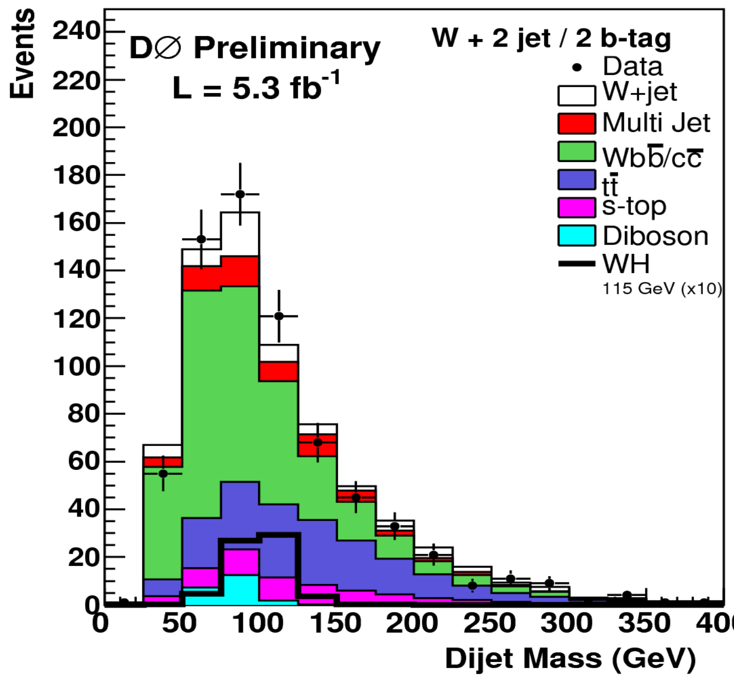


Identifying b-quark jets

- Distinguish b-jets from c/light jets
- Exploits long lifetime of b and large mass
- Tag 50-70% of b-jets with 1-6% of l-jets
- WH->lvbb: requiring double tags reduces background from W+jets significantly

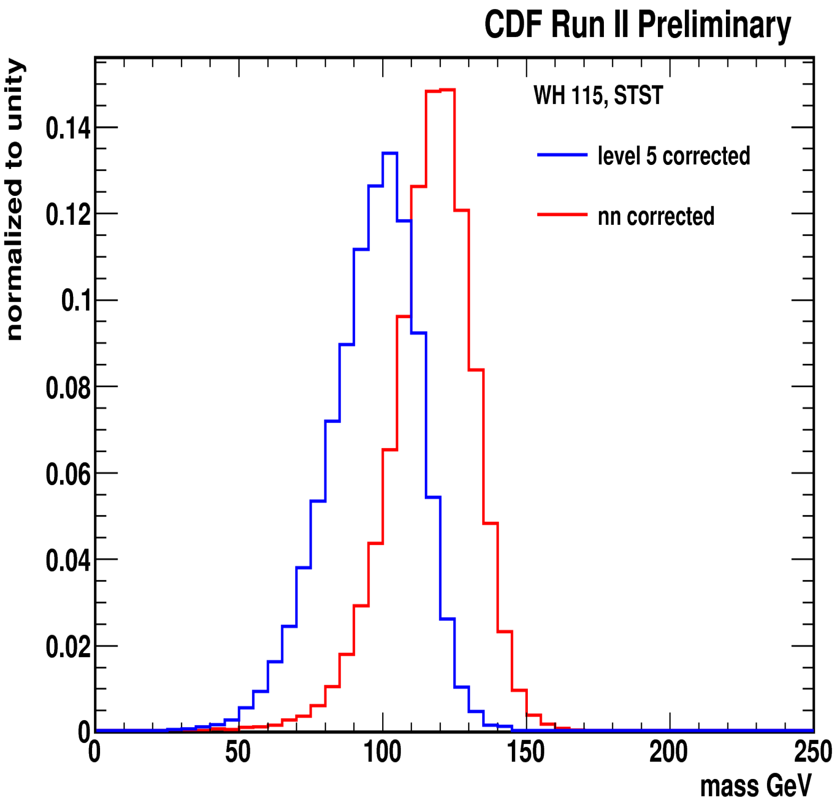


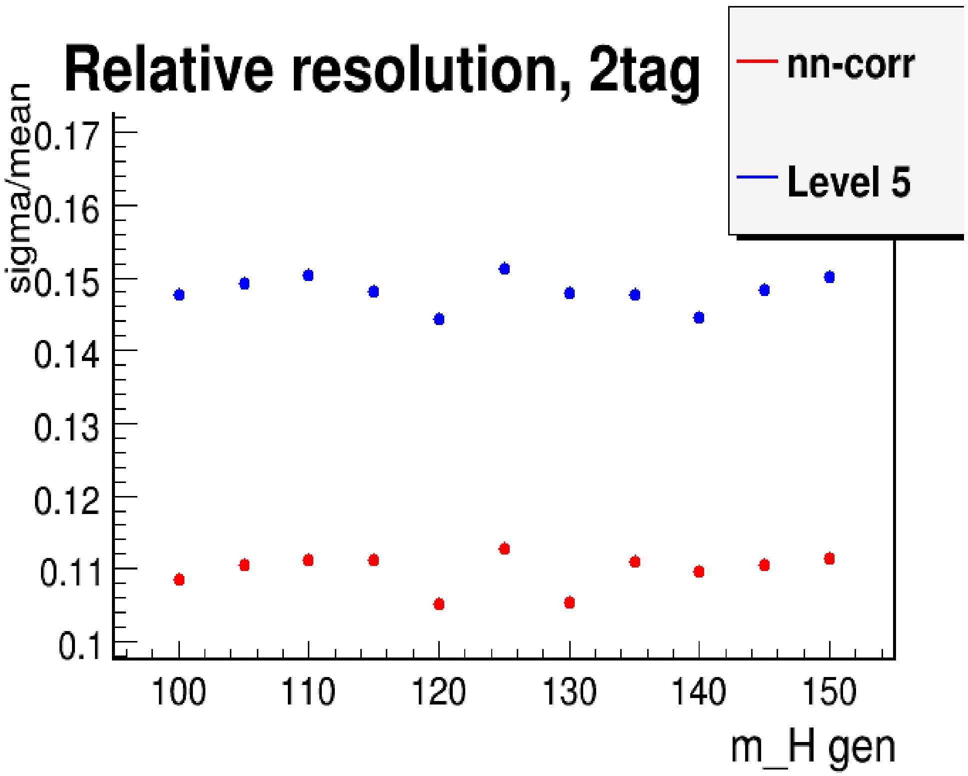




Improving Dijet Mass

- The invariant mass of two b-jets provides most discriminant power between Signal and Background.
- Improving its resolution by combining calorimeter and tracking information using Neural Network.



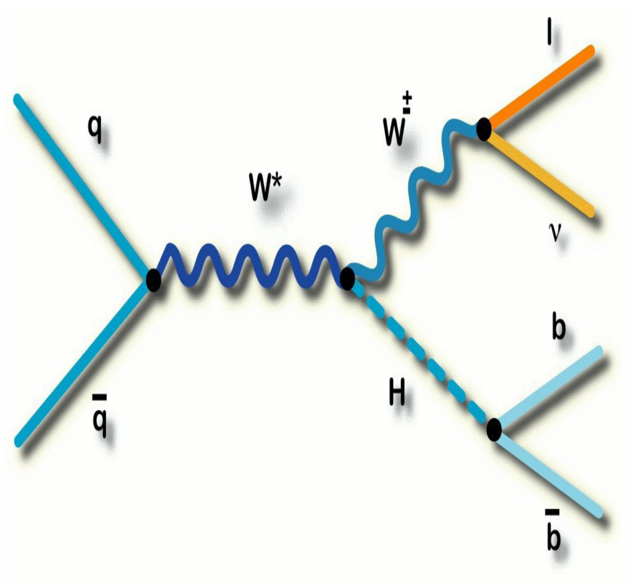


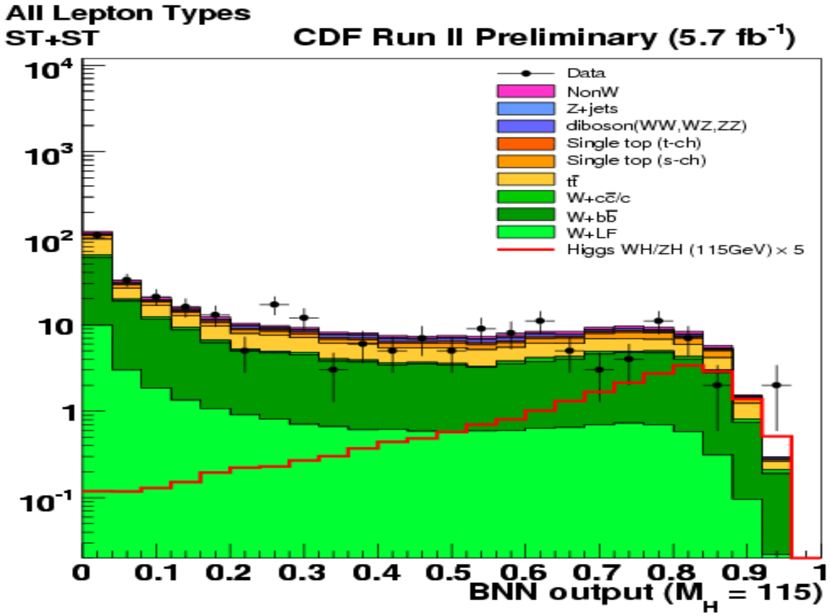
Advanced Multivariate Techniques

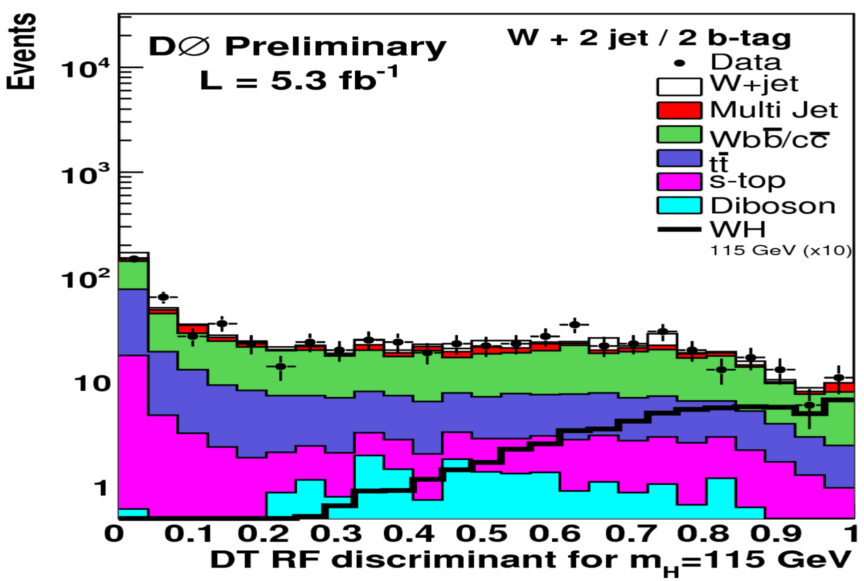
- In order to suppress large background, we use various advanced multivariate technique.
- LO Matrix Elements (ME): are used to calculate event probabilities and likelihood ratios.
- Neural network (NN): combine various kinematic variables, including ME into a final discriminant.
- Boosted Decision Tree (BDT): an alternative to NN
- Typical Improvement is ~25% respect to use a single variable, such as dijet mass.
- However, the primary gains in recent years mainly from improved signal acceptance: more triggers, looser lepton ID, better b-tagging...

Search for WH→lvbb

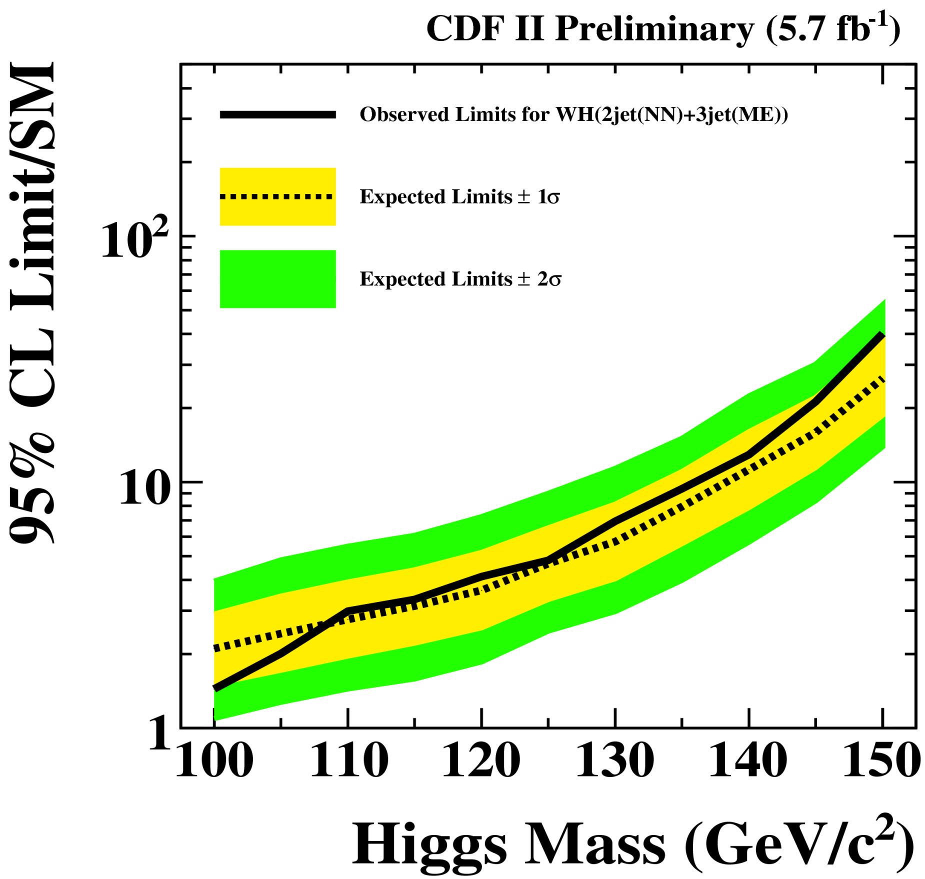
- WH→lvbb is one of most sensitive channel for low mass Higgs.
- Easy to trigger on lepton, missing Et
- Require b-tag and MV discriminate.
- CDF:use Bayesian NN(2jet)+ME(3jet)
- D0: use Random Forest DT(2jet,3jet)

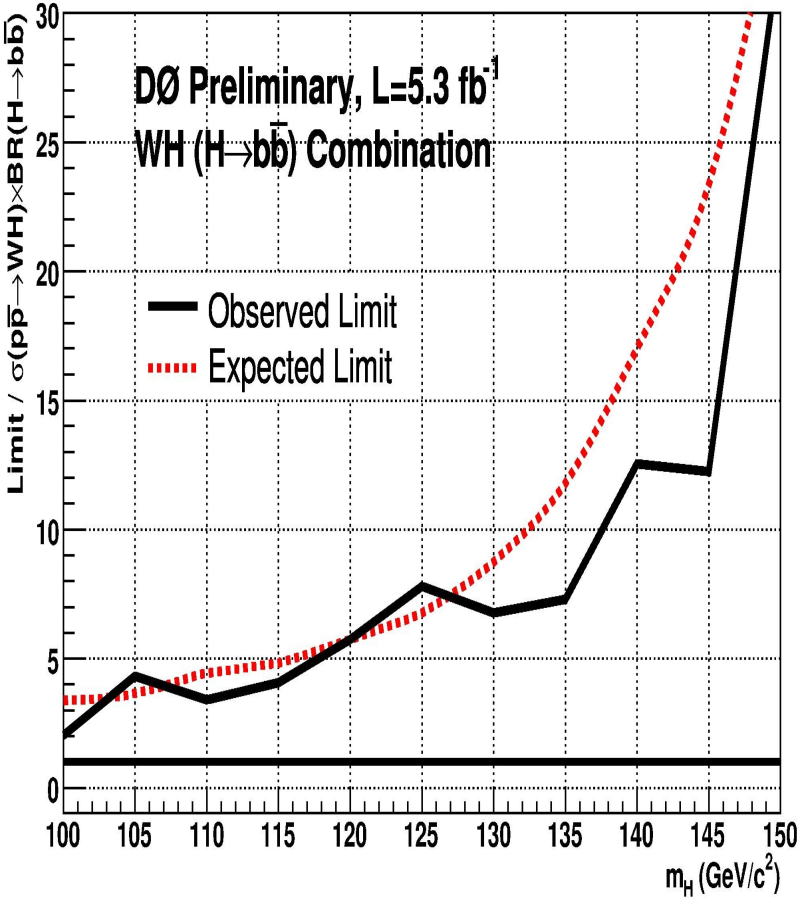






WH→lνbb Limits

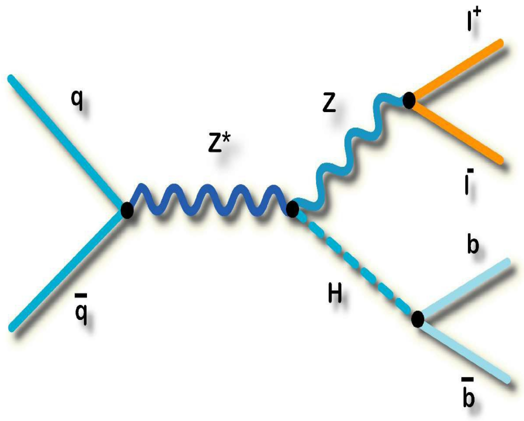


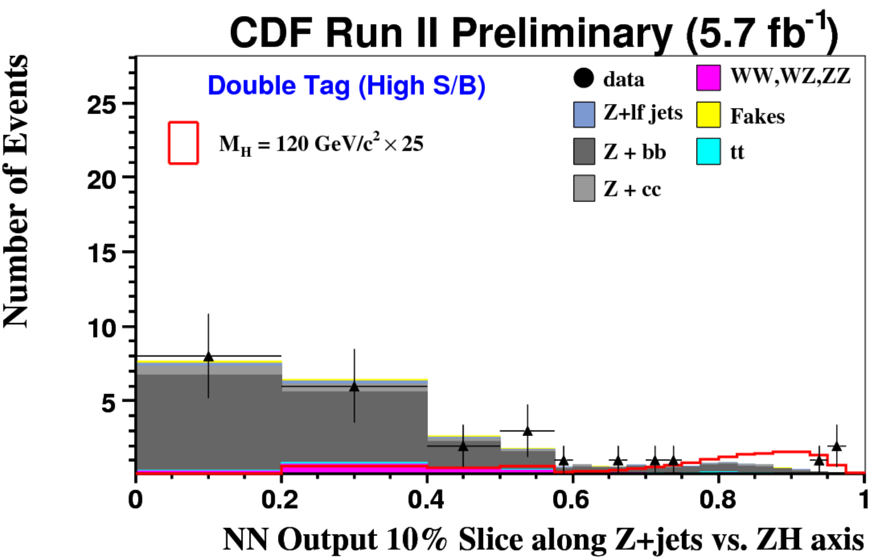


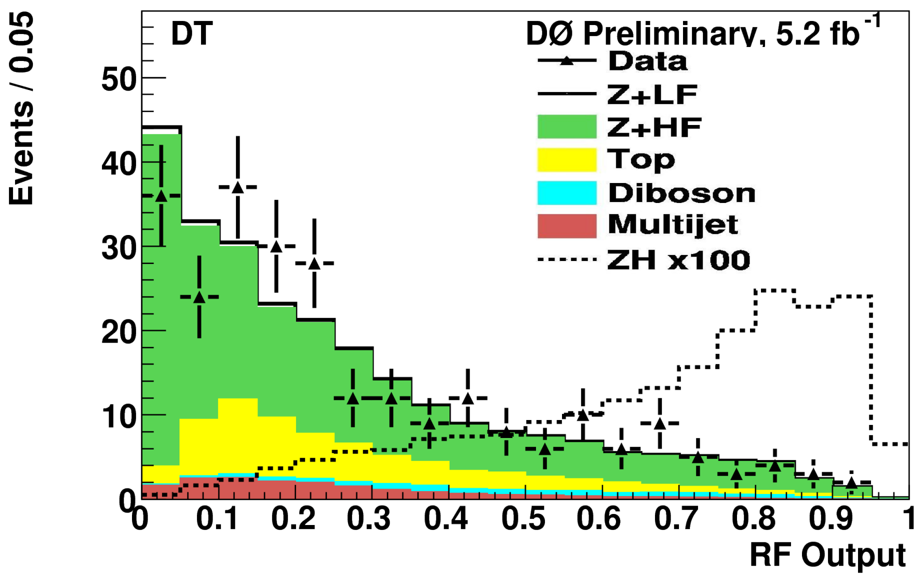
- Obs./exp. Limits: 3.3/3.1(CDF) and 4.1/4.8(D0) @115GeV
- Not competitive for a single channel, need to combine all channels and both CDF and D0.

Search for ZH→llbb

- Low event rate but clean signature
- Select two high Pt leptons (tight and loose)
- Split off 1 or 2 b-tags
- Improve dijet mass using met constrain
- NN train to separate ZH from top & Z+jets

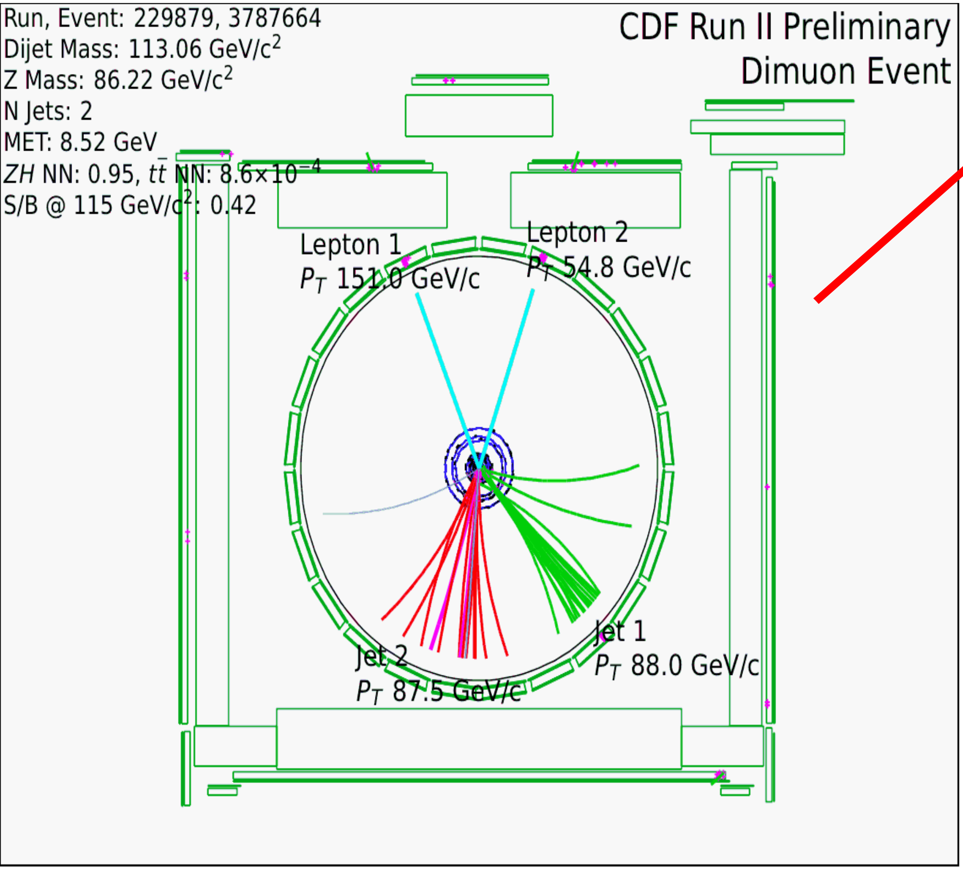




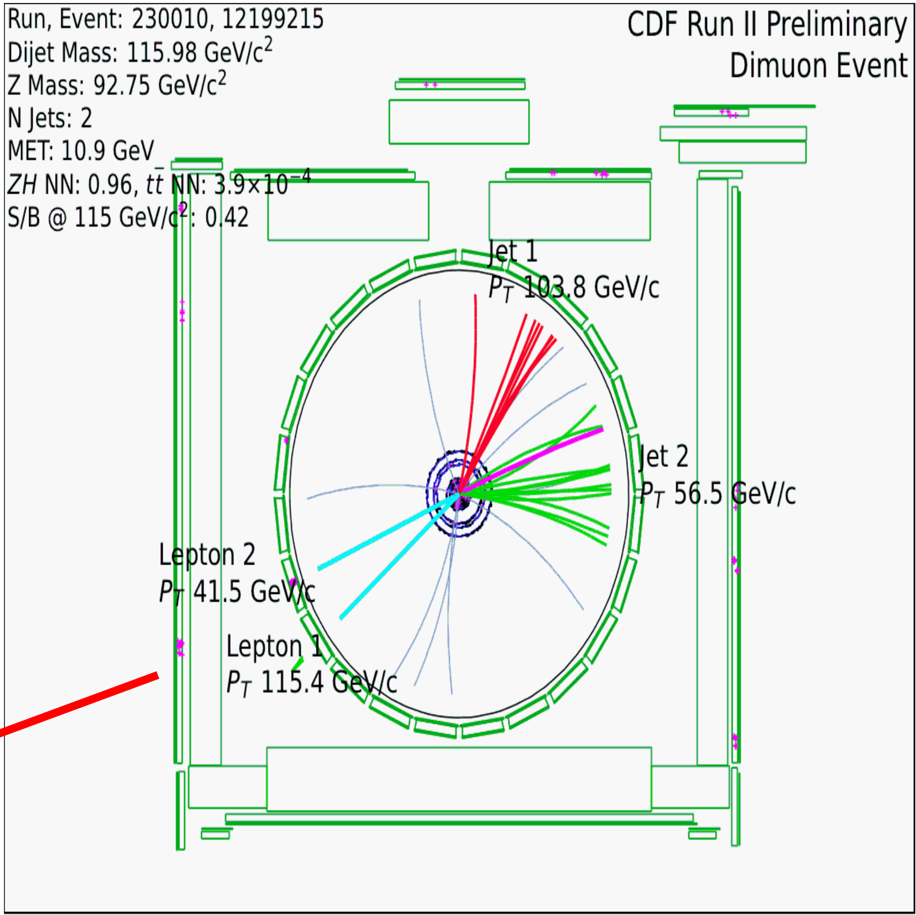


- Obs./exp. limits: 6.0/5.5(CDF) and 8.0/5.7(D0) @115 GeV

ZH→llbb Candidates



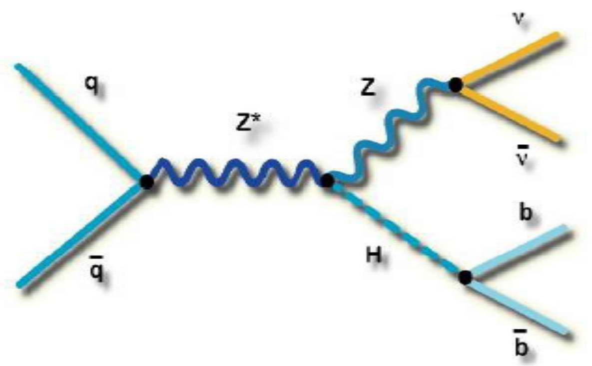
Dijet mass=113 GeV,
Z mass=86 GeV,
Met=8.5 GeV

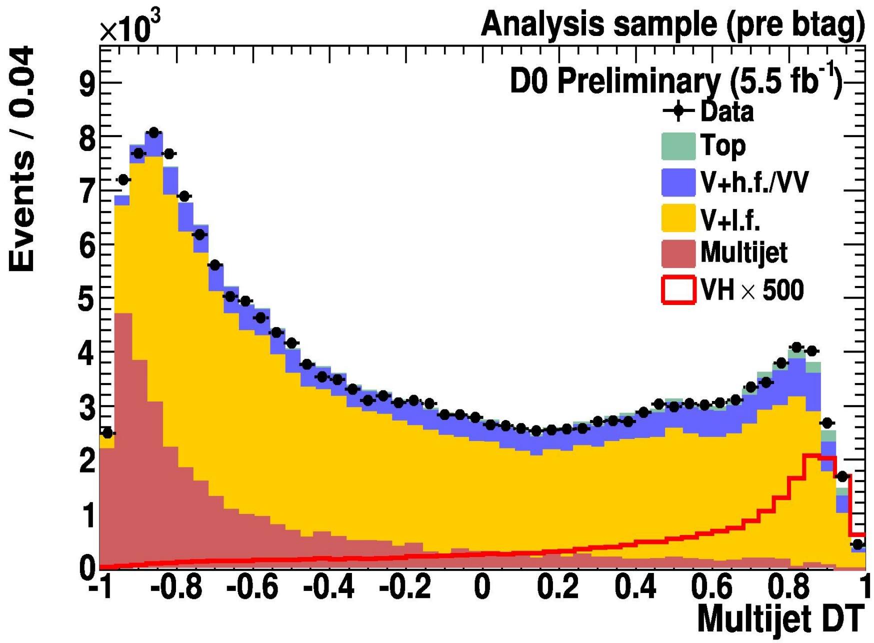


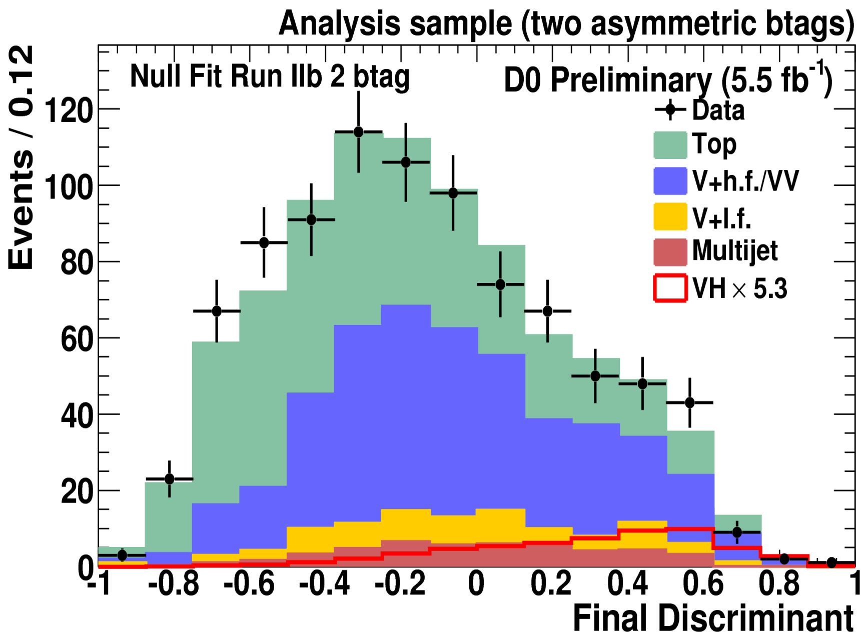
Dijet mass=116 GeV,
Z mass=92.8 GeV,
Met=11 GeV

Search for ZH→vvbb, WH→(l)vbb

- Large xsec*BR, but large QCD difficulty
- Require Met>50 GeV + 2jet
- Split off 1 or 2-btag
- Reject Multijets: Δφ, track met, met/σ

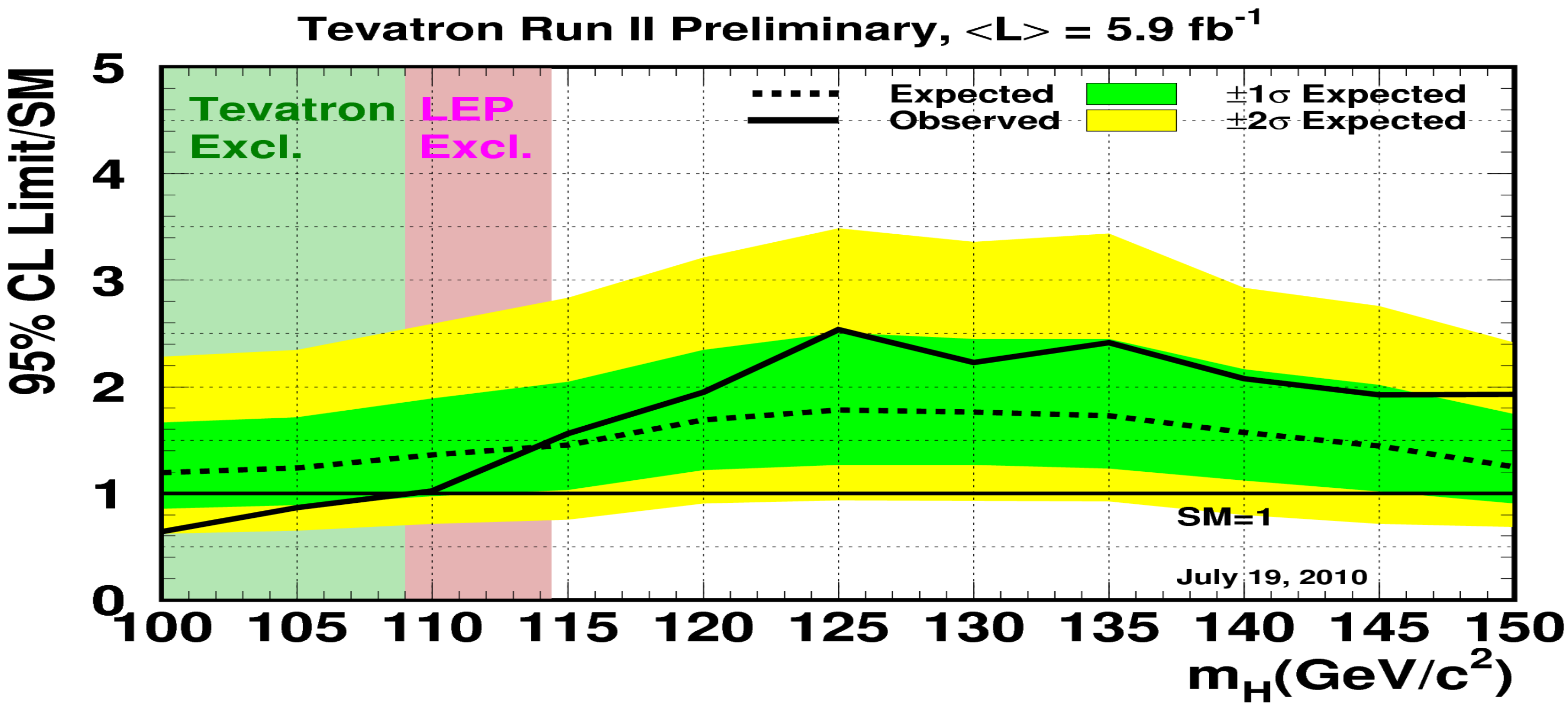






- Obs./exp. limits: 2.3/4.0(CDF) and 3.4/4.2(D0) @115 GeV

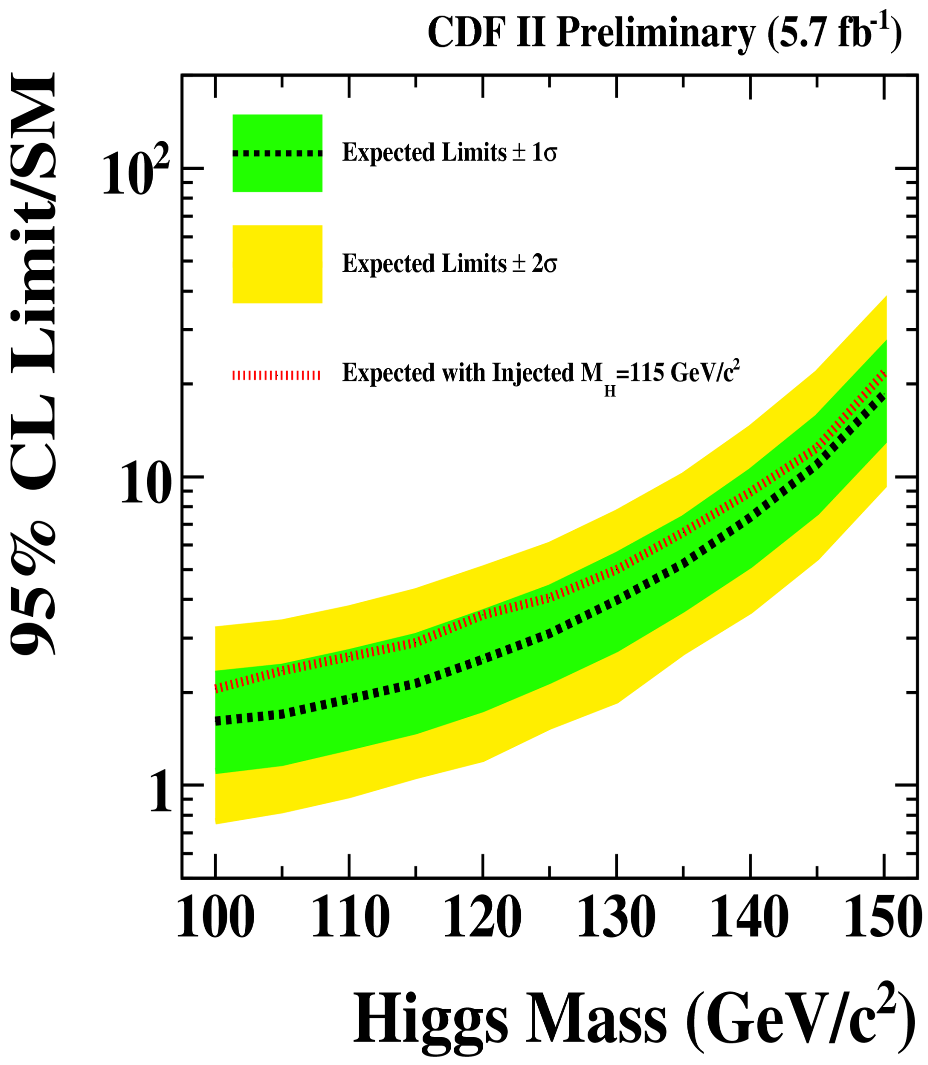
Tevatron Combination



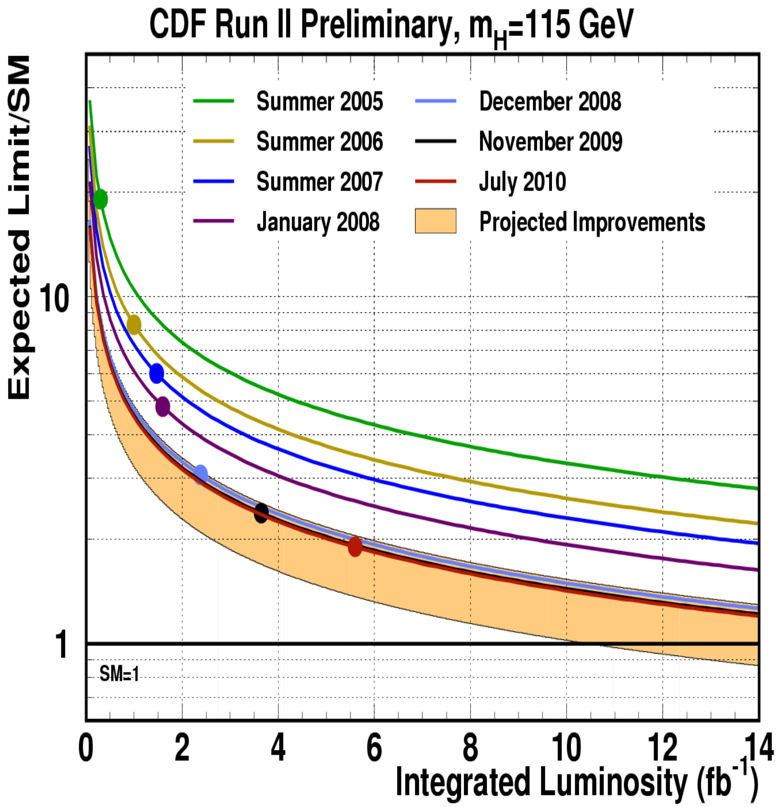
- **Combining CDF and D0 for maximum sensitivity.**
- Set 95% CL Limit: 1.56 (Obs) with 1.45(Exp) x SM @115 GeV
- Both CDF and D0 set limit close to 2xSM @ 115 GeV

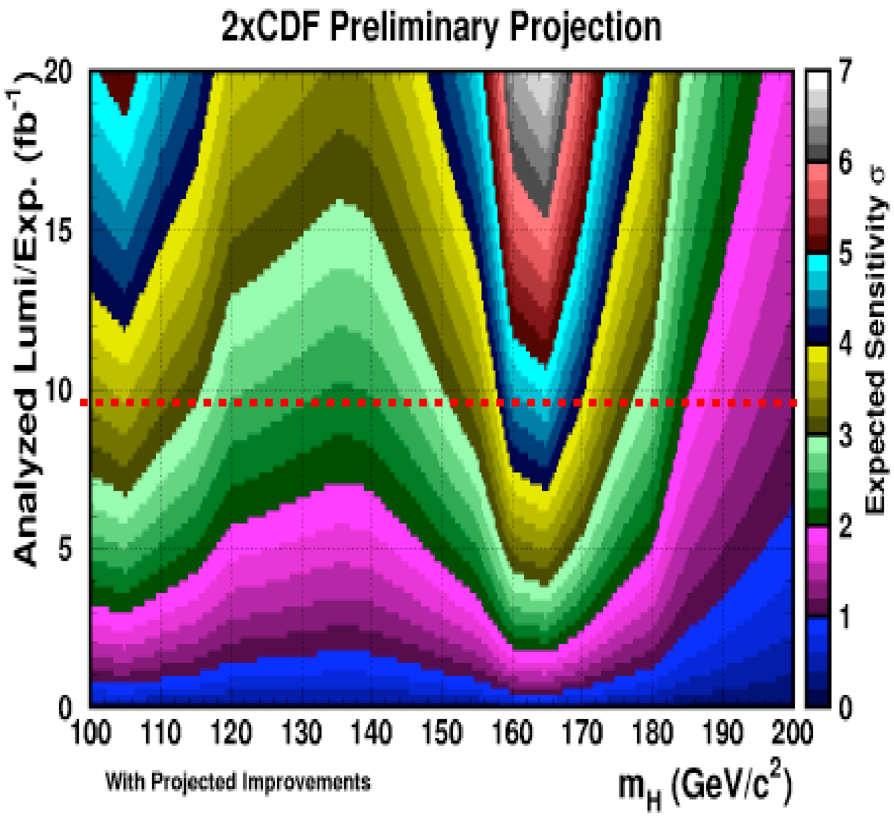
What if Higgs exist at m_H=115 GeV...

- Injecting Higgs signal into pseudo experiments for low-mass channels (VH→lvbb, llbb, vvbb).
- If Higgs exist, we would observed the limit 1 σ higher than expected where Higgs signal is absent.
- More pronounced with other channels and D0 included as well.



Tevatron Prospects





- Achieved & projected expected limit on the SM Higgs over time.
- With 10 fb^{-1} data, Tevatron could exclude significant fraction of low mass Higgs at 95% CL.

Conclusion

- Tevatron's doing very well that makes the search possible.
- "No channel too small" strategy seems work well for both CDF&D0 and the Higgs sensitivity will continue to improve.
- With 10 fb^{-1} analyzable dataset and improved analysis, the Tevatron could exclude significant fraction of the low mass Higgs by the summer of 2012.
  - Near Term: update low mass searches with more data and some improvements for summer 11.
  - Long Term: Focus on improving analysis and update full dataset for the summer of 12.
- The Tevatron is scheduled to shutdown at the end of FY2011.
- But the ideas and techniques developed at the Tevatron will certainly benefit LHC.