SM Higgs Boson Searches at the Tevatron

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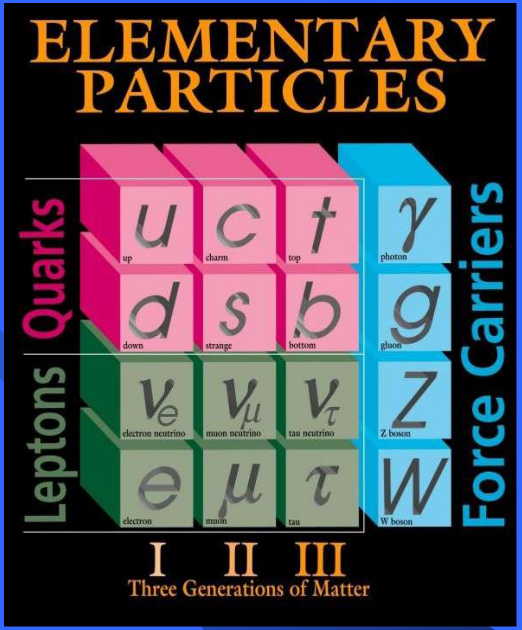
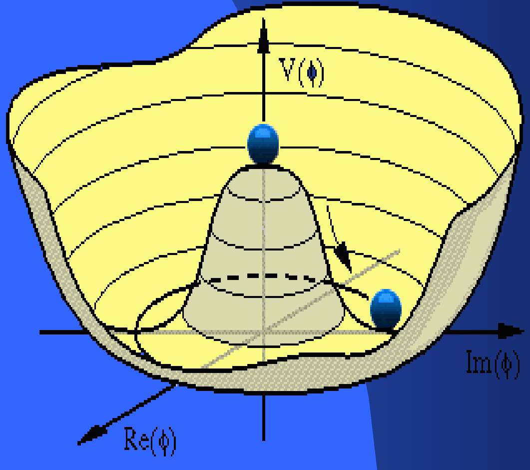
OutLine

- Introduction
- SM Higgs Search Strategies and Challenges
- CDF and D0 Results with up to 3.0 fb^{-1}
- Tevatron Combination
- Future Prospects
- Conclusion

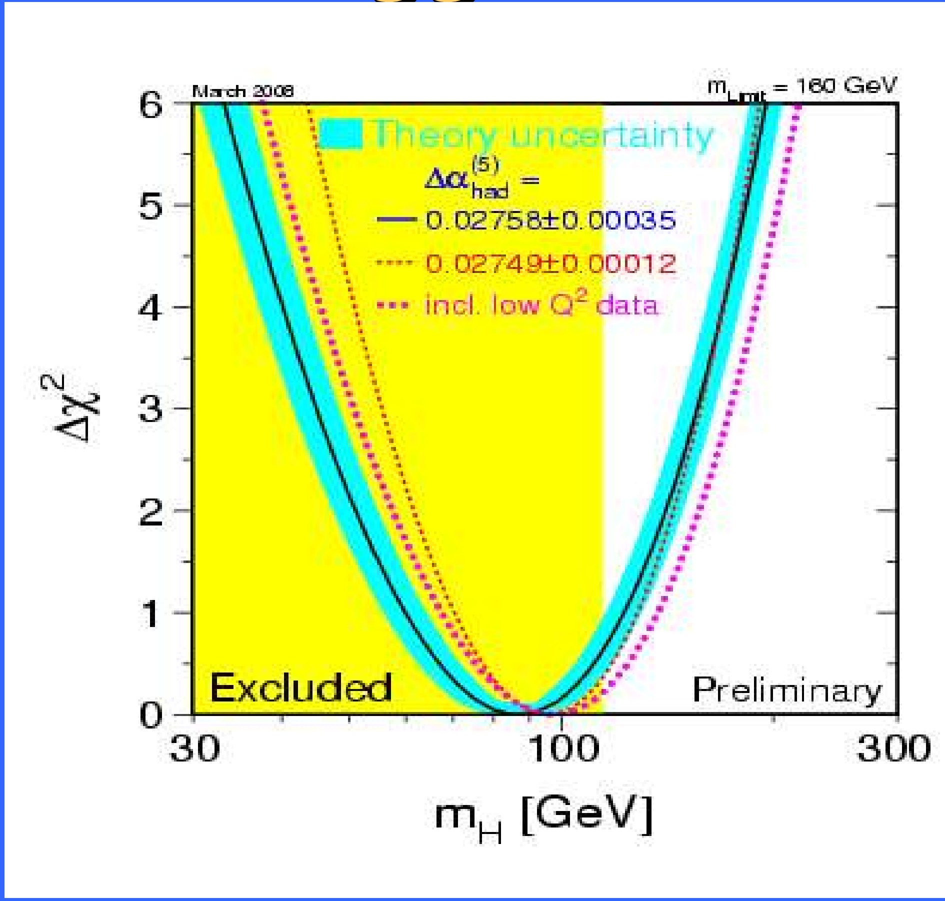
Introduction

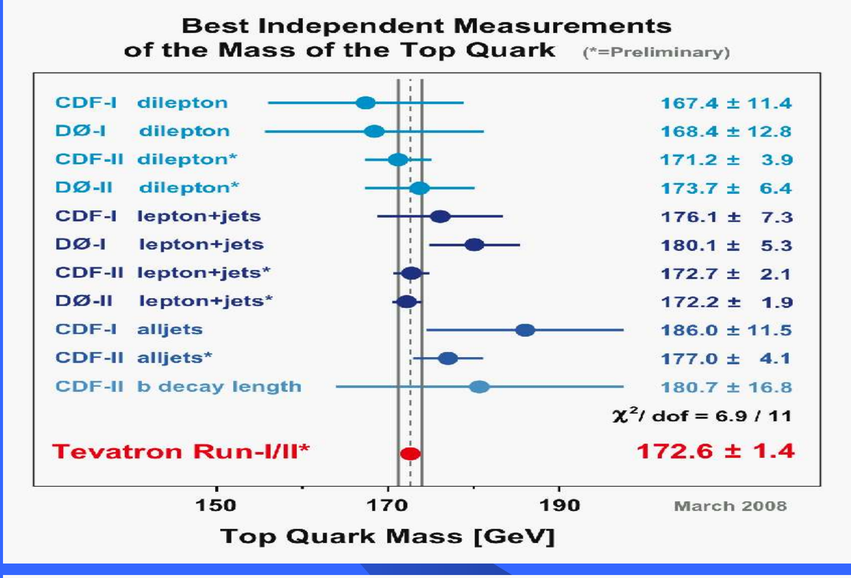


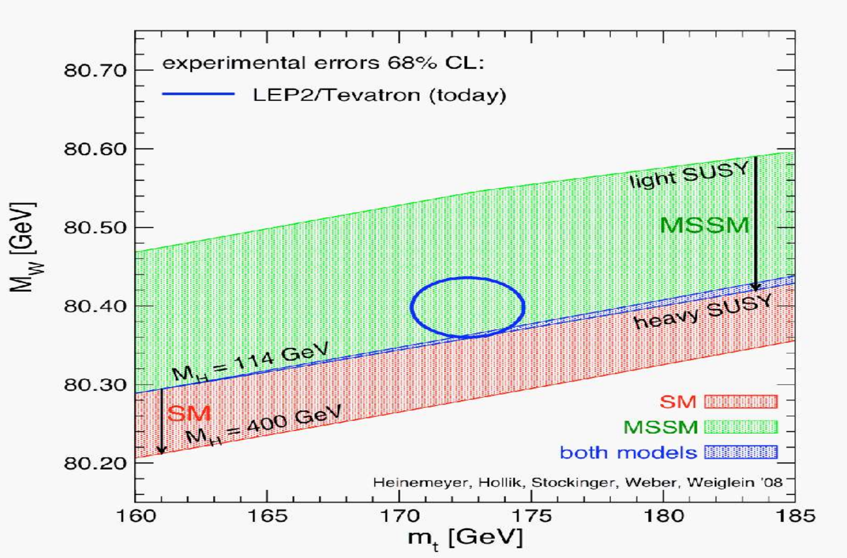
- The Standard Model describes nature well in terms of fundamental particles, but provides no explanation about the origin of mass.
- The Higgs mechanism:
  - provides a clue for EWSB
  - predicts the existence of Higgs boson, that has yet observed experimentally.
- LHC has the best shot for Higgs discovery, but Tevatron has lots of data and would be the hunting ground until 2010.
- If Higgs does exist some kind of new physics beyond SM is required to stabilize its mass, such as SUSY, EDM…



What we know about the Higgs Boson







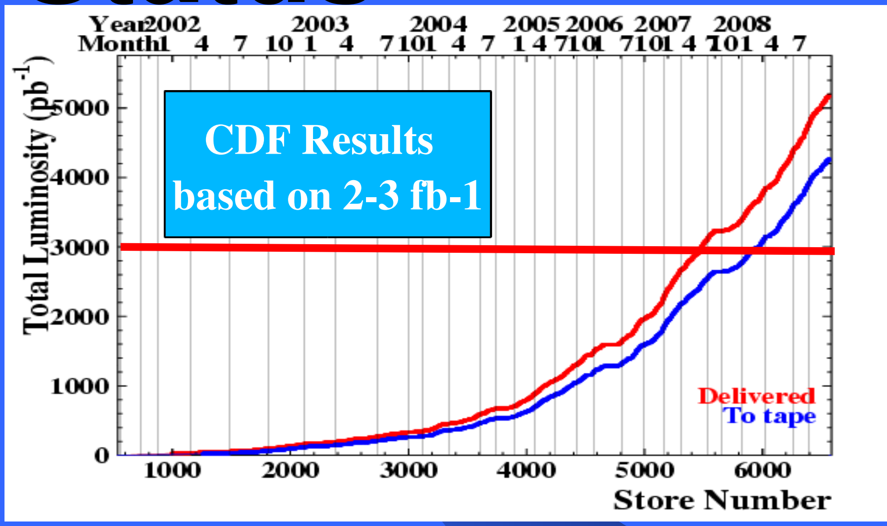
- Direct Searches at LEP: exclude M_H<114.4 GeV at 95% C.L.
- Global fit give best fit of M_H= 87^{+36}_{-27} or <160 GeV at 95% C.L.
- The low-mass Higgs hard to reach with early LHC data.

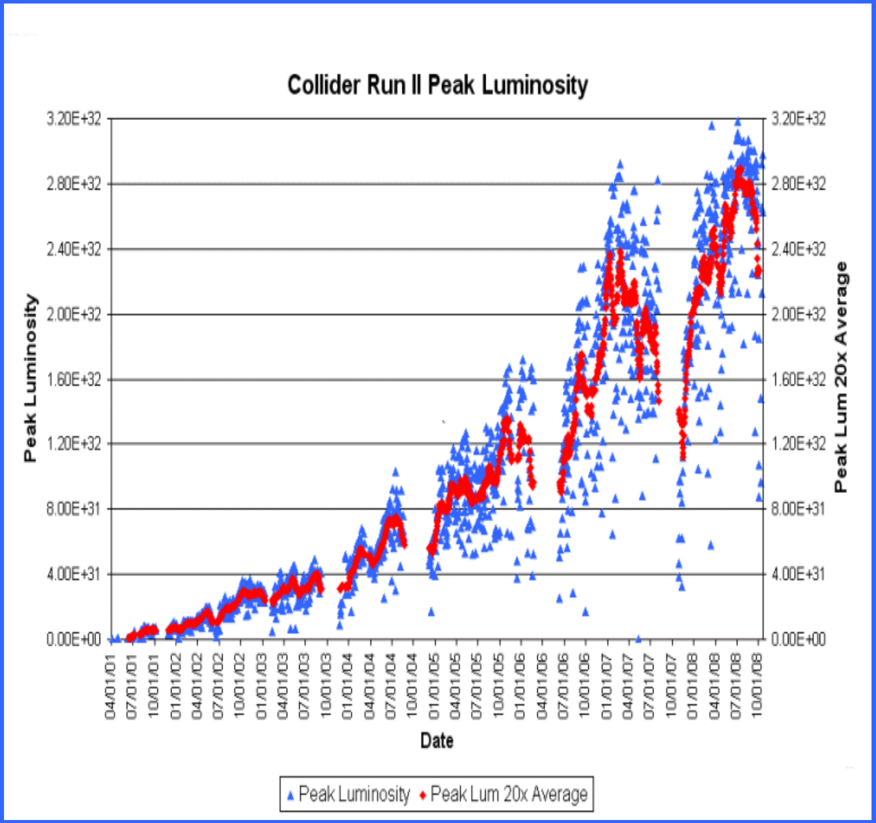
Tevatron Status

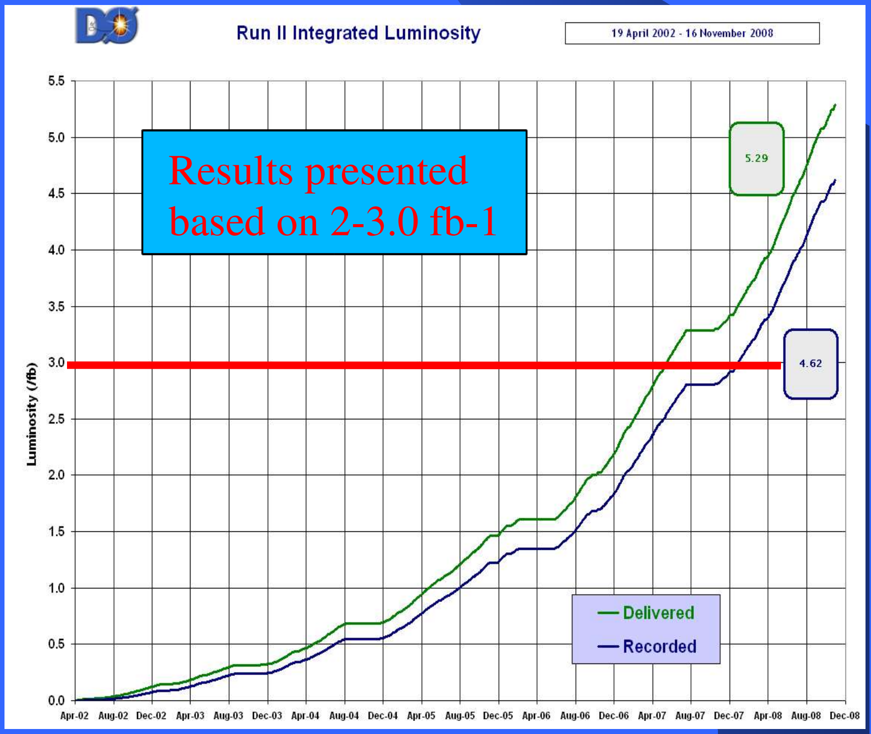
Tevatron are doing great !

Record luminosity: 3.20*x10*^{32}

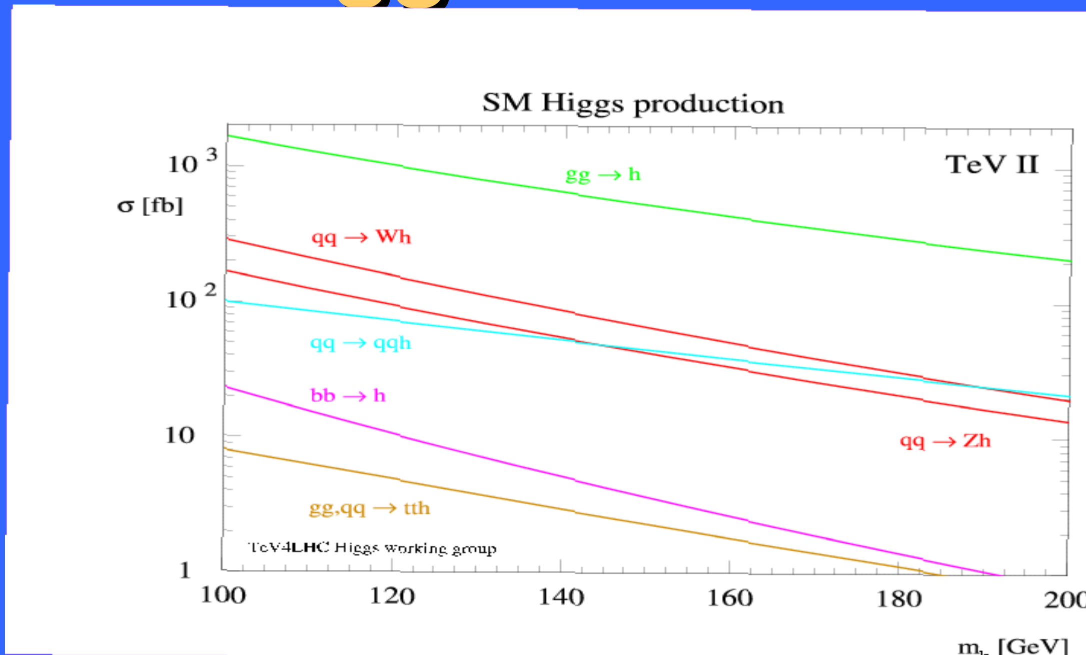
Delivered >5 fb^{-1} and will double the dataset if running through 2010

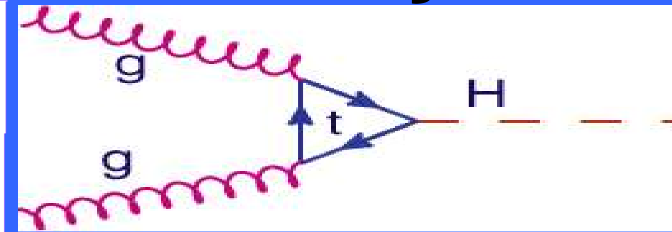


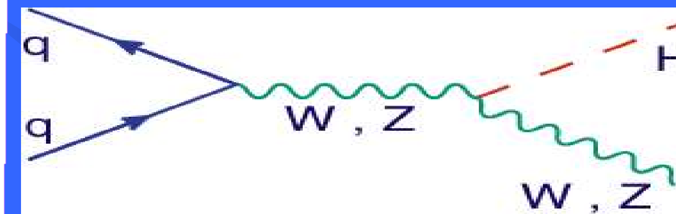


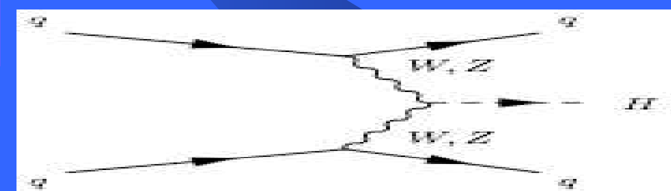


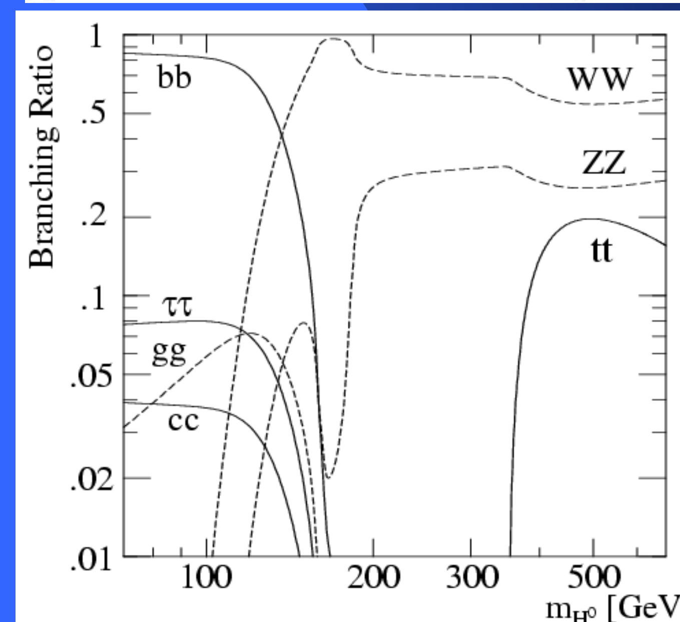
SM Higgs Production and Decays





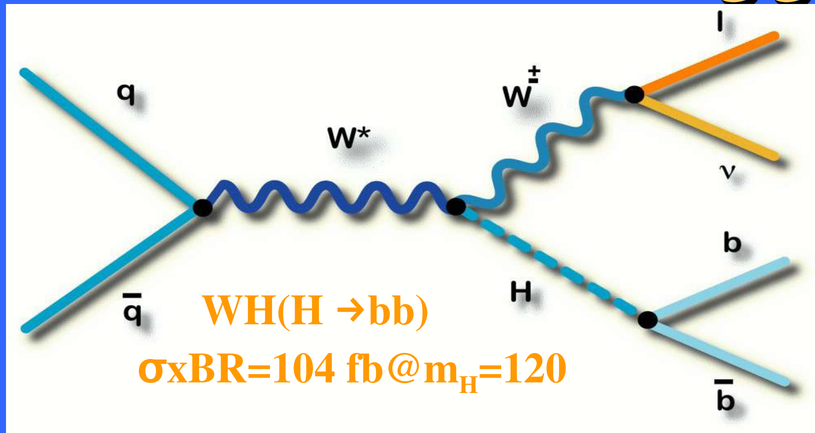


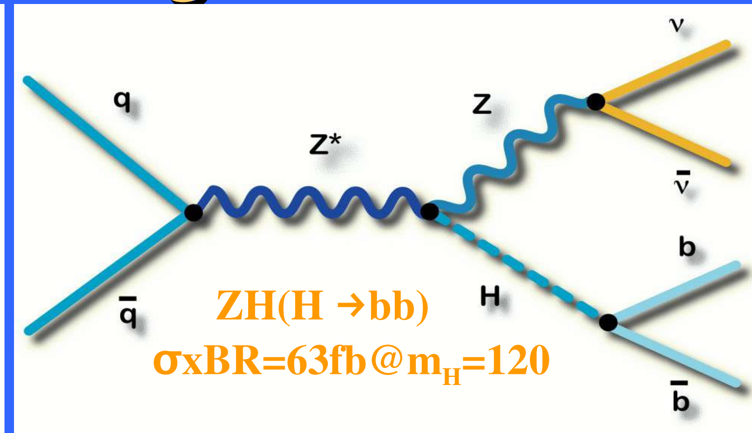




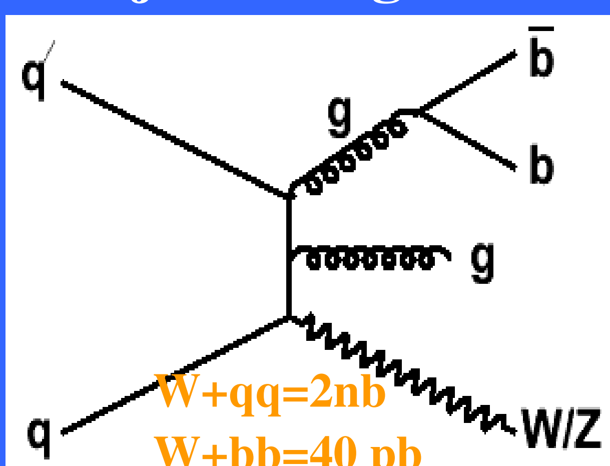
- M_H<135 GeV: H→bb
  - ➢ WH→lvbb; ZH→vvbb, llbb most accessible (easy to trigger)
  - ➢ Excellent b-tag and dijet mass
- M_H>135 GeV: H→WW^*
  - ➢ Exploit large σ (gg→H)
  - ➢ *H→WW→lvlv:clean final states*

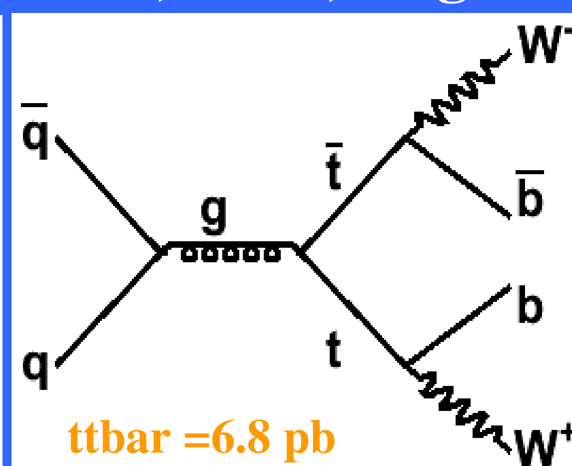
Low Mass Higgs Signatures

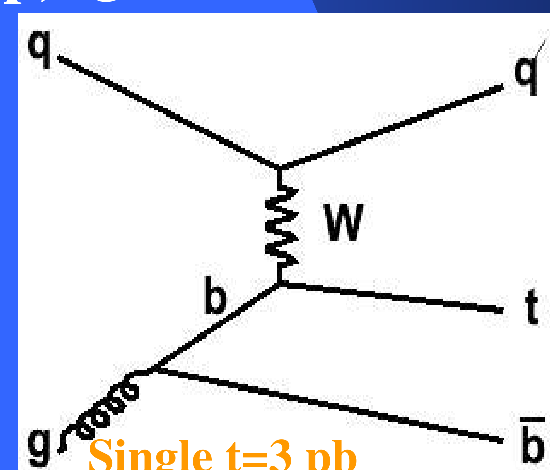




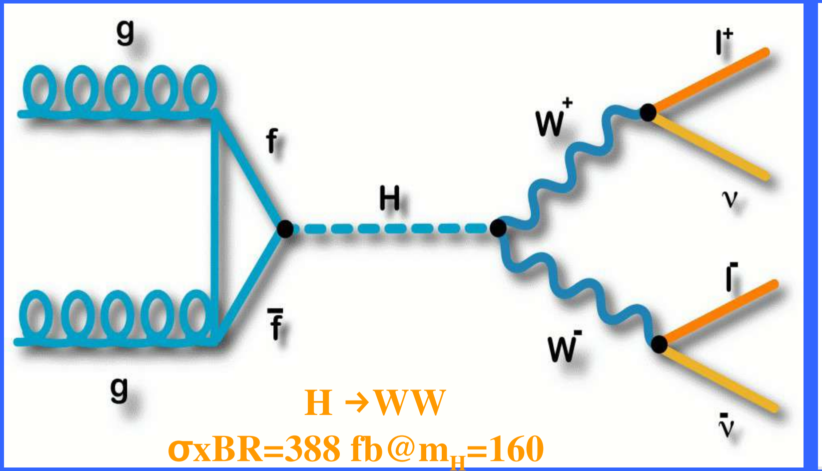
- WH→lν bb: 1 Lepton(Isotrk)+Met+2b
- ZH→llbb: 2 Leptons +2b
- WH→(l)νbb, ZH→ννbb: Met +2b
- VH→jjbb: 4jets
- (V)H →ττ+2jets: $\tau_{lep}\tau_{had}$+2jets
- H→γγ: di-photon
- Major Backgrounds: Wbb, ttbar, single-top, QCD…

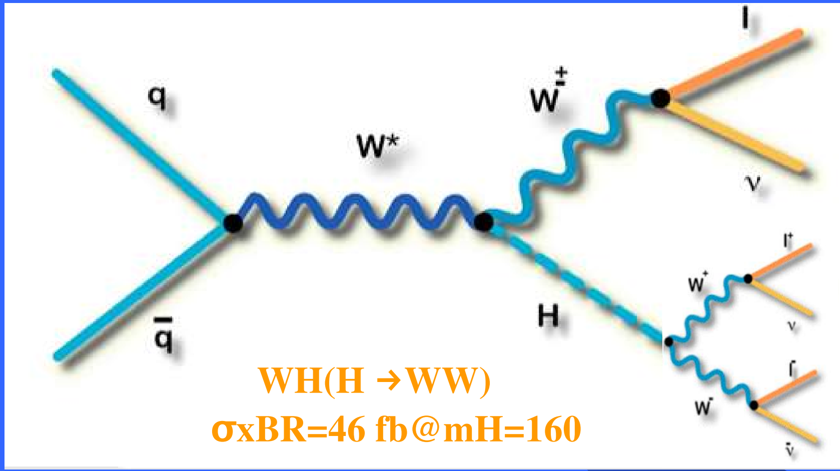




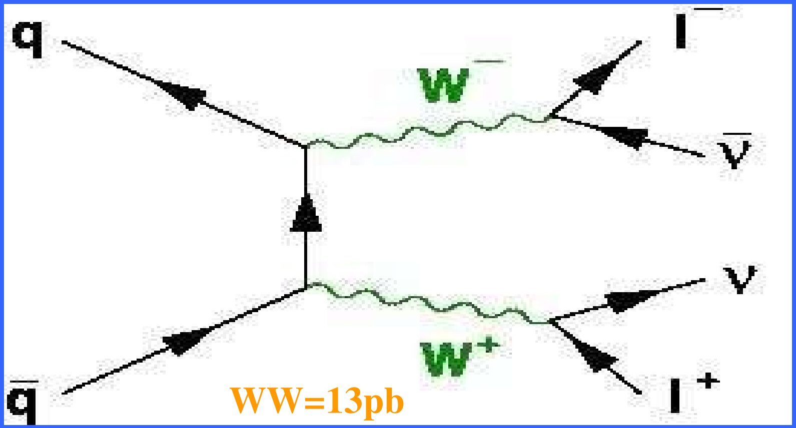


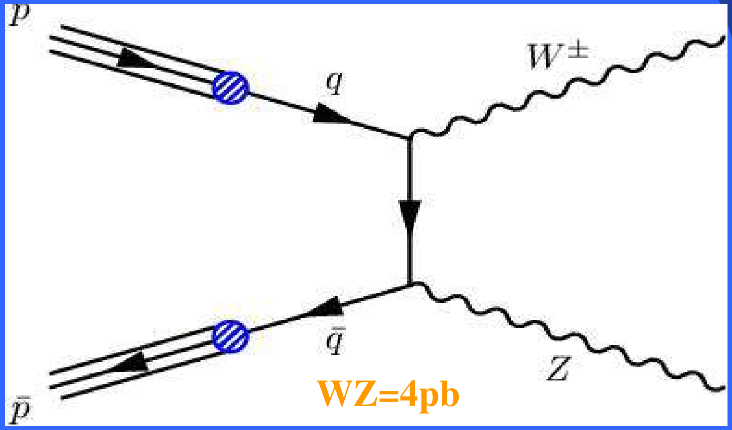
High Mass Higgs Signatures





- **H→WW*→llvv:** 2 opp-sign Leptons + Met
- WH →WWW*->$l^\pm l^\pm$vvX: 2 same-sign Leptons + Met
- Major Backgrounds: WW, WZ, ZZ, top, QCD…



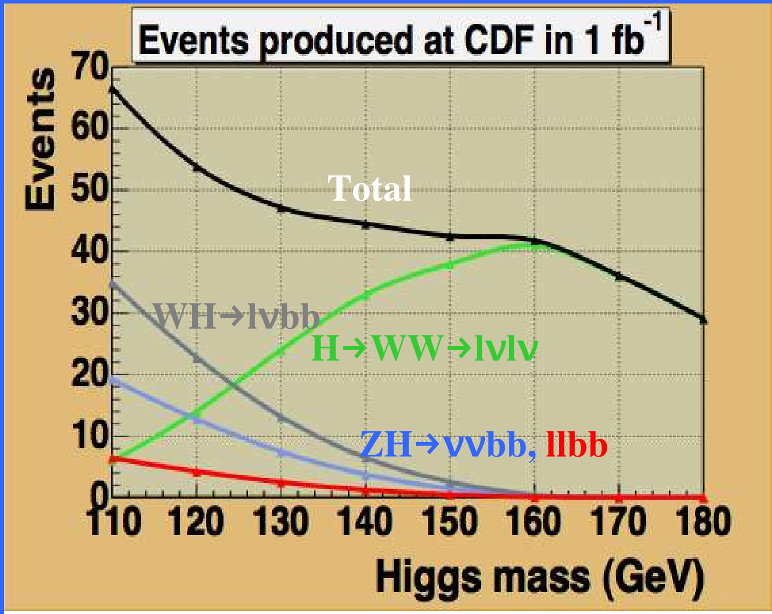


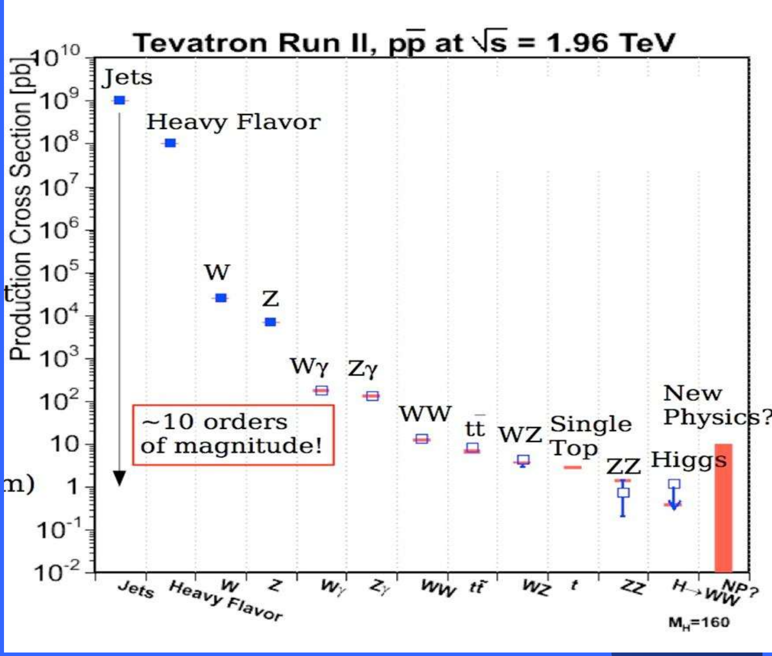
The Search Strategies…

- SM Higgs production rate is very small at the Tevatron.
- There are huge backgrounds with many orders of magnitude higher.

- **To achieve $>10^{10}$ S/B rejection:**
  - Focus on final states with leptons
  - Selecting events with large met
  - Require btagging and good M_{bb}
  - Using more advanced techniques

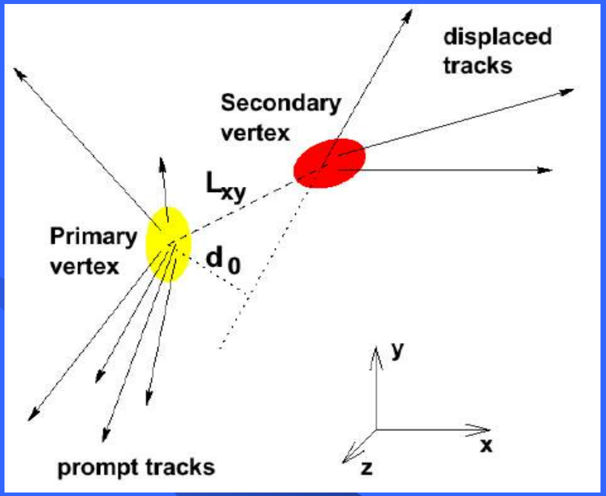
- Discovery Higgs at Tevatron is extremely challenge that requires the best of all and lots of data.

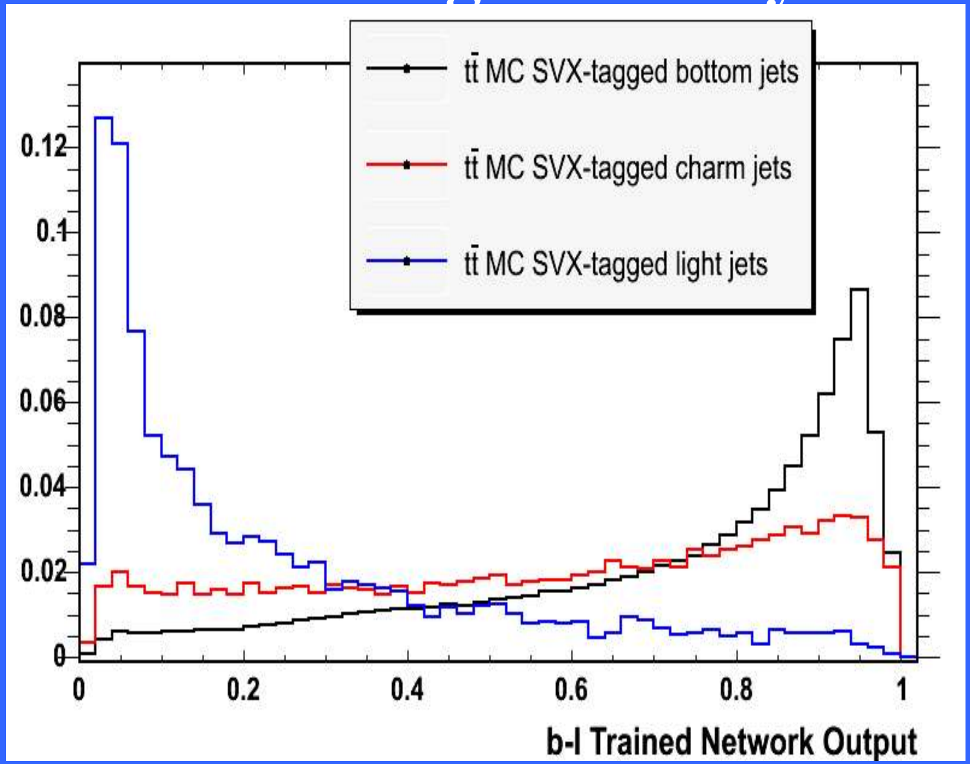


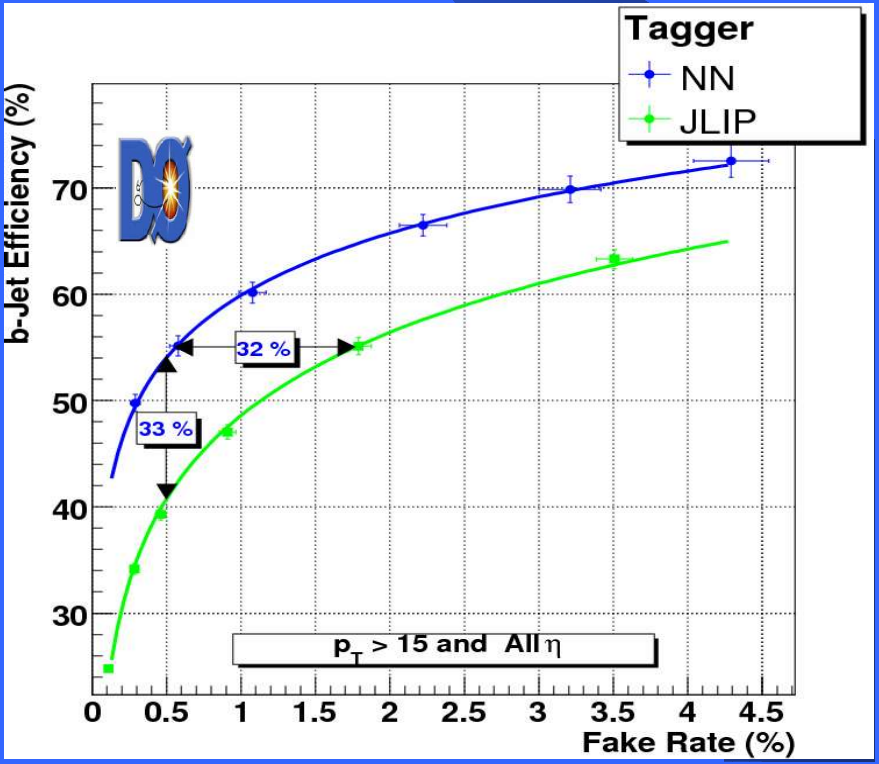


B-jet Identificaton (B-tagging)

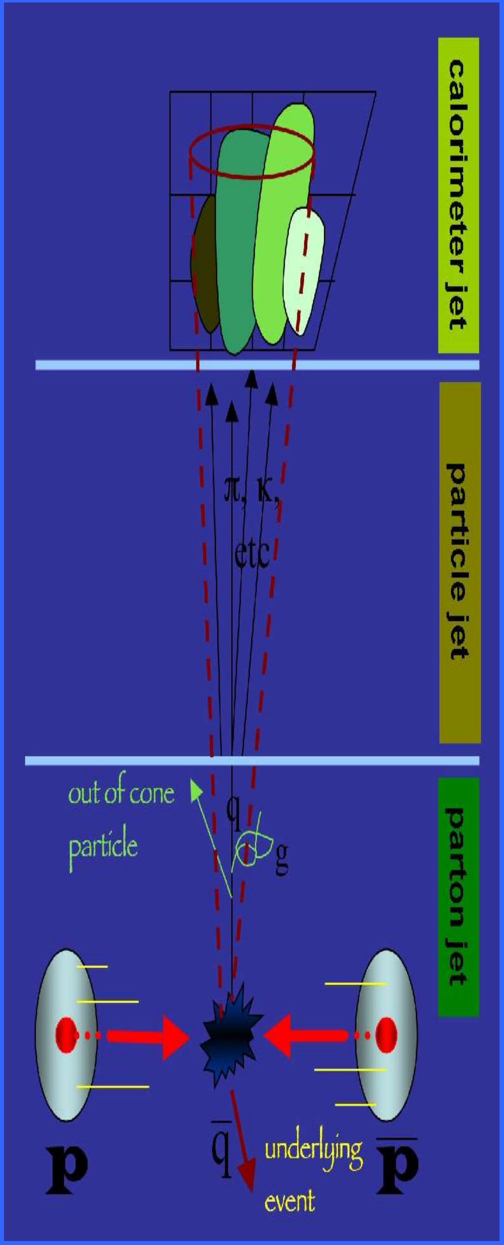
- B-hadron are long-lived – search for displaced tracks/vertex inside the jet
- Combining existing taggers with neural network: to purify mistags or increase btag efficiency



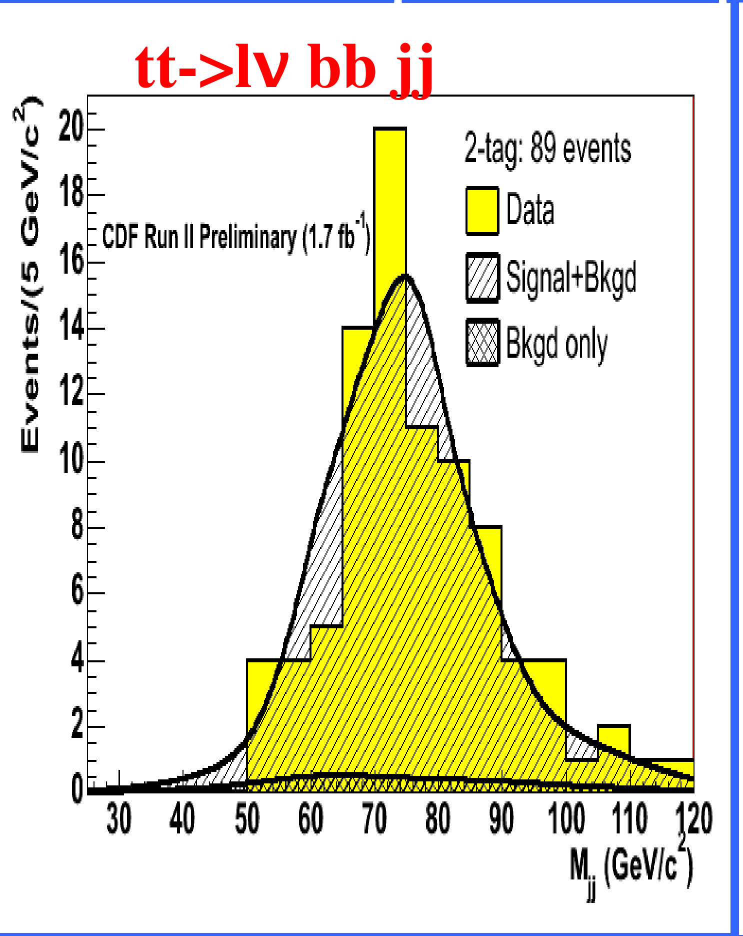


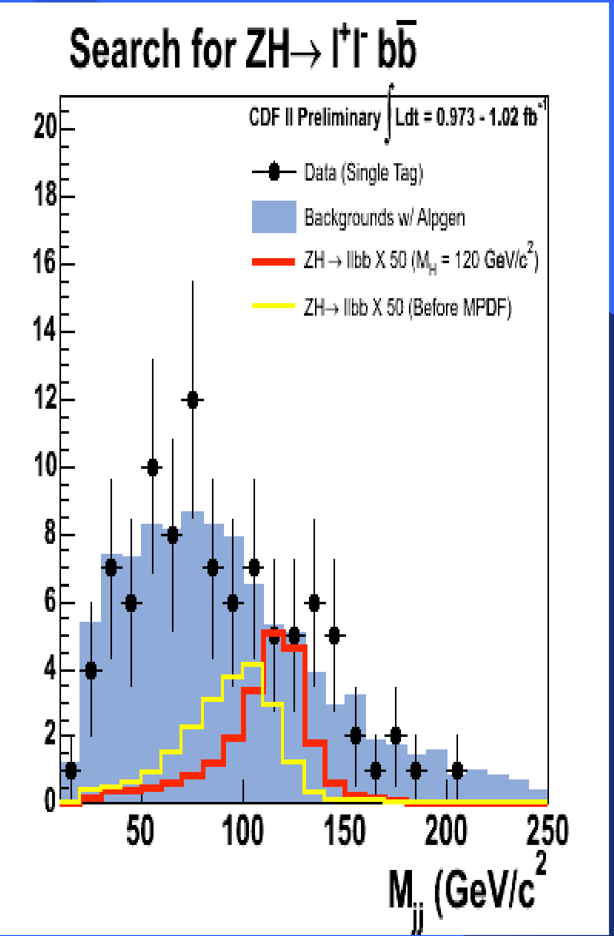


Jet Energy Resolution (Di-jet Mass)



- Jet Et depends on the cal. response to hadrons: energy scale, non-linearity, out-cone, underlying activities.
- Particle flow, b-jet specific correction, and more advanced techniques would help…





Advanced Multivariate Techniques

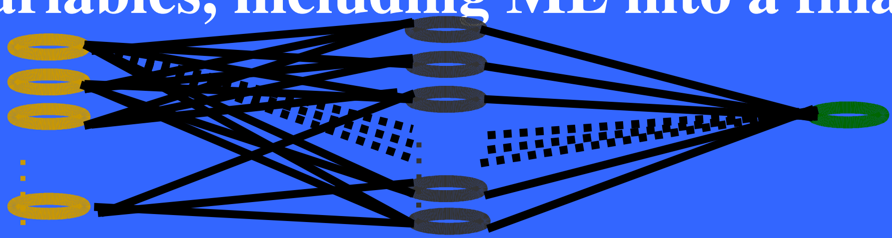
- In order to suppress large background, we use various advanced multivariate techniques

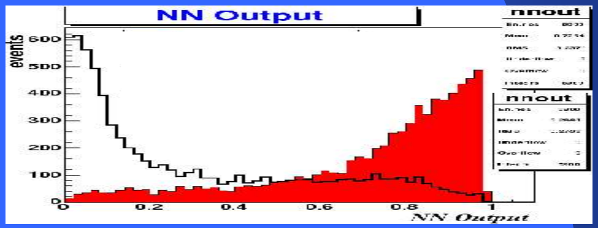
- **<u>LO Matrix Elements (ME):</u>** are used to calculate event probabilities and calculate likelihood ratio:

$$P_m(x_{obs}) = \frac{1}{<\sigma_m>} \int \underbrace{\frac{d\sigma_m^{th}(y)}{dy}}_{\text{ME}} \underbrace{\epsilon(y)}_{\text{efficiency}} \underbrace{G(x_{obs}, y)}_{\text{resolution}} dy$$

$$LR(x_{obs}) \equiv \frac{P_H(x_{obs})}{P_H(x_{obs}) + \sum_i k_i P_i(x_{obs})}$$

- **<u>Neural network (NN):</u>** combine various kinematic variables, including ME into a final discriminant variable.

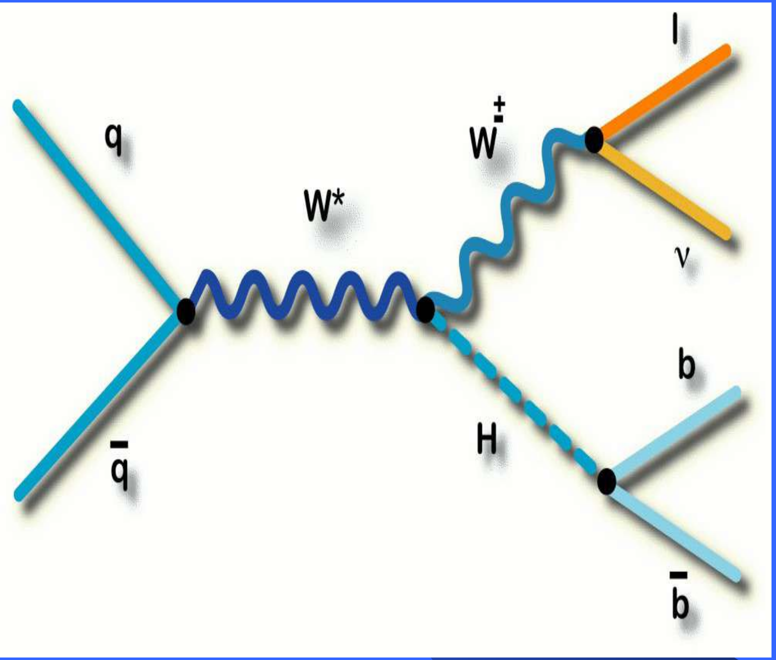


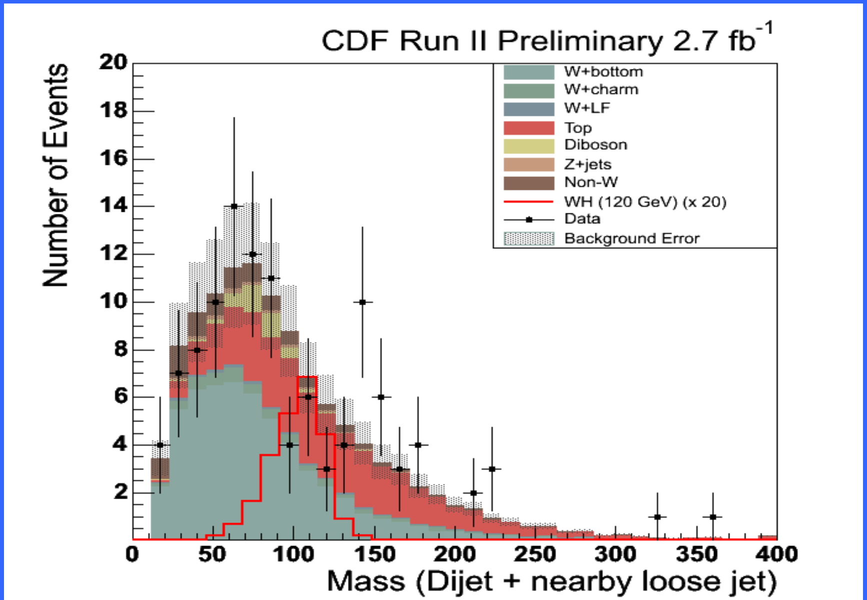


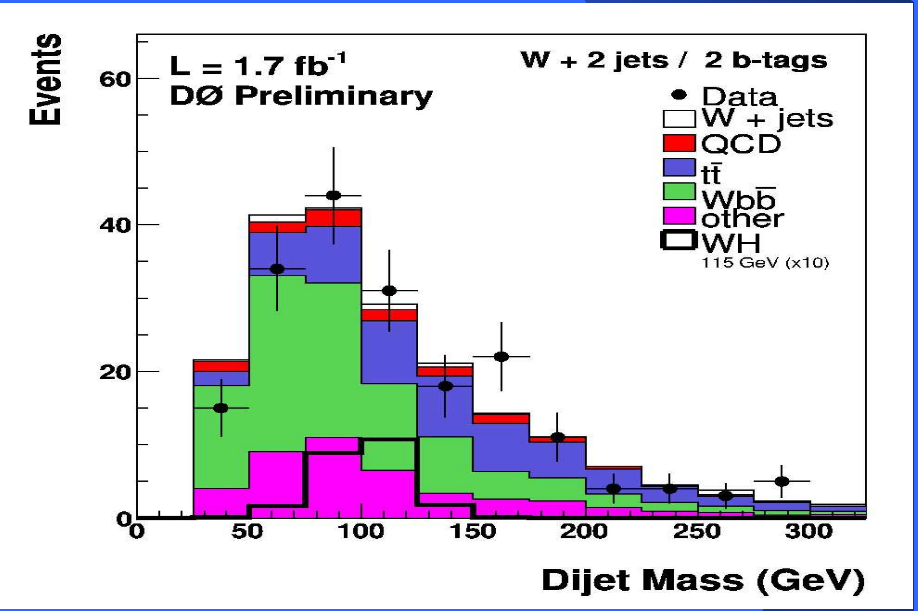
- **<u>Boosted Decision Tree(BDT):</u>** an alternative to NN
- On-going intense optimization efforts in terms of trigger, lepton selections, btagging, and dijet mass resolution.

Search for WH→lνbb

- Selecting W+2jets:
  - 1 isolated lepton or track (>20 GeV)
  - Large missing Et >20 GeV
  - 2 jets with Et>20 GeV and |eta|<2
- Btagging: 2b(tight+loose) + 1b(tight)
- W+bb: dominant and irreducible
- Discriminant: dijet mass + kinematics
- Methods: NN, ME, and BDT

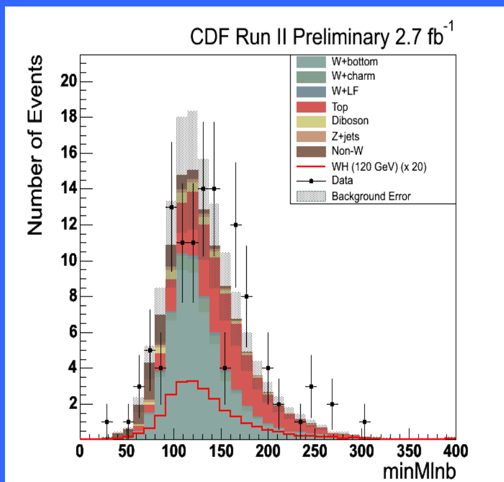


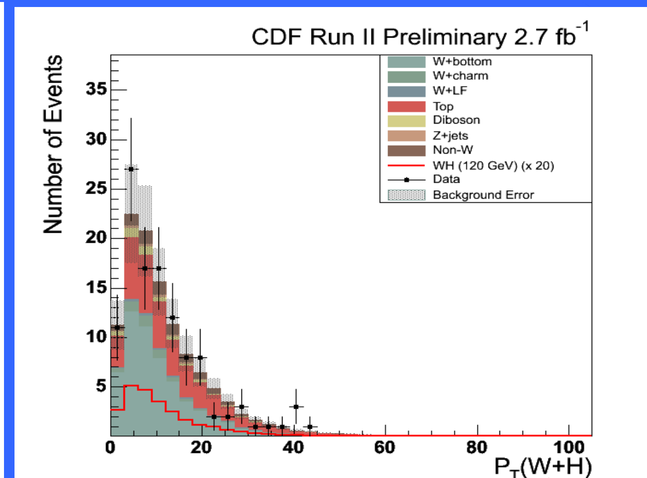


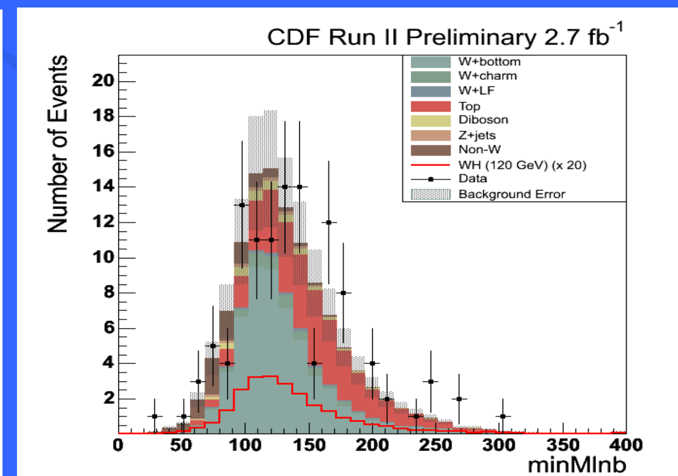


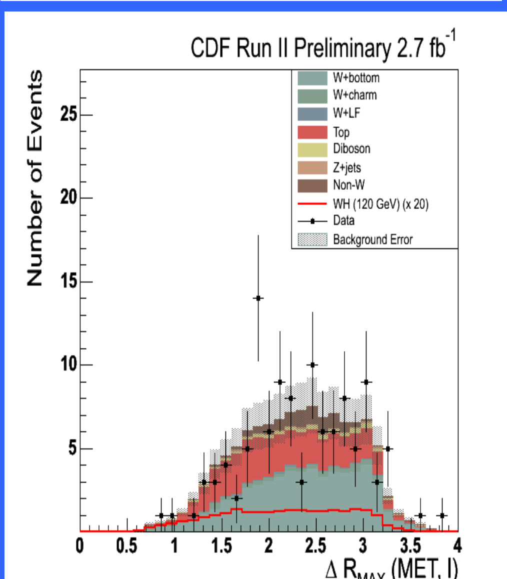
Discriminating Signal from Background

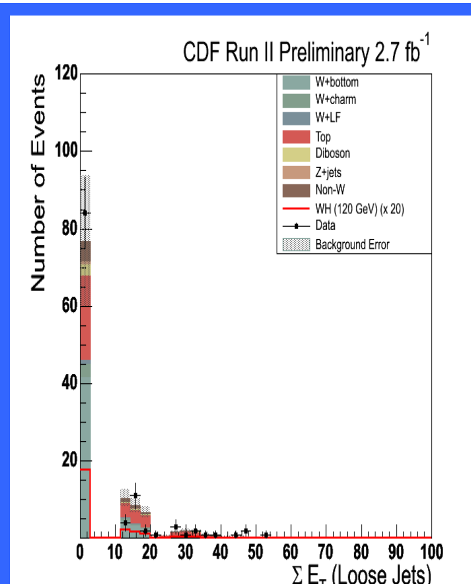
- ➢ Validation data with Monte Carlo background modeling
- ➢ Combine these variables plus Mjj with ANN to optimize sensitivity

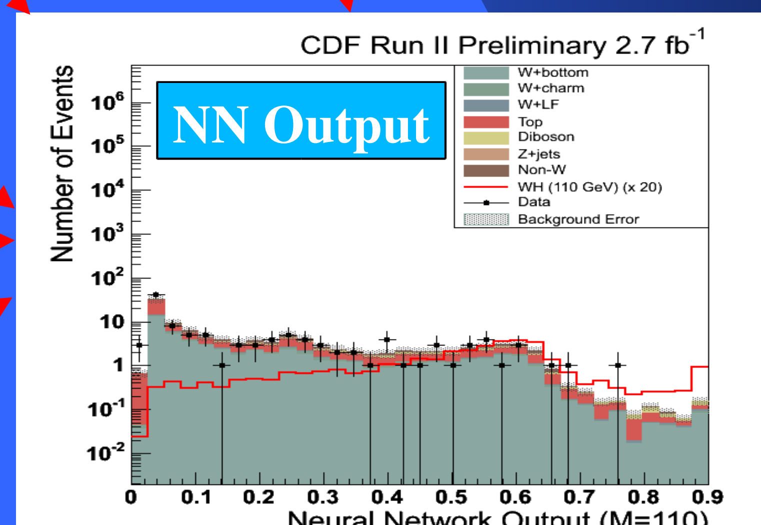






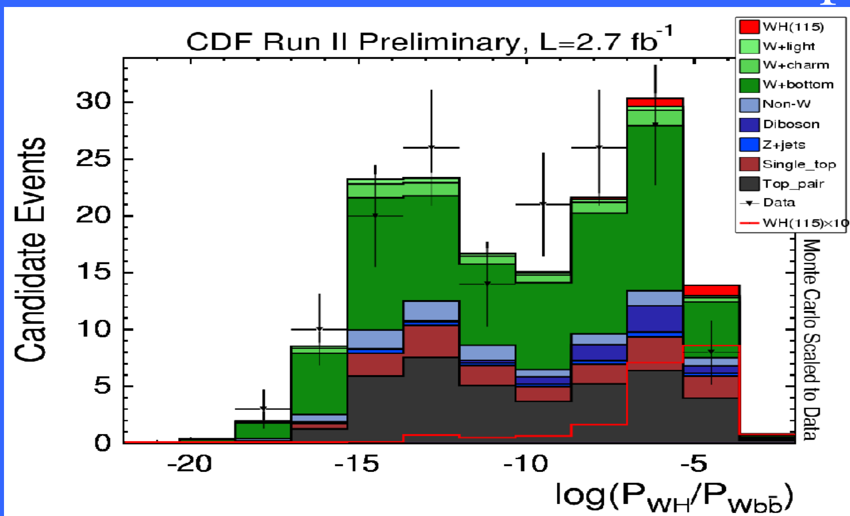


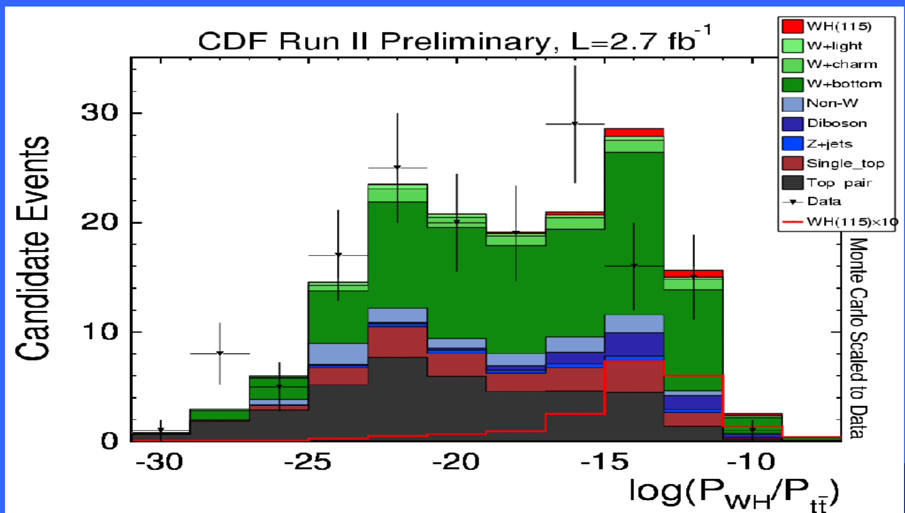


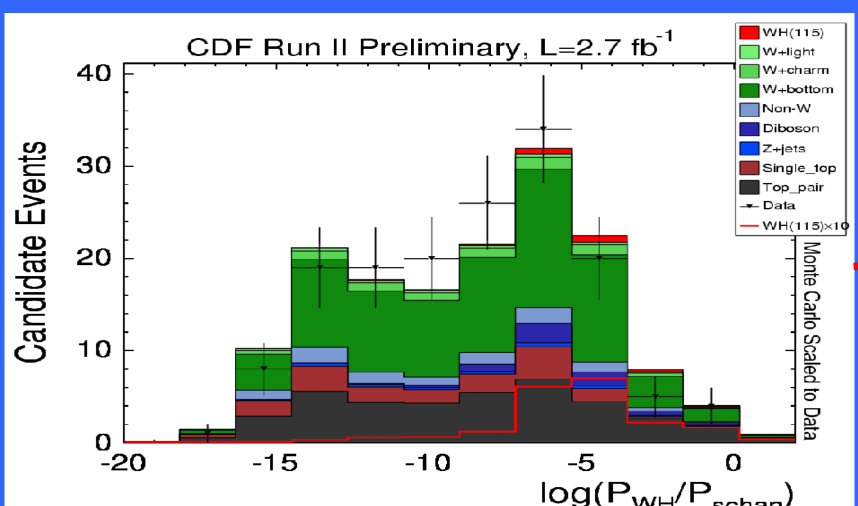


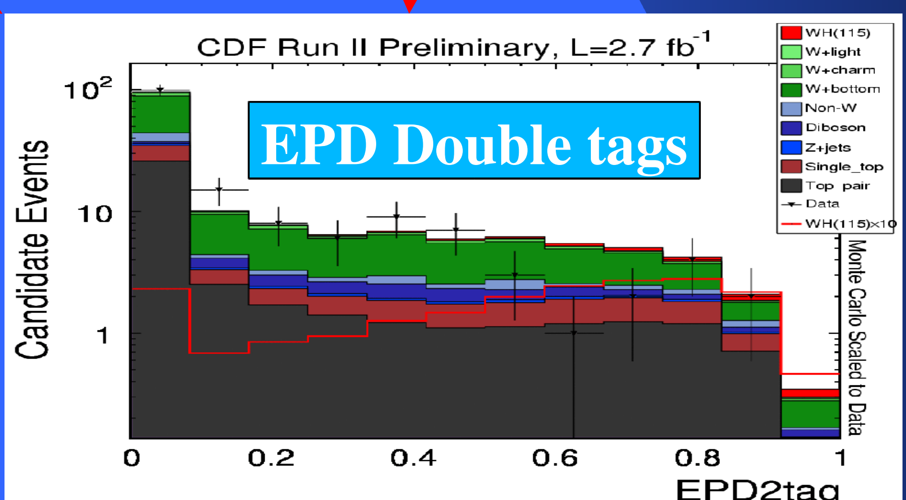
Discriminating with ME+BDT

- ME calculate event probability densities for both signal and backgrounds
- BDT is used to combine these probabilities and other kinematics



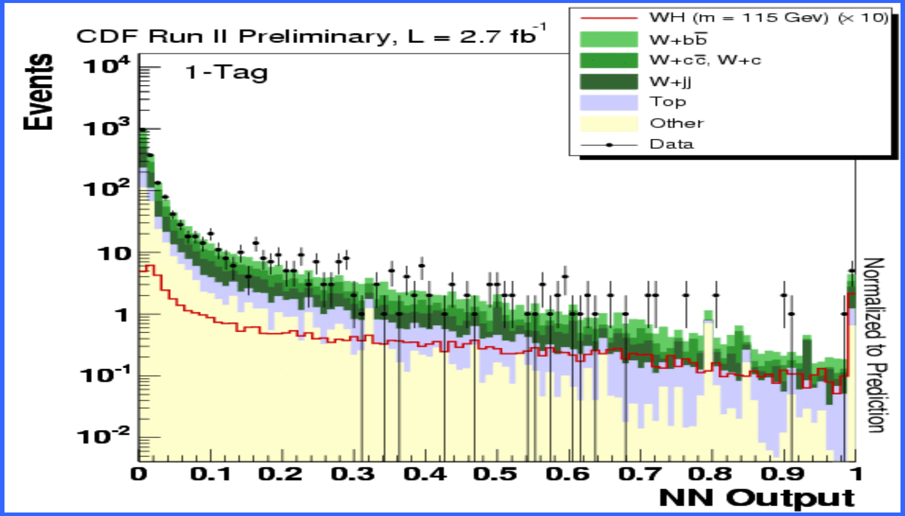


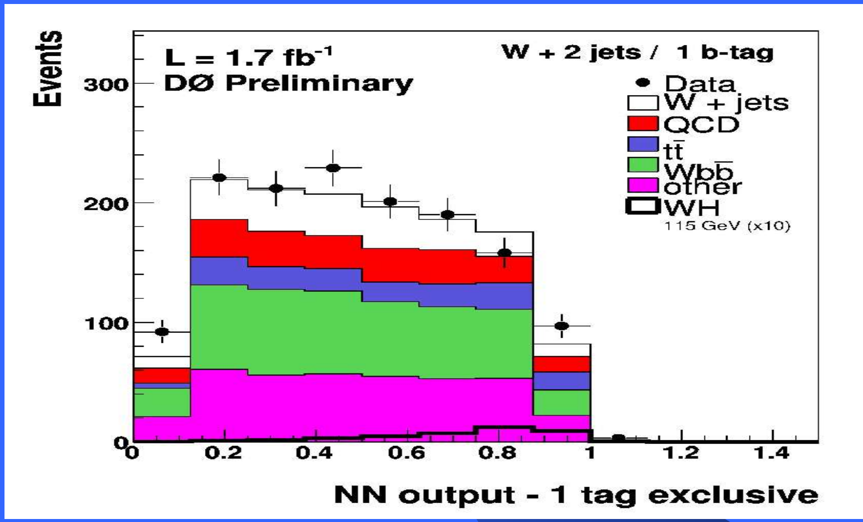


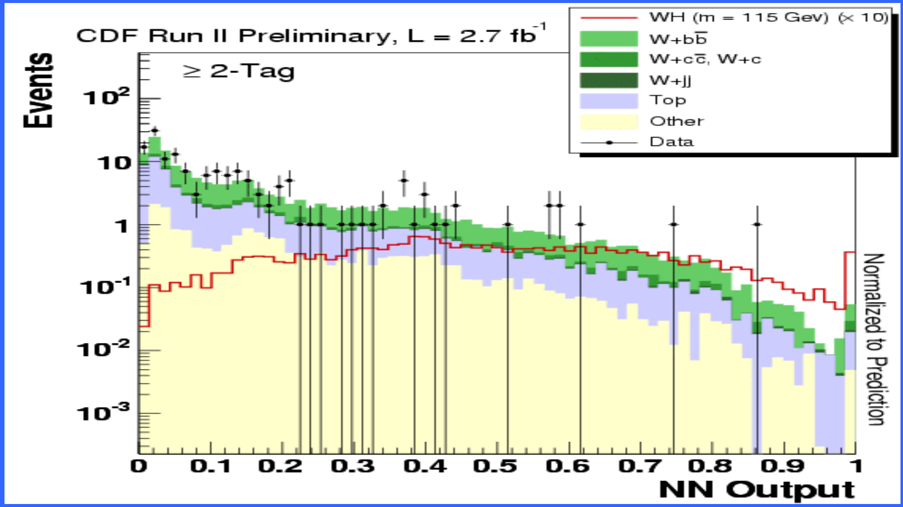


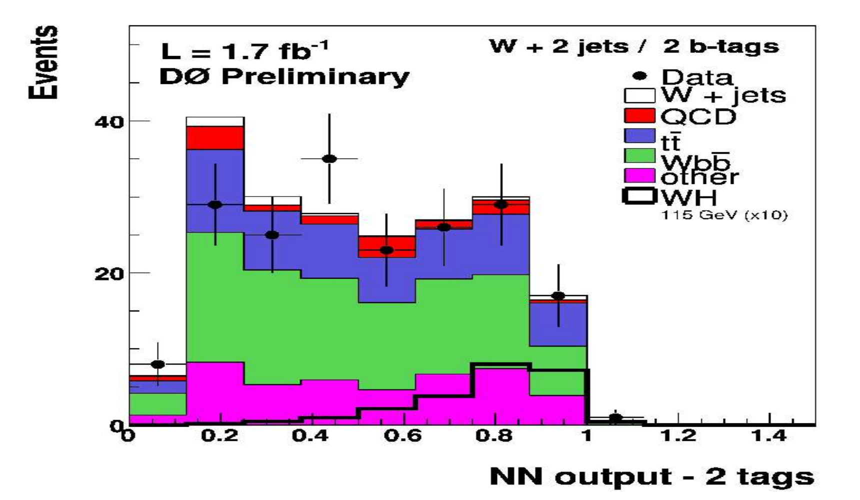
Final NN Output

CDF(NN+ME/BDT) | **D0 (NN)**



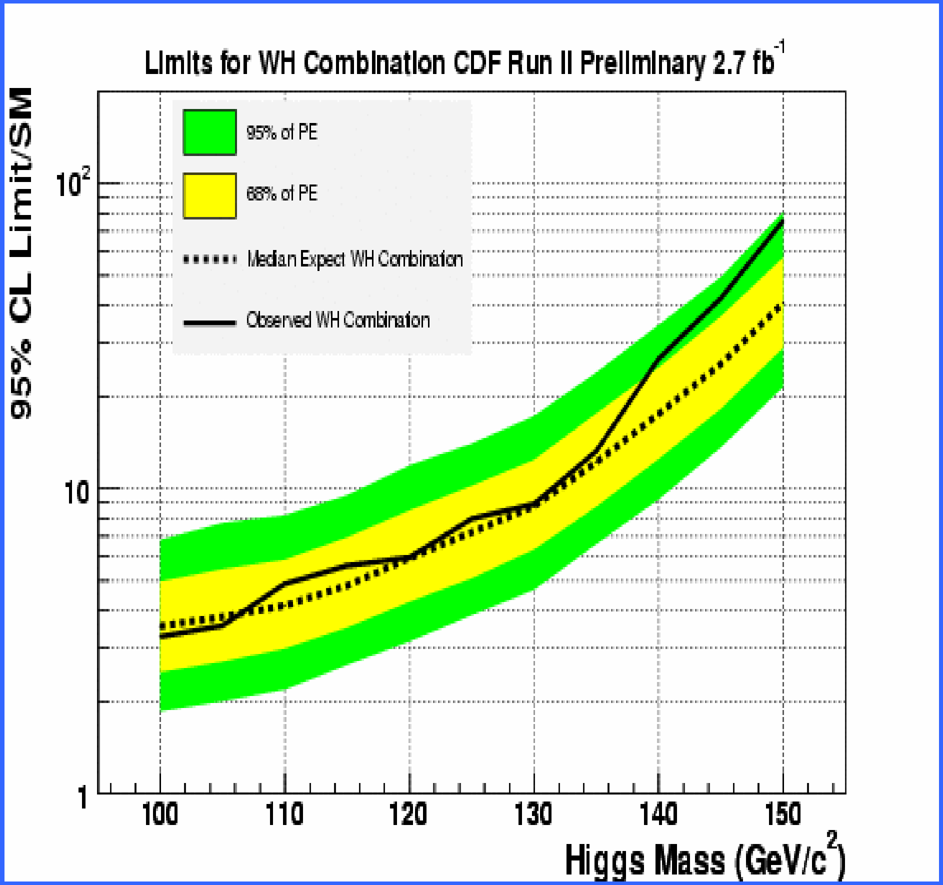


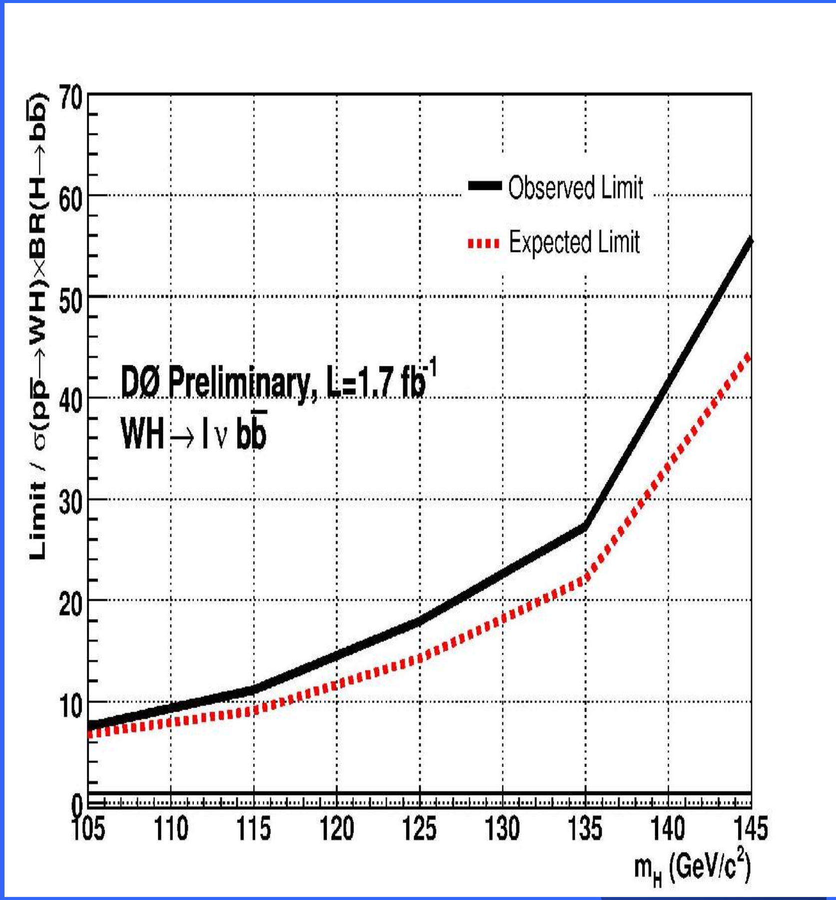




- CDF improves sensitivity by 15% over individual result alone
- Half is due to unify event selections and rest is combination

Expected and Observed Limits

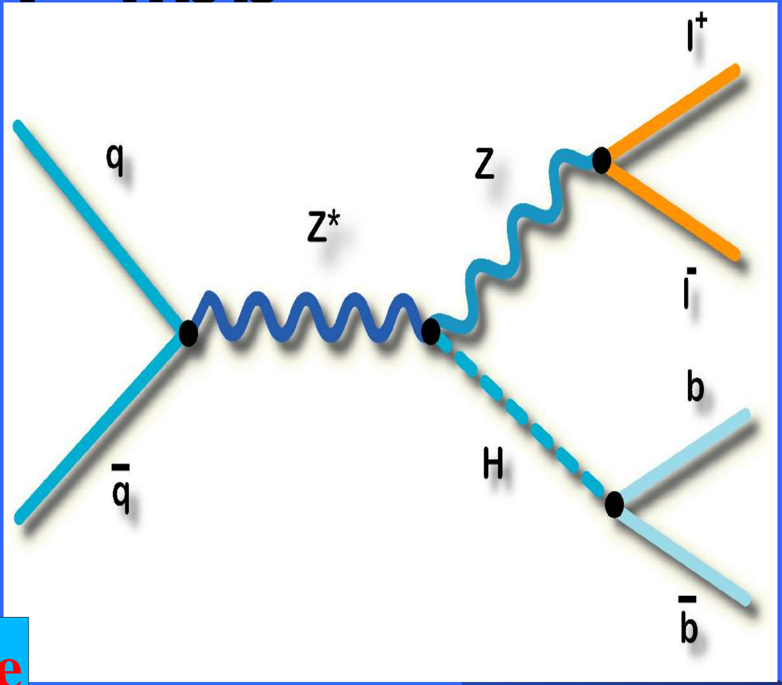




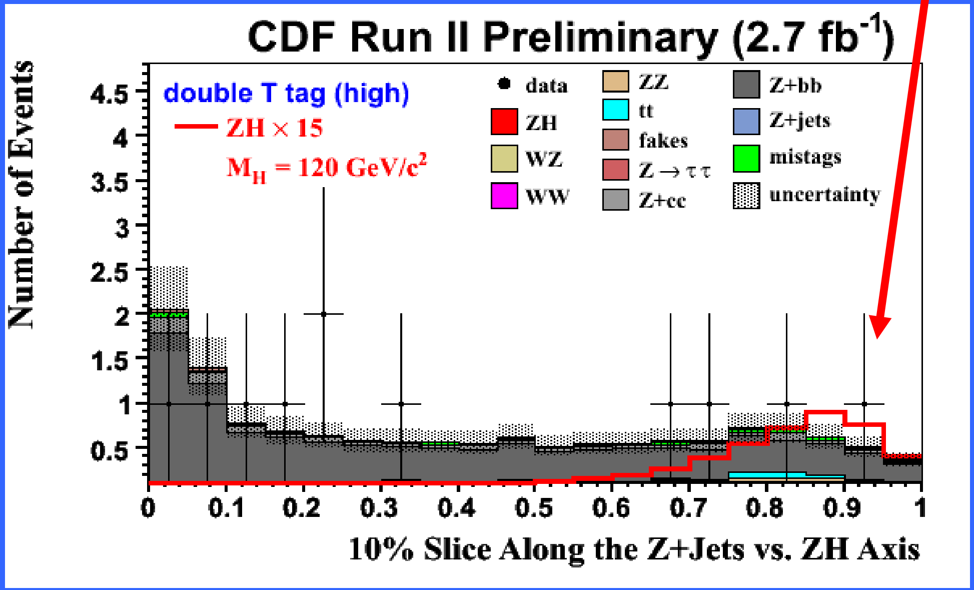
- CDF observed/expected limit: 5.6/4.8 x SM at mH=115 GeV
- D0 observed/expected limit: 11/9 x SM at mH=115 GeV.
- Future improvements: improving btagging, dijet mass resolution and individual analysis …

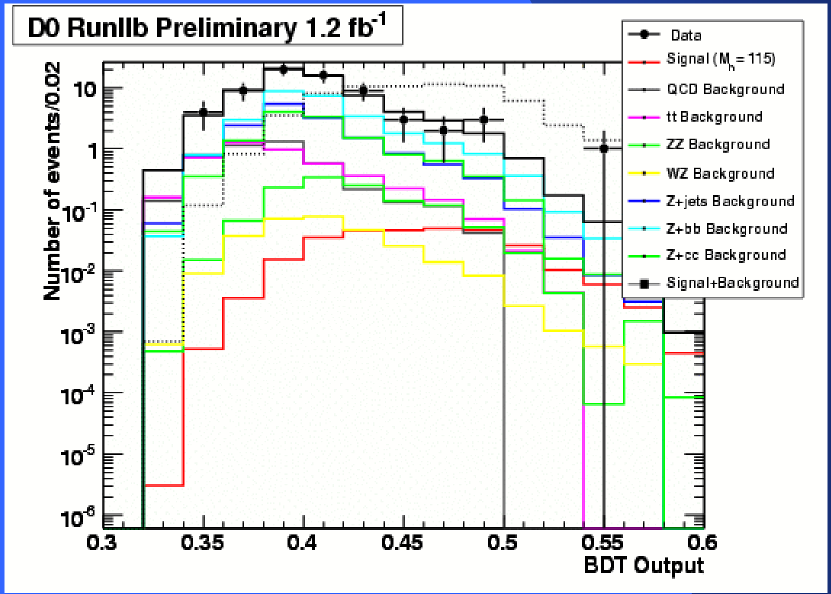
Search for ZH→llbb

- Low event rate but clean signature
- Select two high Pt leptons from Z (tight and lose z's)
- Split off 1 or 2 b-tags
- Improve dijet mass using missing Et.
- NN trained to separate ZH from top and Z+jets backgrounds.



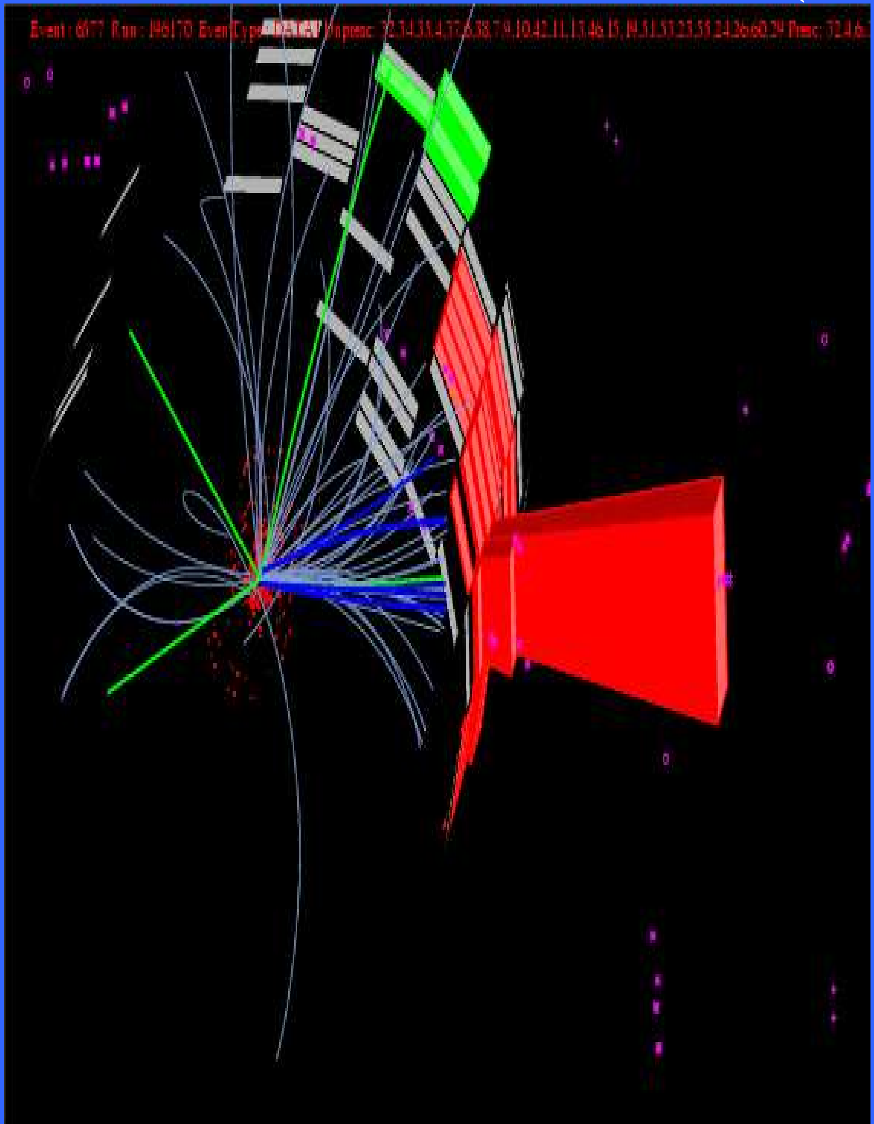
Most H-like

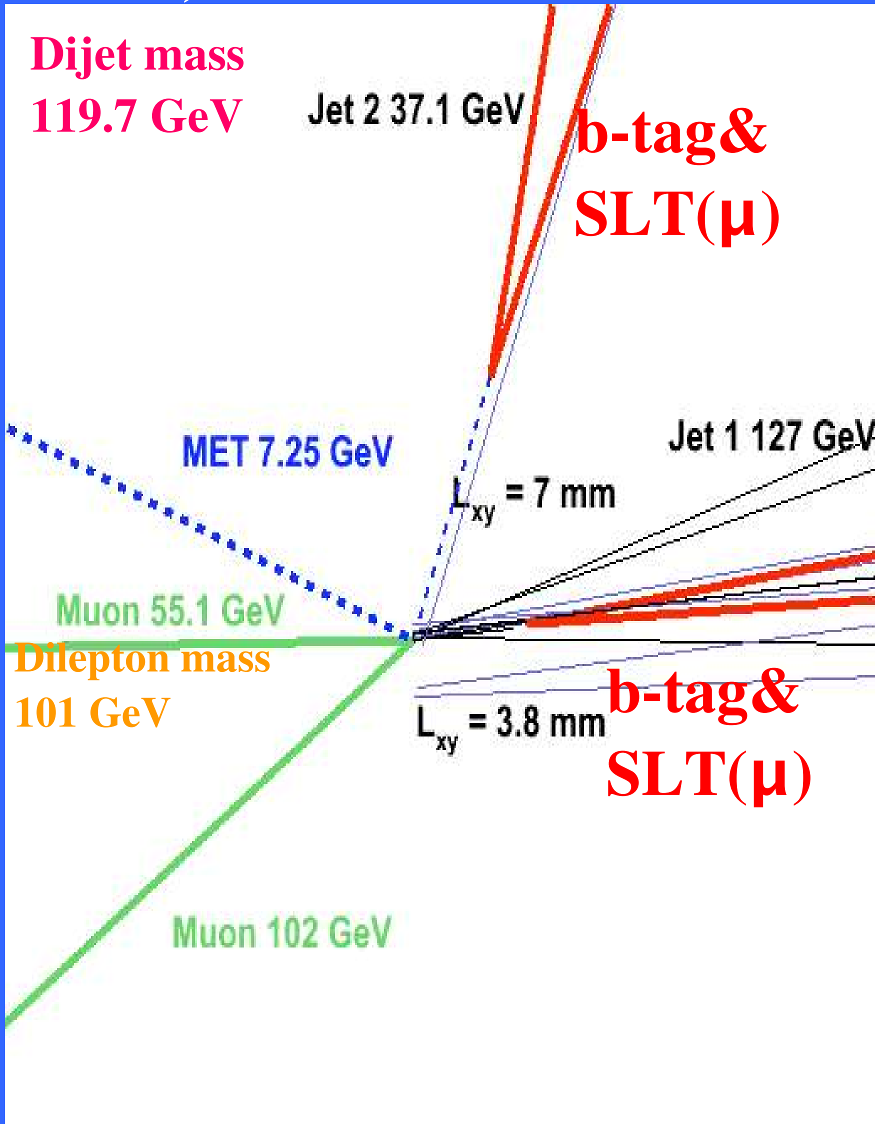




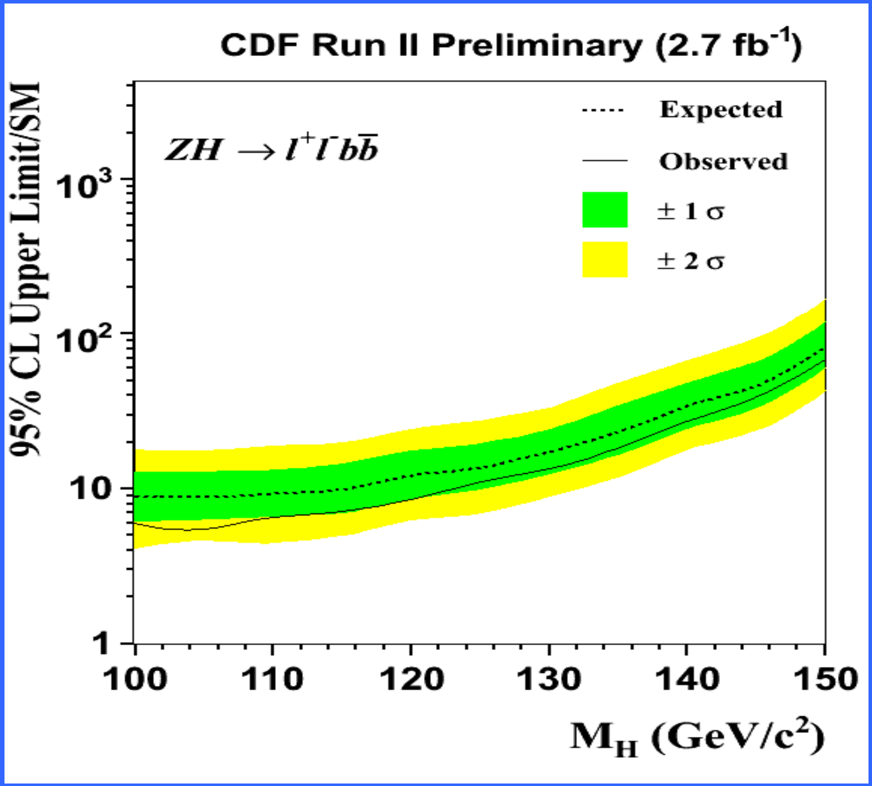
Most Higgs-Like Candidate

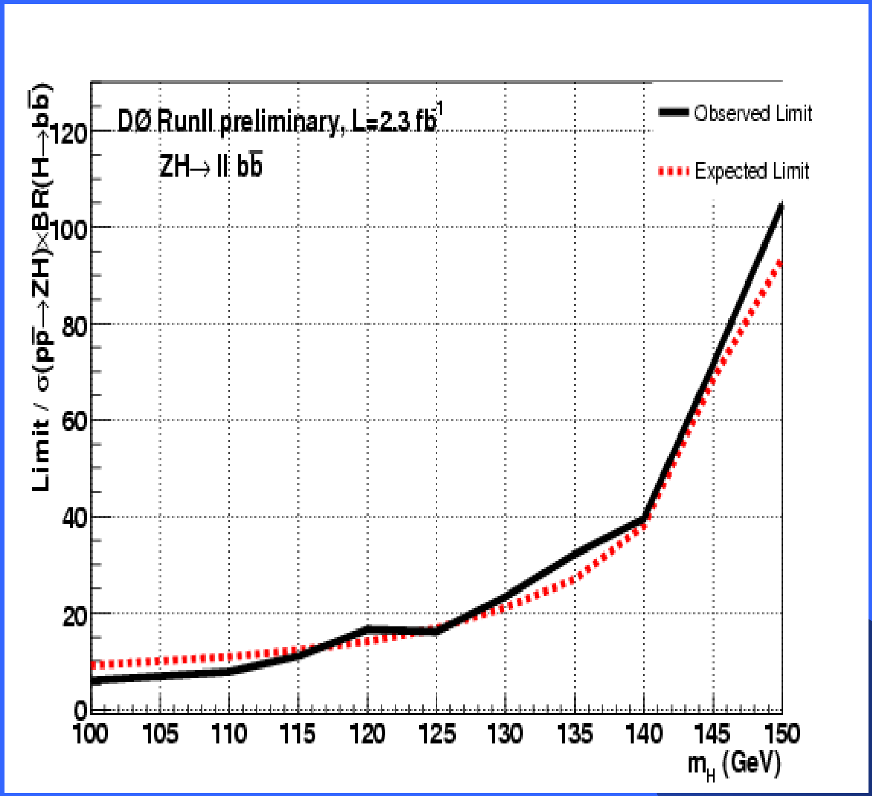
CDF run 196170 event 6577 (S:B~1:10)





Search for ZH→llbb

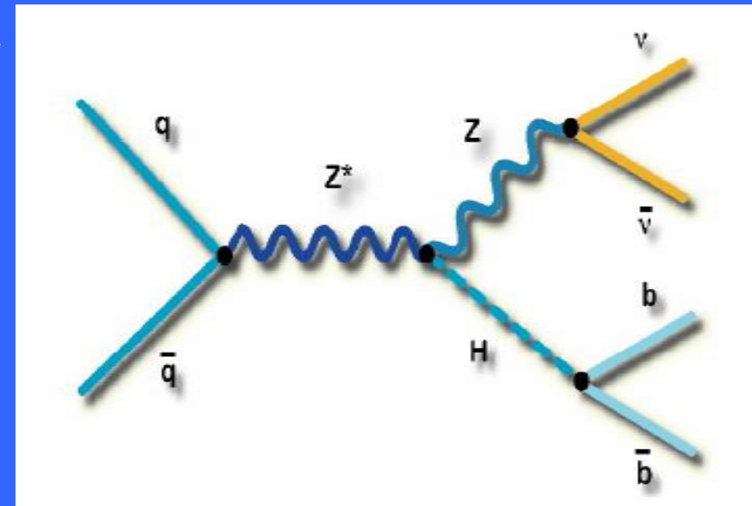


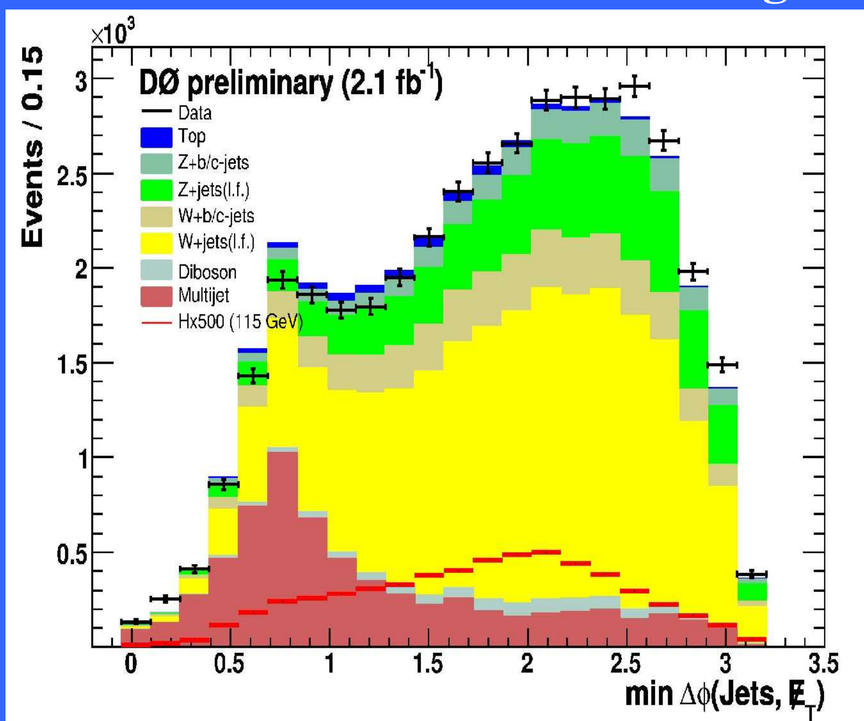


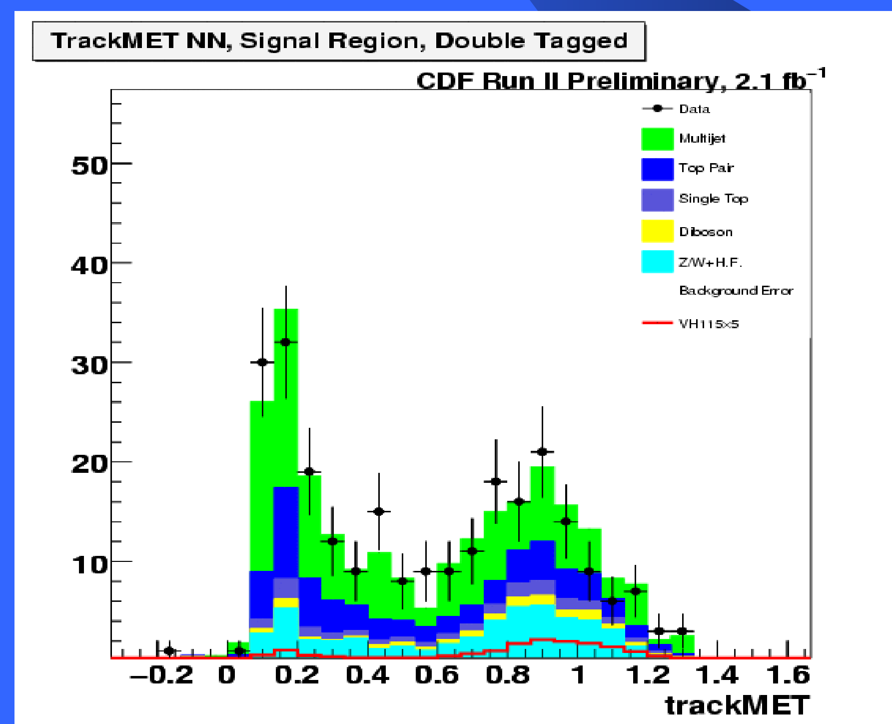
- CDF observed/expected limit is 7.1/9.9 x SM @ m_H =115 GeV
- D0 observed/expected limit is 11.0/12.3 x SM @ mH =115 GeV
- Future Improvements: update with more data, improving HF tagging, combining with ME, and more …

Search for ZH→ννbb, WH→(ł)νbb

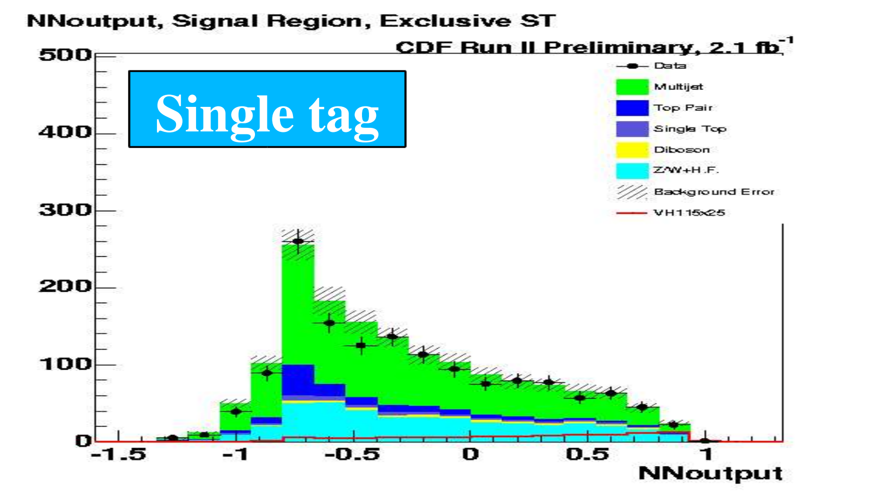
- Large xsec*Br, but large QCD, difficulty
- Rely on large Met>50 GeV +2jet
- Requiring single and double btag
- Rejection of instrumental backgrounds:
  - dφ(Et1, MET)
  - Track Met: NN with charged tracks

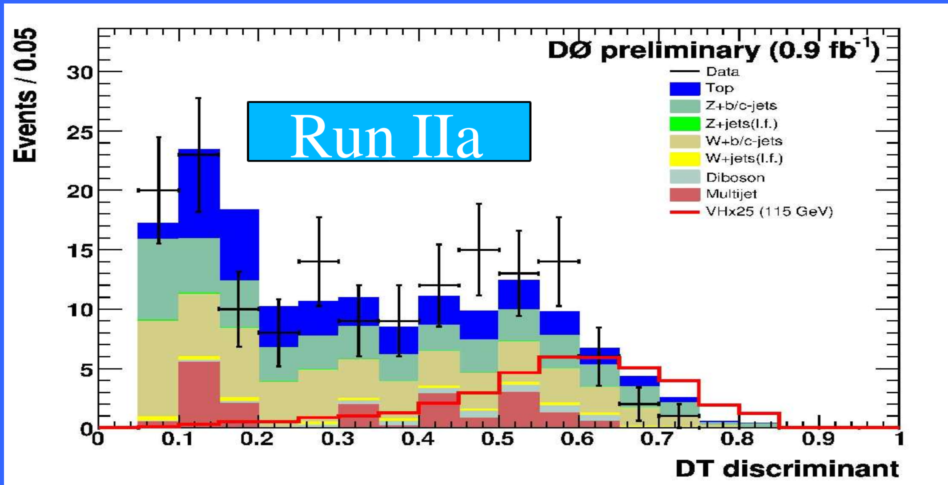


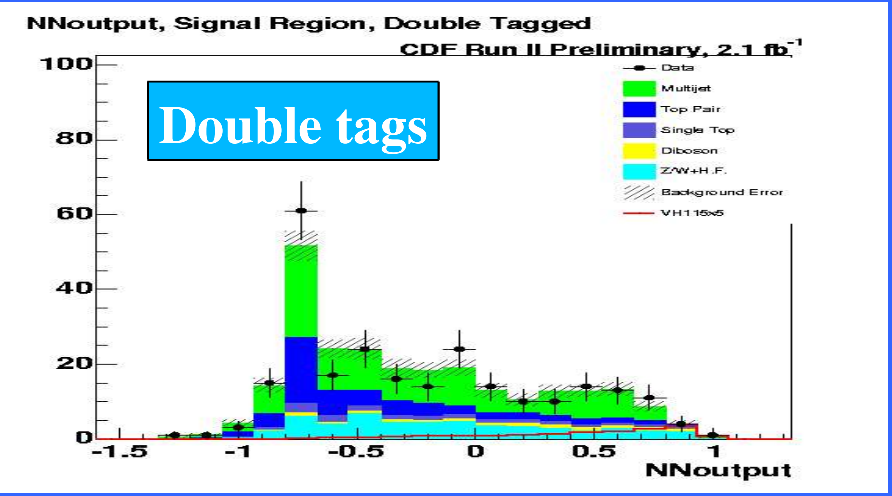


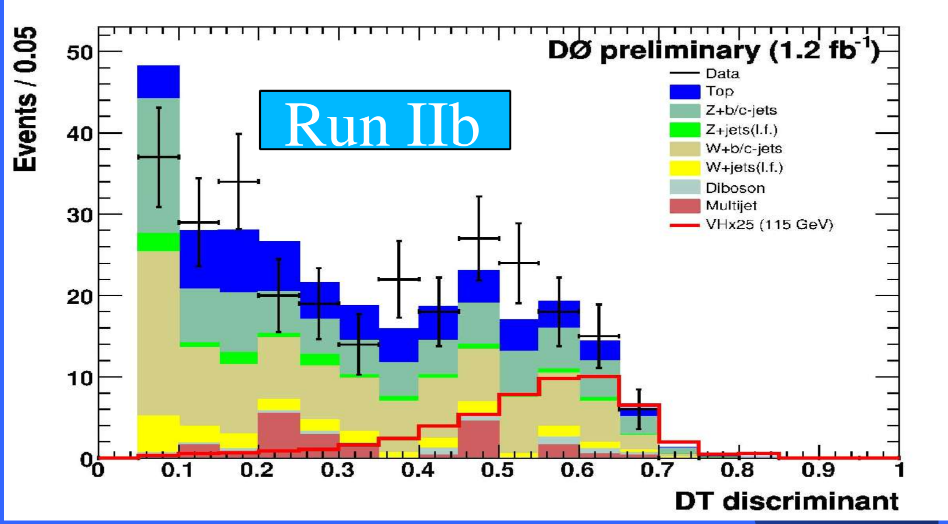


Final Discriminant for ZH→ννbb, WH→(ł)νbb



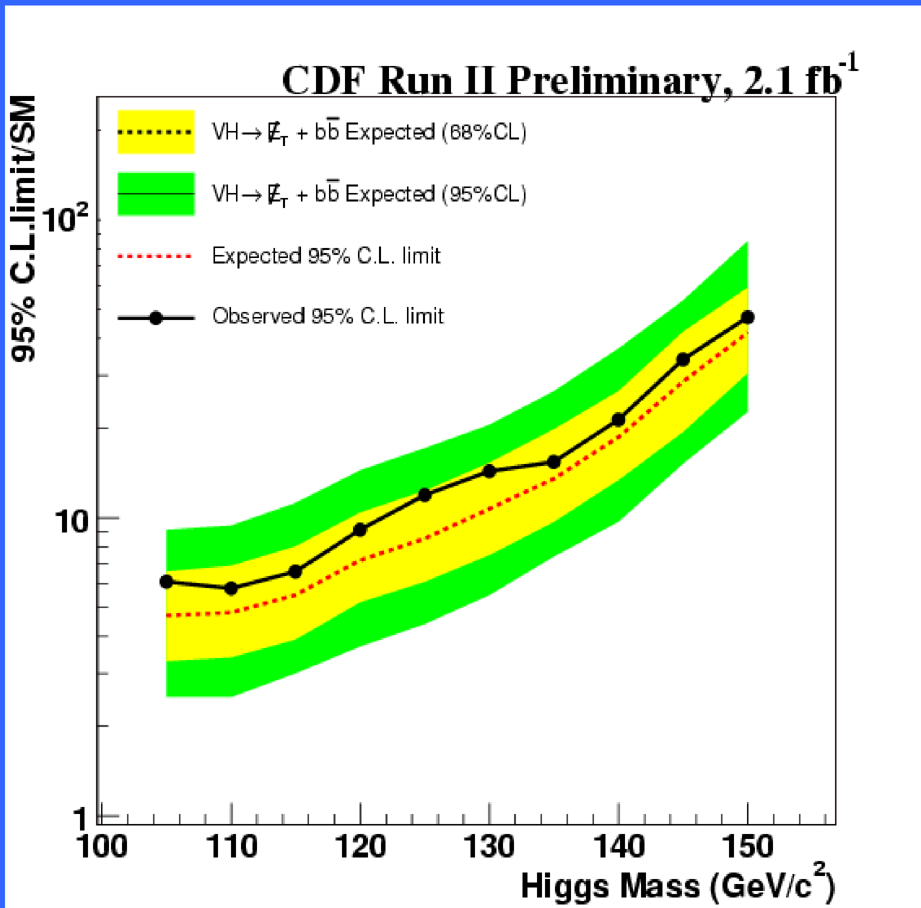


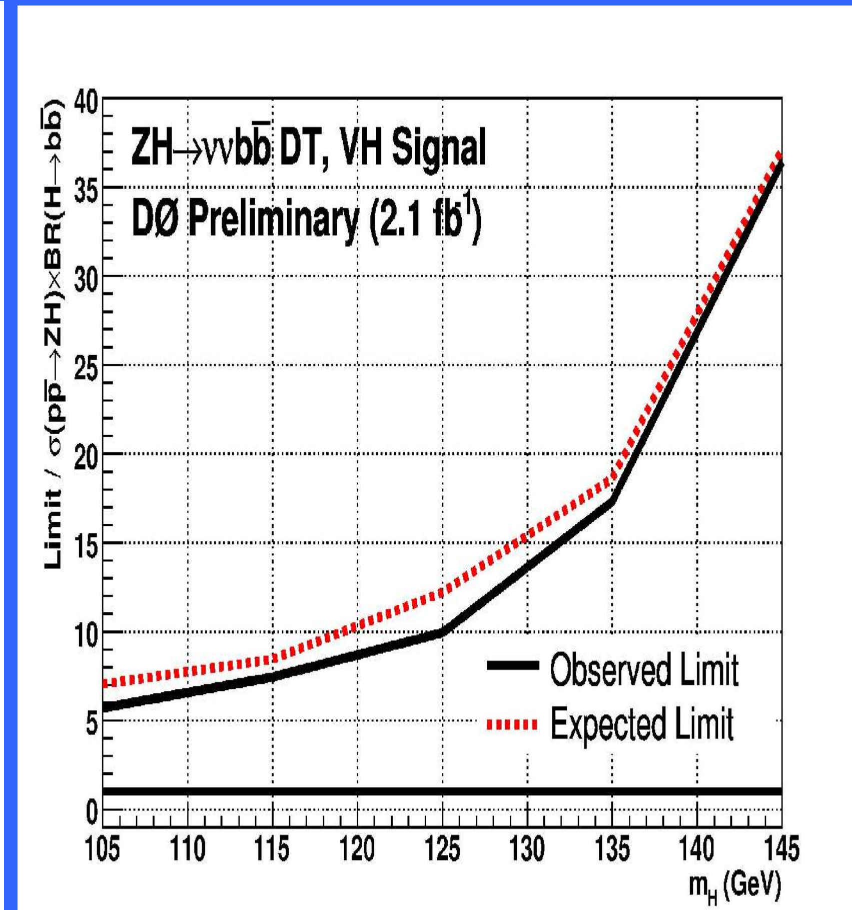




- Combining Mjj, track met, and other kinematics into final NN (CDF) or Boosted Decision Tree (D0) for double tags.

Search for ZH→ννbb and WH→(ł)νbb

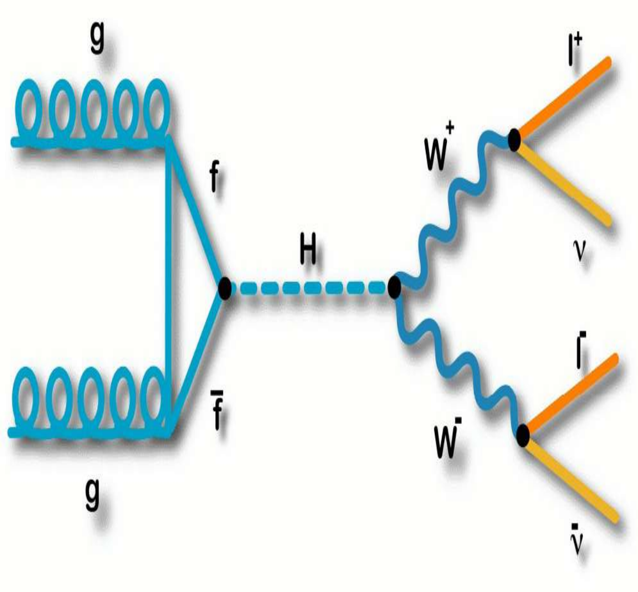


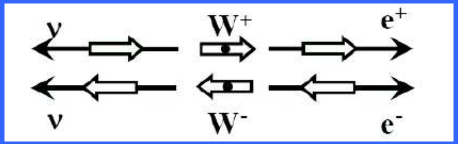


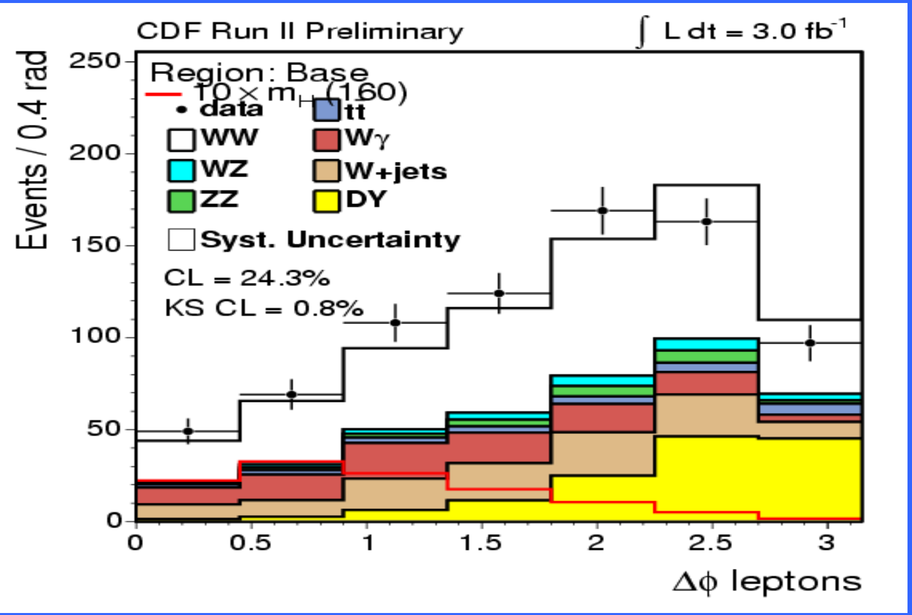
- CDF observed/expected limit is 6.6/5.5 x SM @ m_H =115 GeV
- D0 observed/expected limit is 7.5/8.4 x SM @ mH =115 GeV
- Future improvements: with more data and improving the trigger

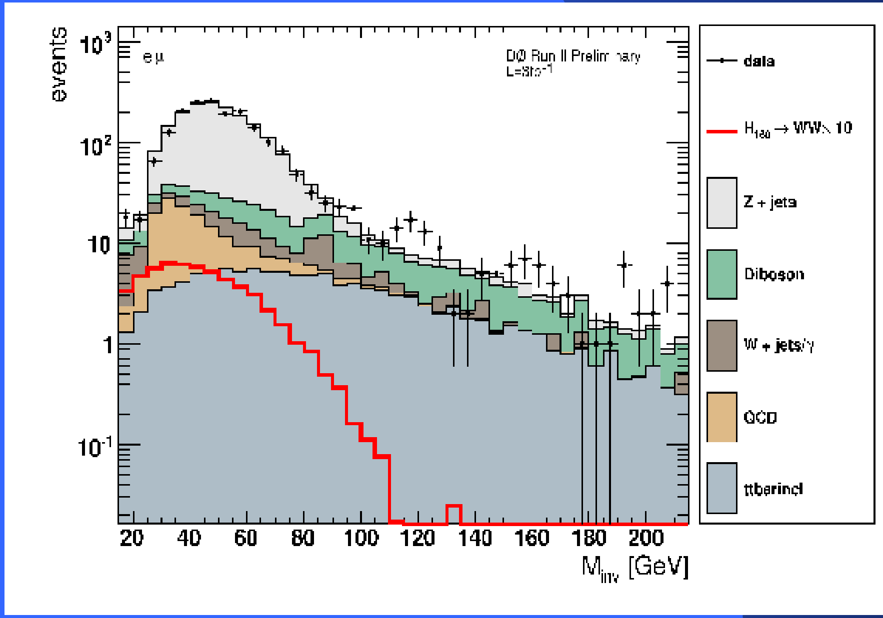
Search for H→WW*→lνlν

- Three main channels (ee, μμ, eμ)
- Two opp-sign high Pt leptons
- Large missing Et and 0, 1, 2 njets
- Dominant Backgrounds: WW*
- Higgs mass can't be reconstructed, but the angular correlation provides handle to reduce WW*.

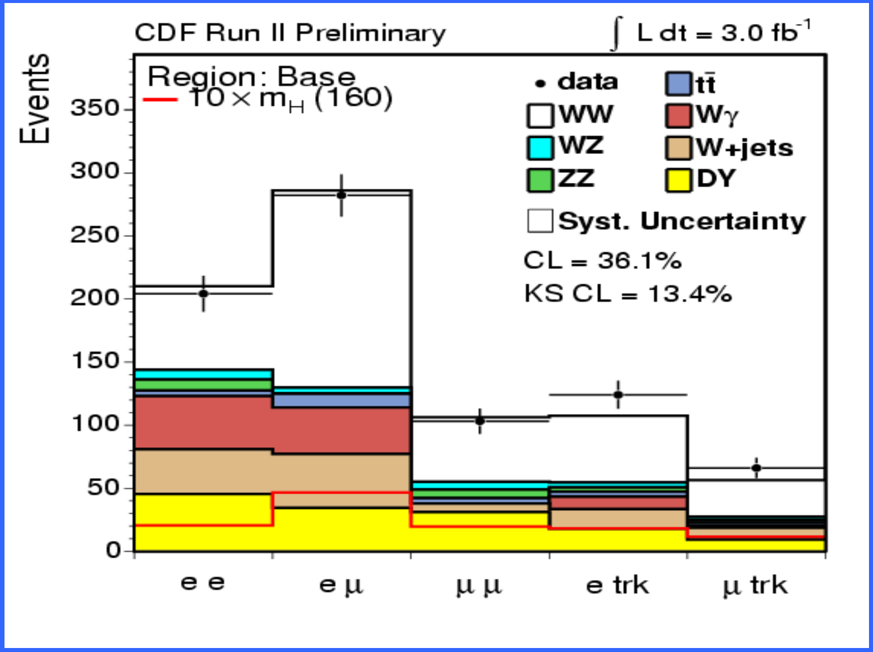


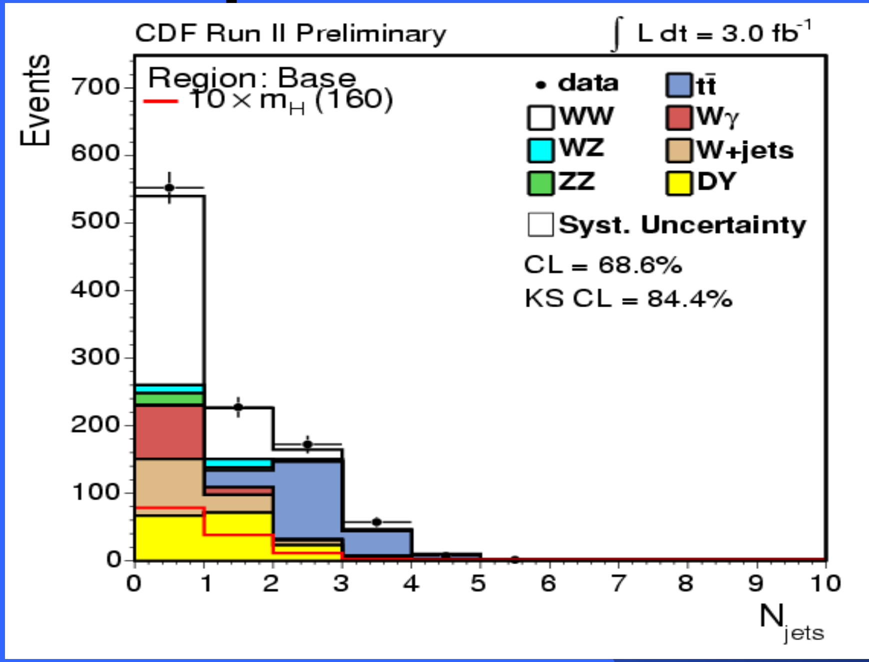






Maximizing the Acceptance

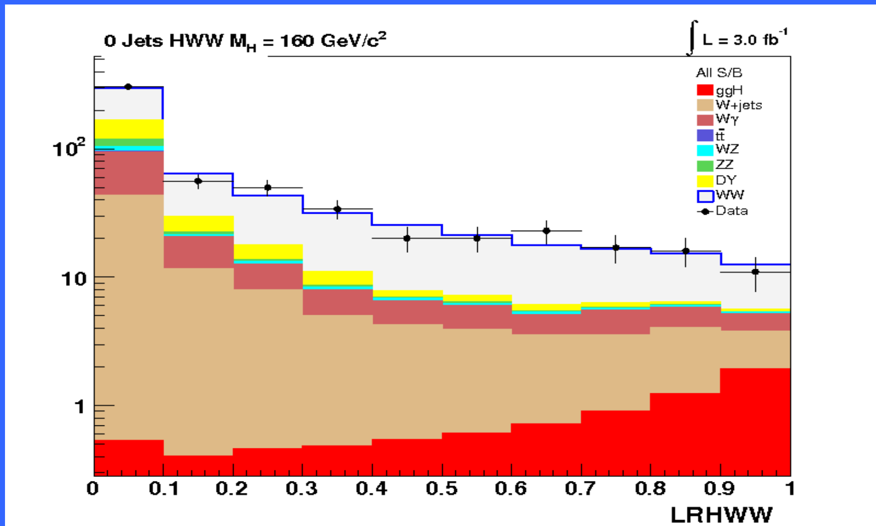


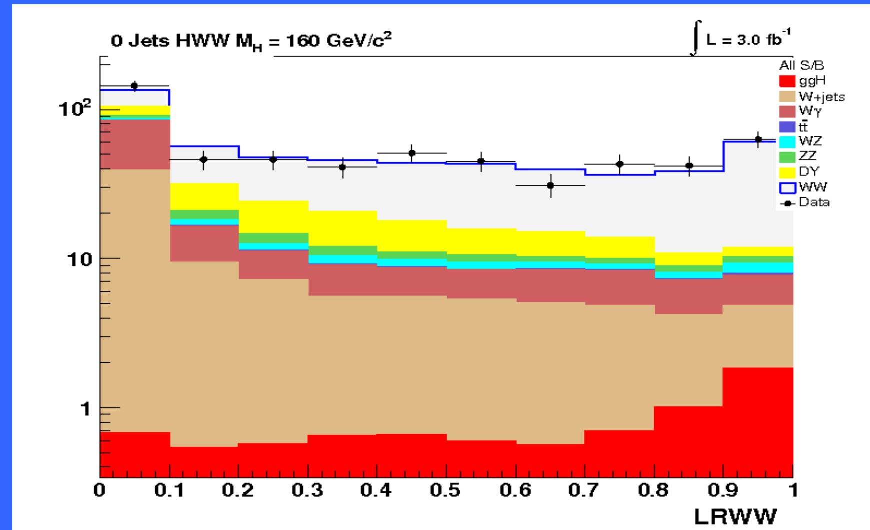


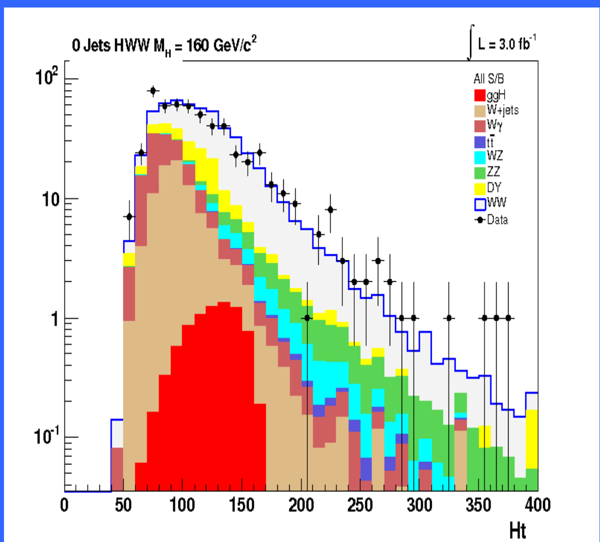
- Optimize lepton selections: ee, emu, mumu, e trk, mutrk.
- Separate final states with either 0, 1, or at least 2 jets to gain extra acceptance for VH-> VWW (V=W,Z).
- Data (918) are well described by SM expectations (985+-113)
- The expected signal events is 17.5+- 2.2 for Hmass=160 GeV/c2

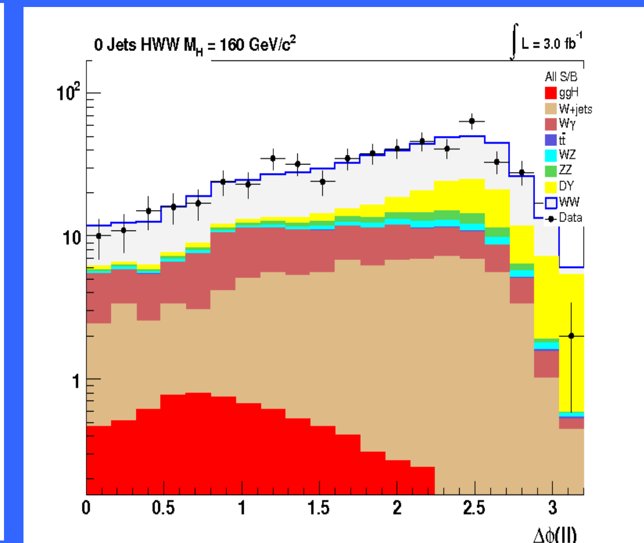
Separating Higgs from Backgrounds

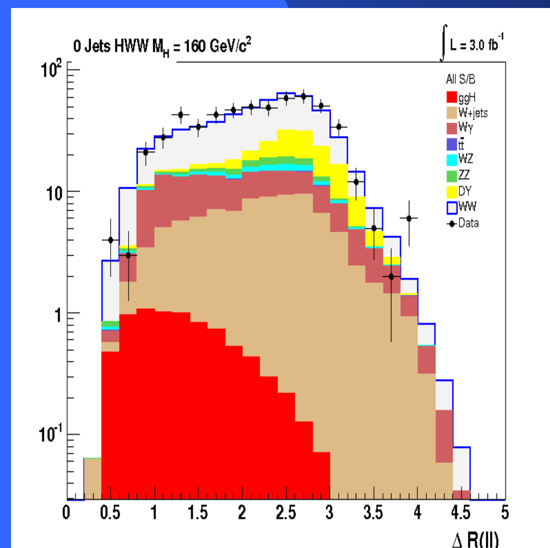
- Validation data with Monte Carlo background Modeling
- NN Discriminant: Combine LO ME and kinematic distributions.





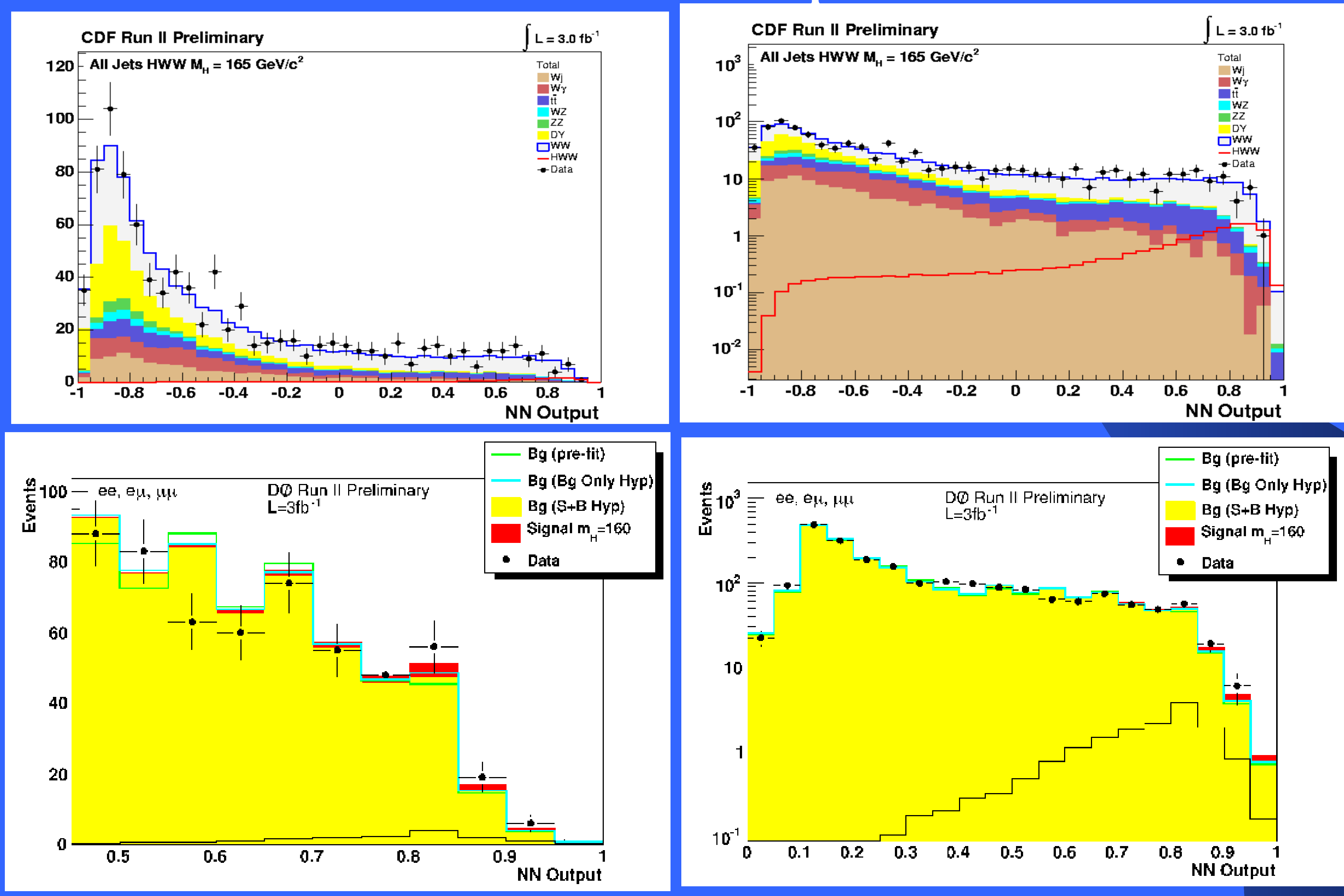




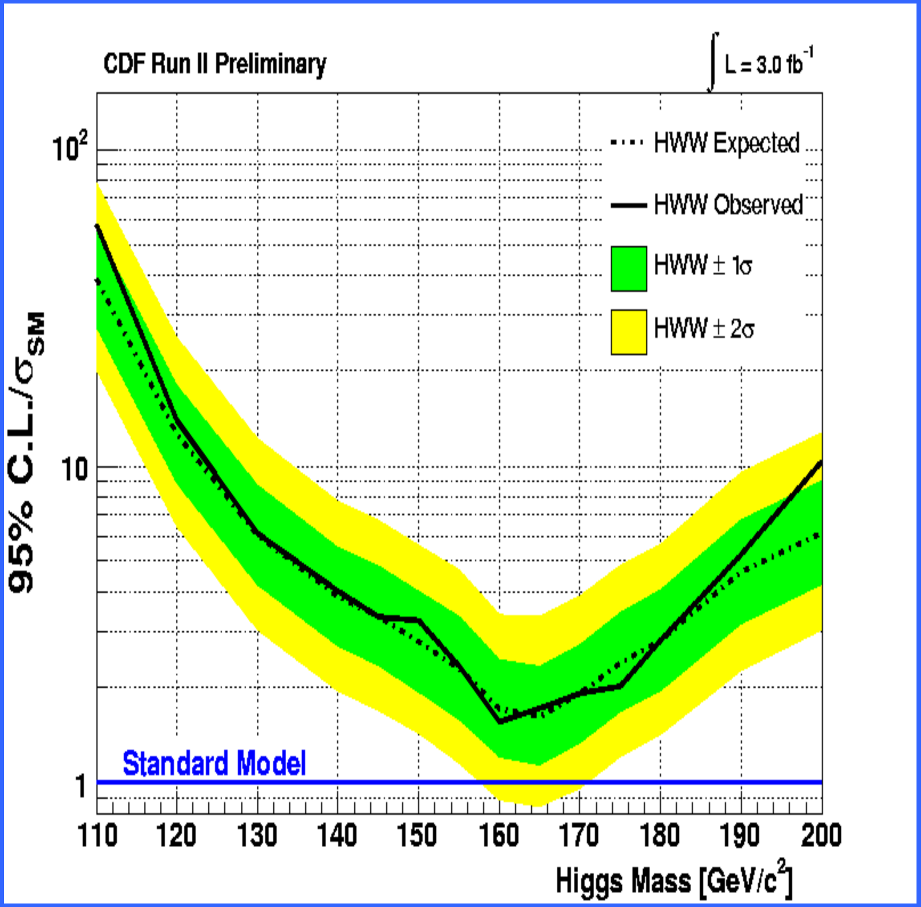


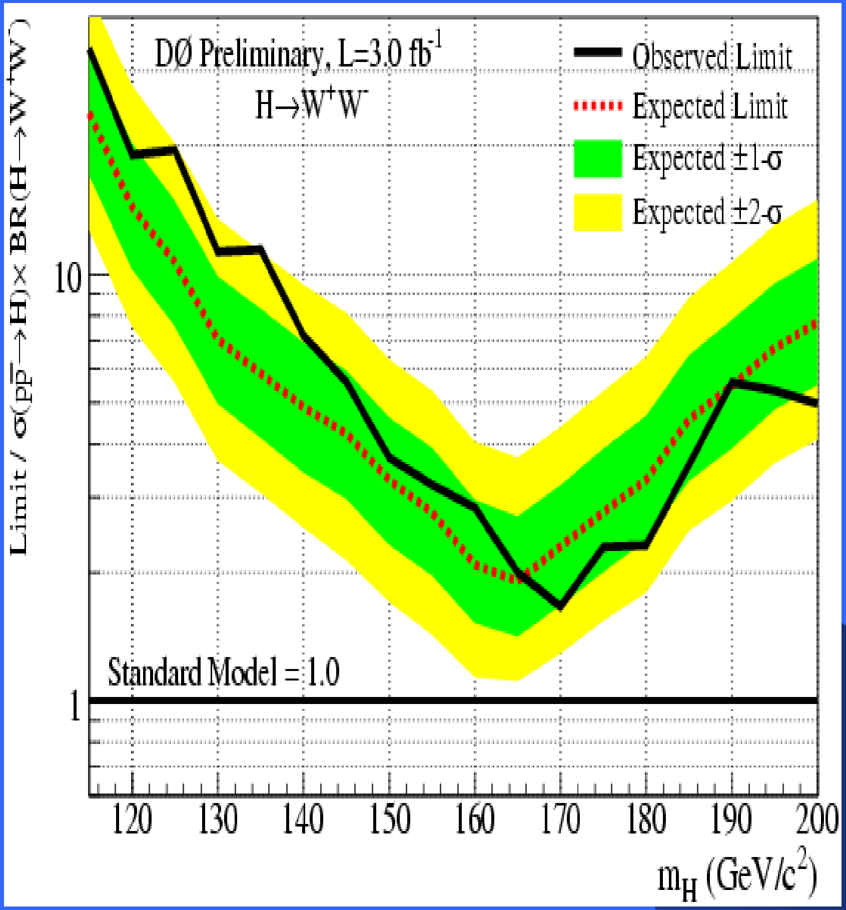
Higgs Discriminant

- Final discriminant based on NN output



H→WW*→llνν Limits

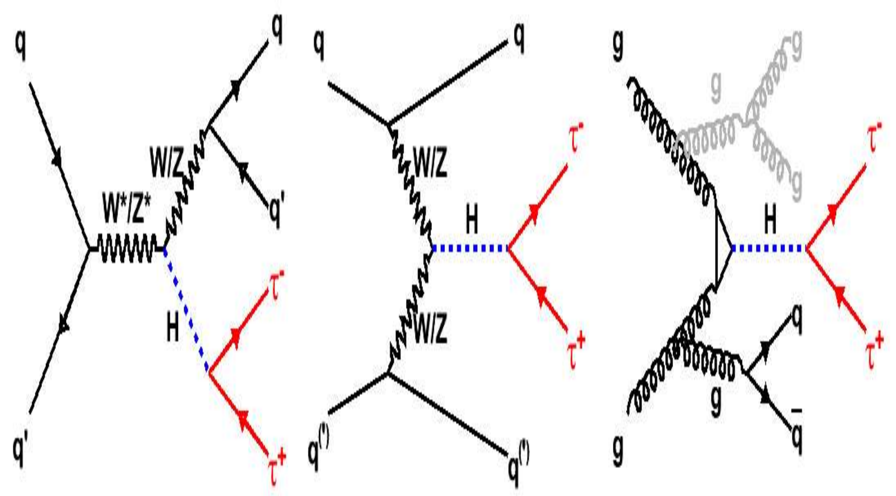


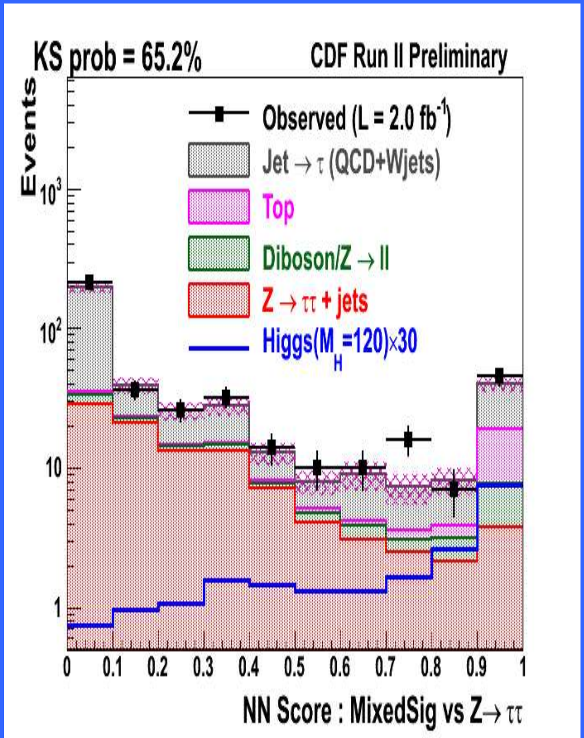


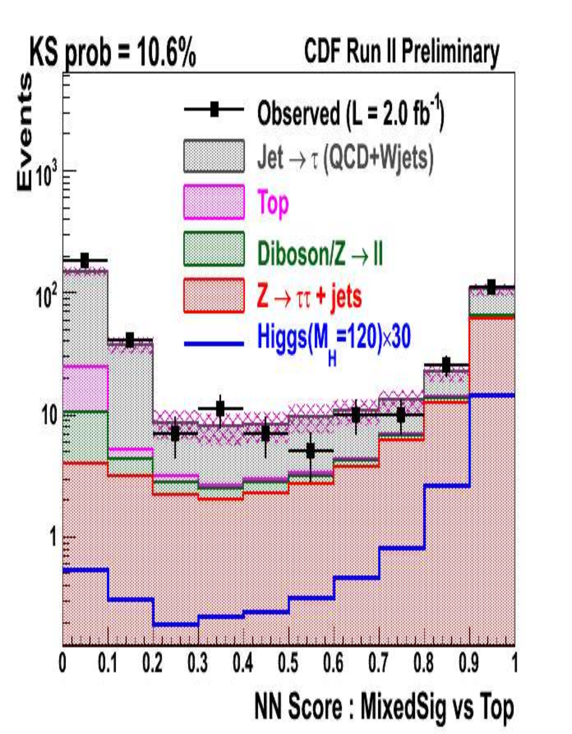
- ➢CDF obs/exp limit is 1.72/1.62 x SM @ mH =165 GeV
- ➢D0 obs/exp limit is 2.0/1.9 x SM @ mH =165 GeV
- ➢Future improvements: more data and including the same sign contributions...

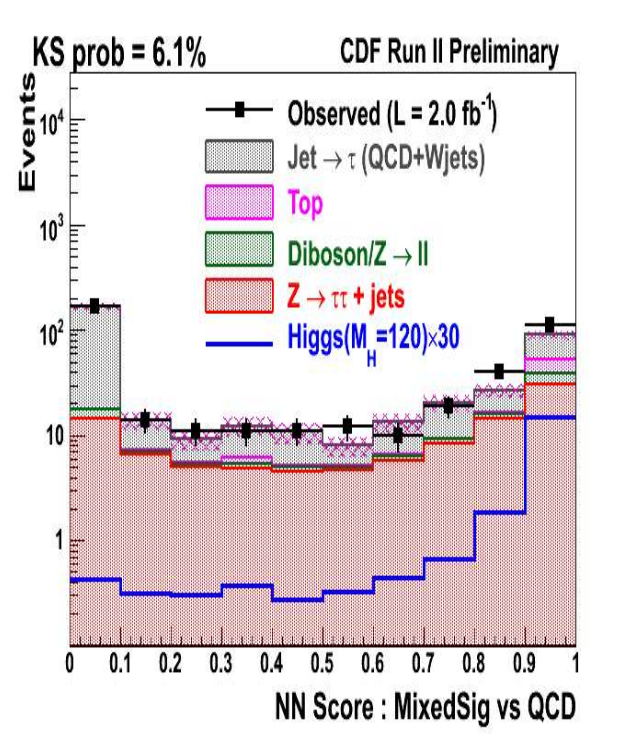
Search for (V)H→ττ +2jets

- New decay, but small Br~8%.
- H→ τ_{lep}(Pt>10) + τ_{had}(Pt>15)
- Opposite sign, not Z , +≥2 jets
- Train 3 NN(H vs DY, H vs top, H vs QCD) with m(ττ), m(lτν), other kin. variables and take the minimum score.

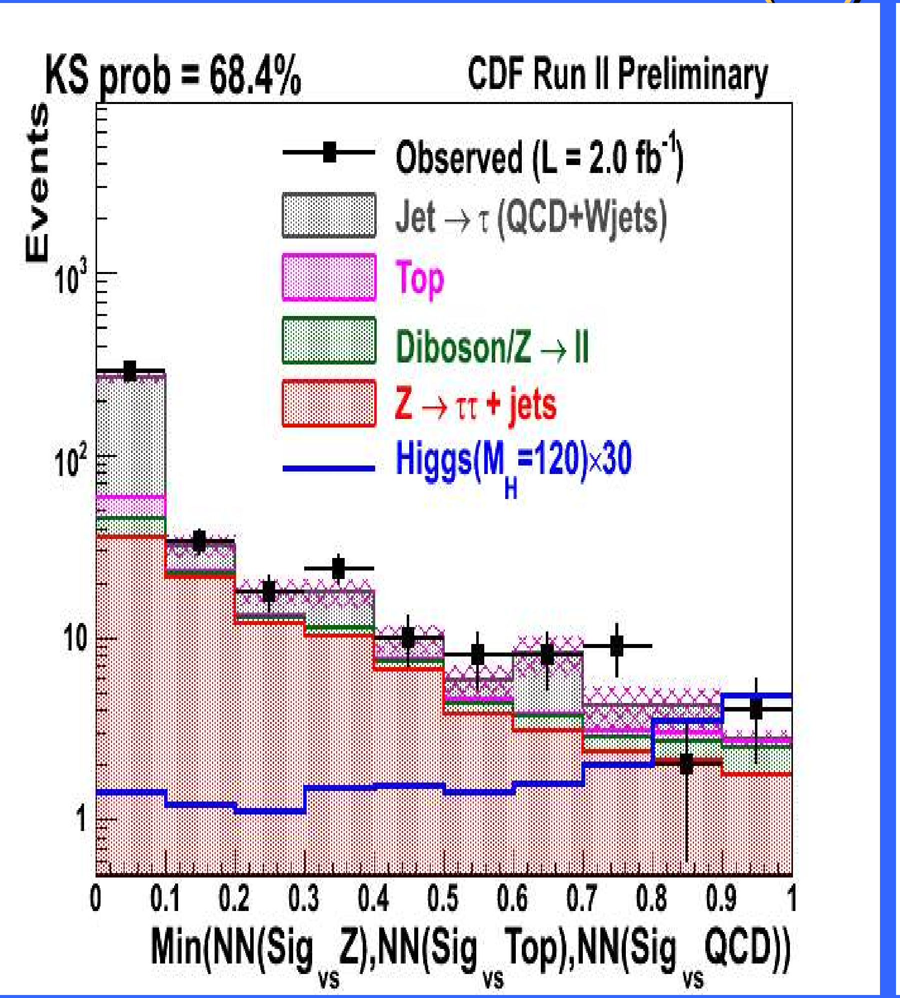


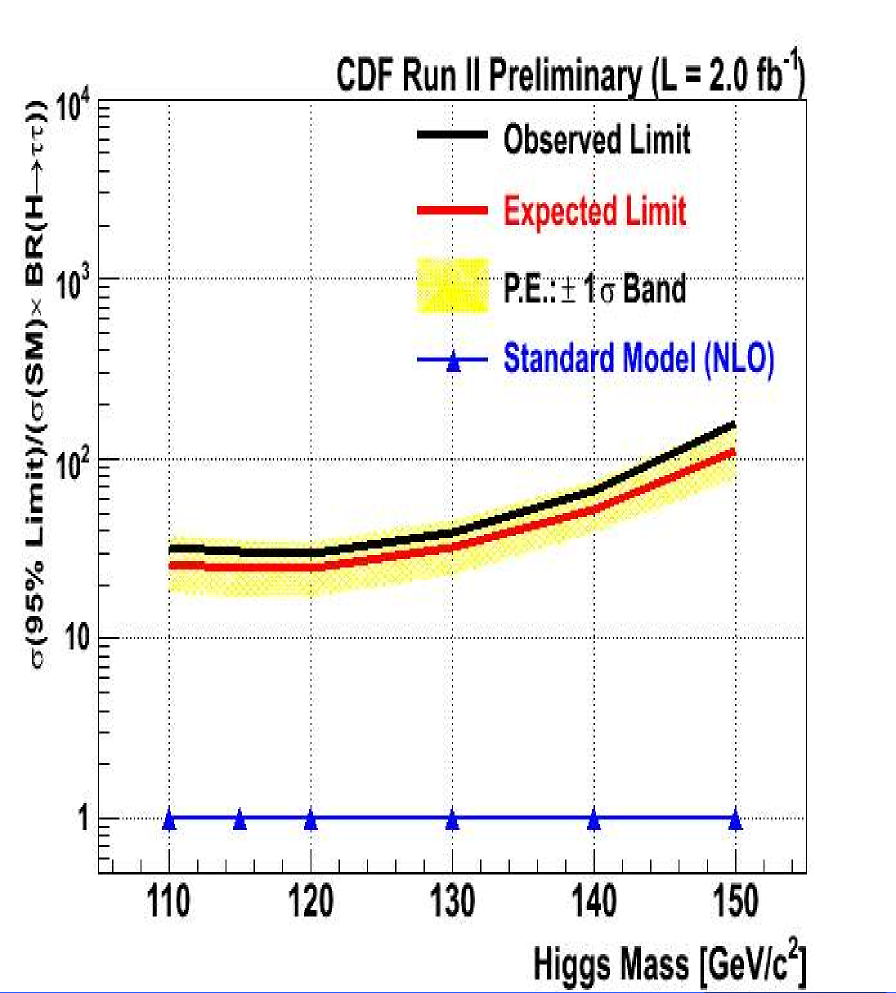






Search for (V)H→ττ +2jets

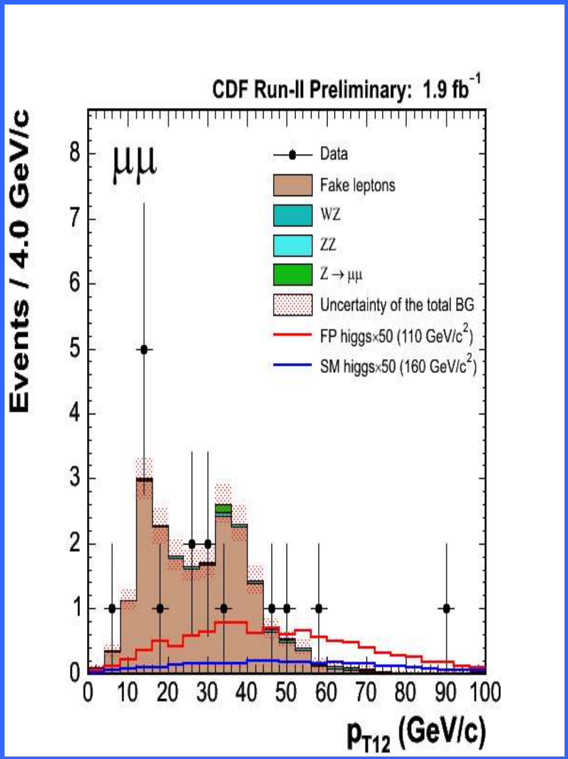


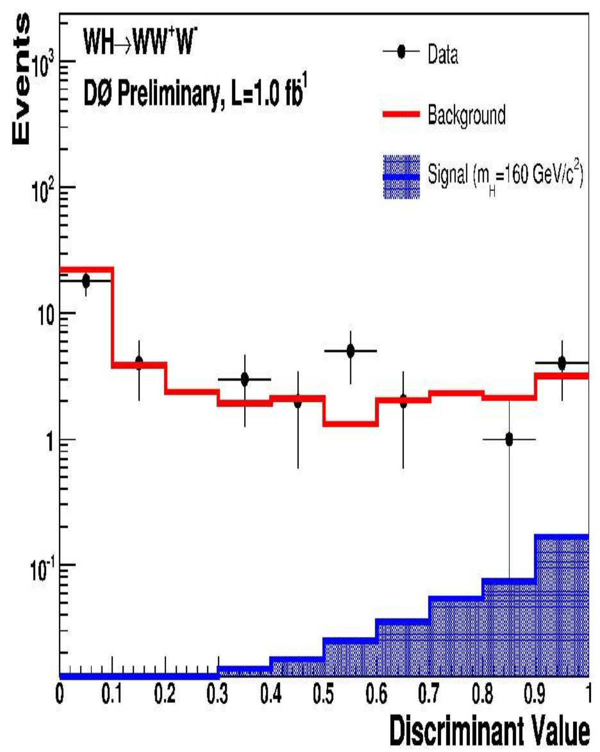


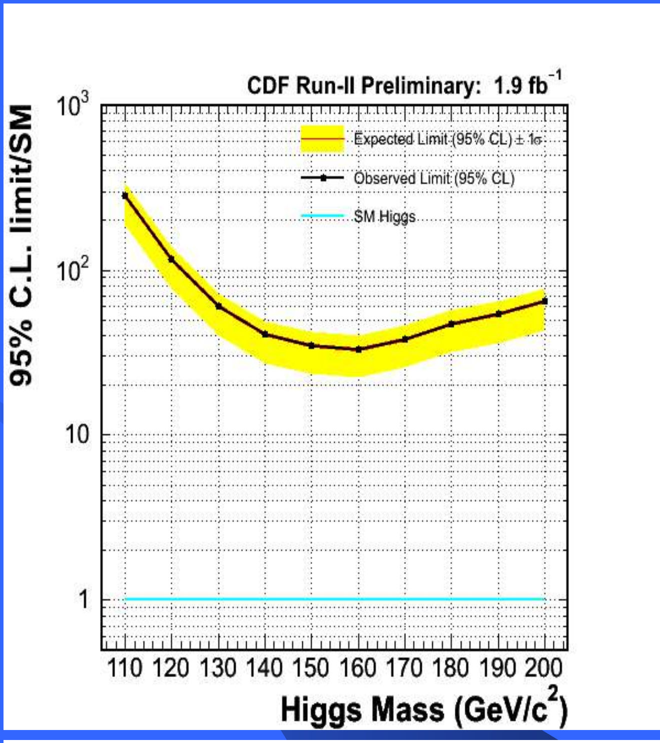
- CDF first time set H→ττ limits: 30.5/24.8 @ mH=115 GeV
- Future improvements: better trigger and optimized analysis

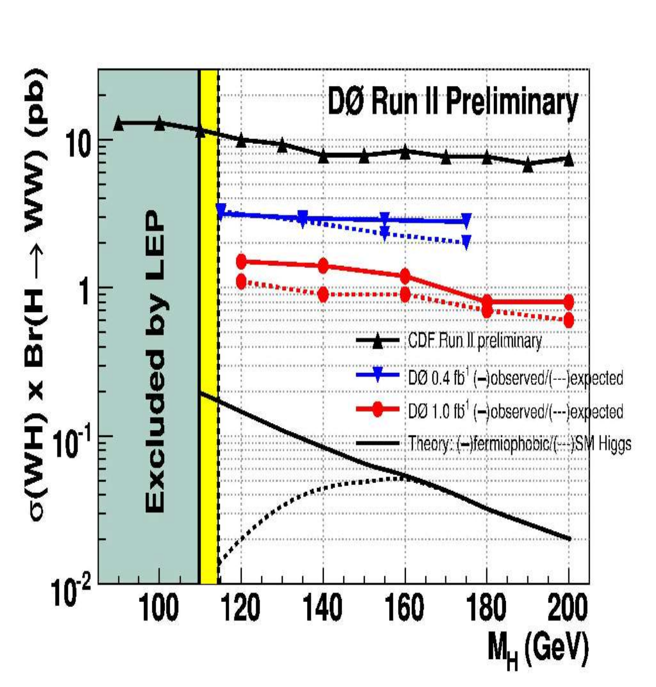
WH→WWW*→l±l±νν+X

- ➢Helps to cover intermediate mass region
- ➢Selection: two same charged lepton
- ➢Main backgrounds: WZ and fakes





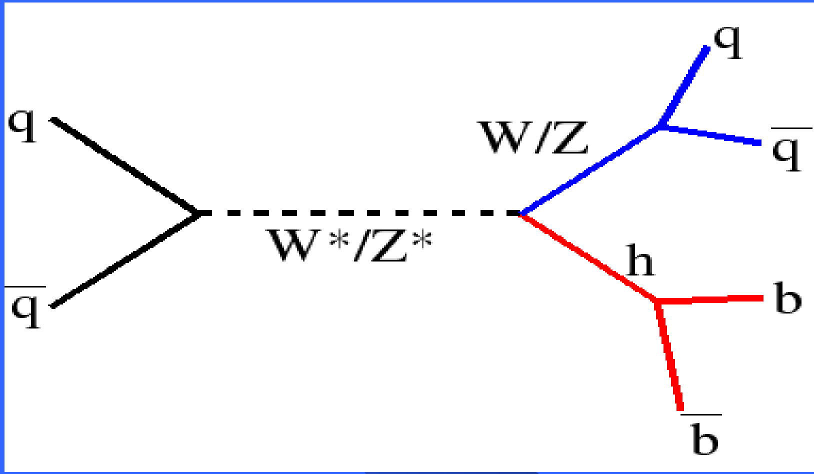


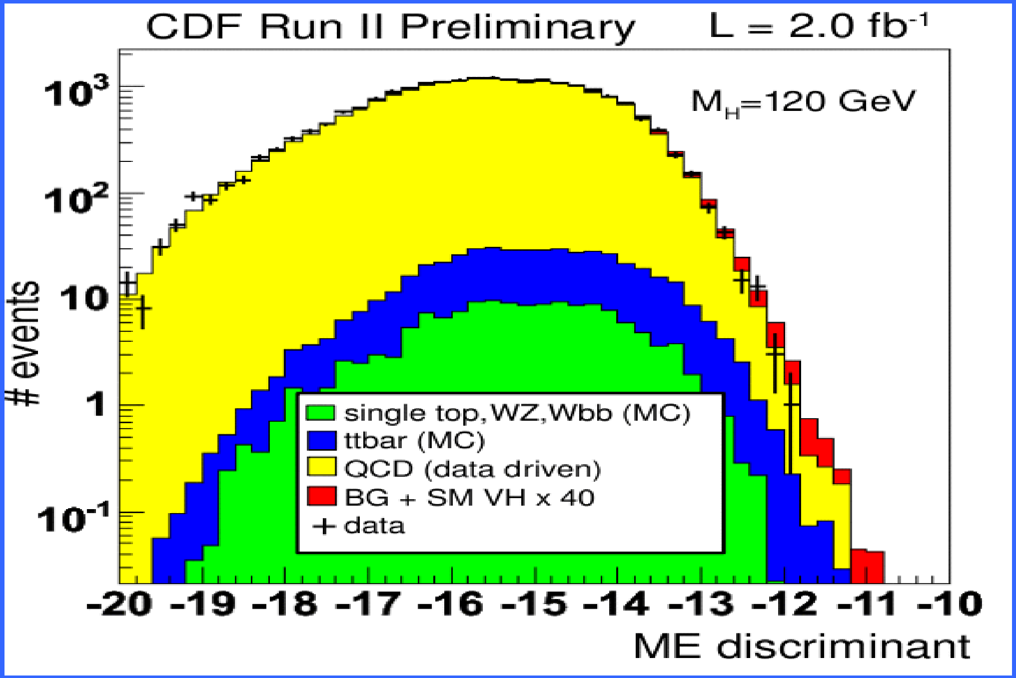


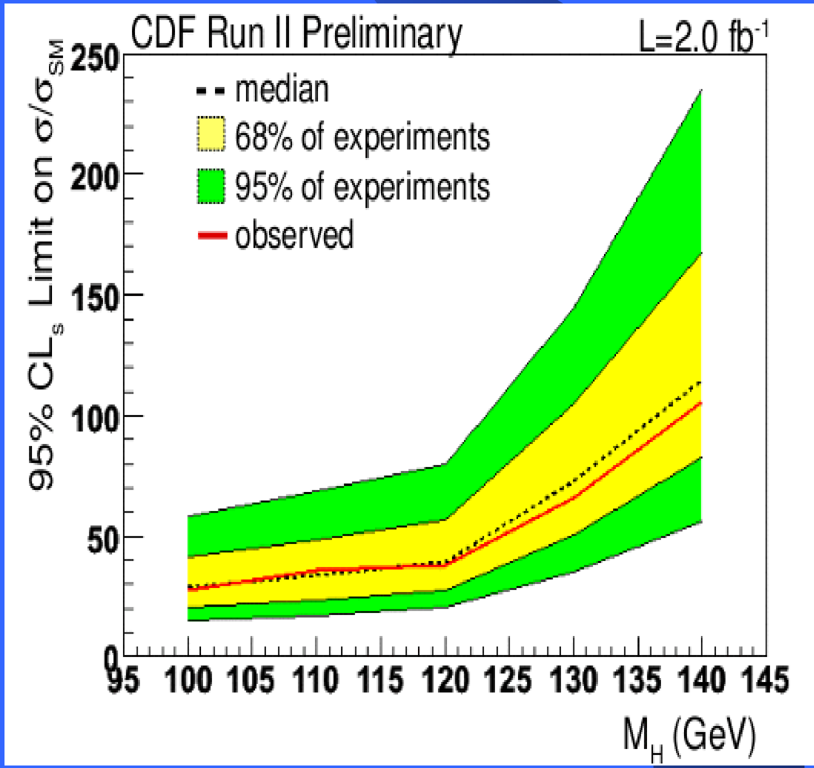
- ➢CDF obs/exp limit: 33/33 @mh=160
- ➢D0 obs/exp limits: 26.5/20 @mh=160

Search for VH→jjbb with ME

- Associated production with hadronically decaying W or Z
  - 4jets, 2 of wich are tagged
  - Large branching fraction, but huge QCD backgrounds =>S/B=5.3/21,000
  - Discriminating S from B with ME



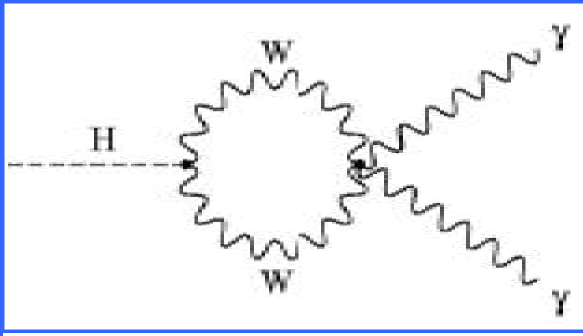


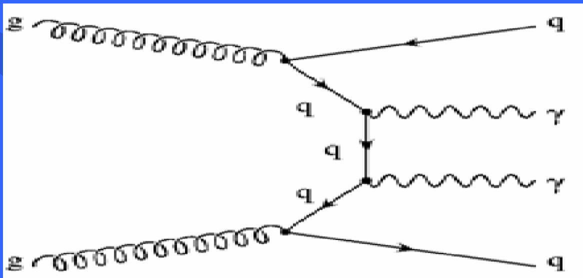


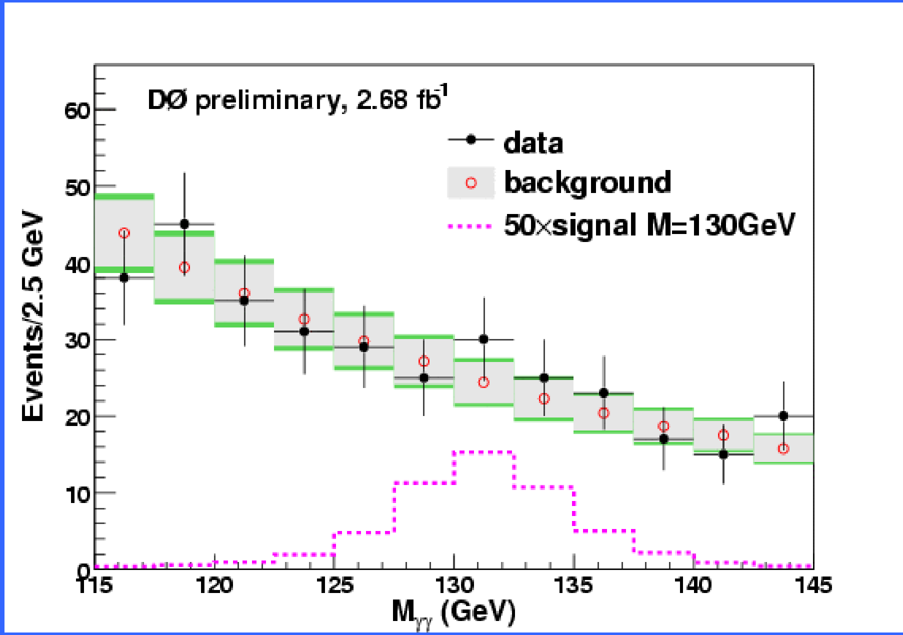
- CDF set limit: ~40 x SM @ M_H =120 GeV

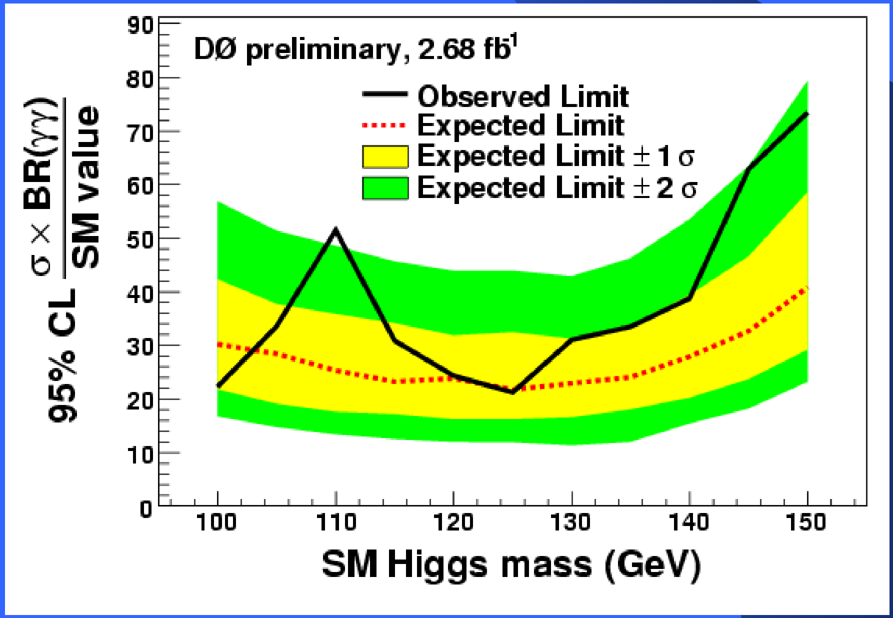
Search for H→γγ

- LHC's gold channel: low mass Higgs
- Neural net to identify photon
- Selecting 2 isolated γ with Et>25 GeV
- Look for a peak in $M_{\gamma\gamma}$ mass spectrum
- Main Backgrounds: γ+γ, DY,γ+jet, dijet







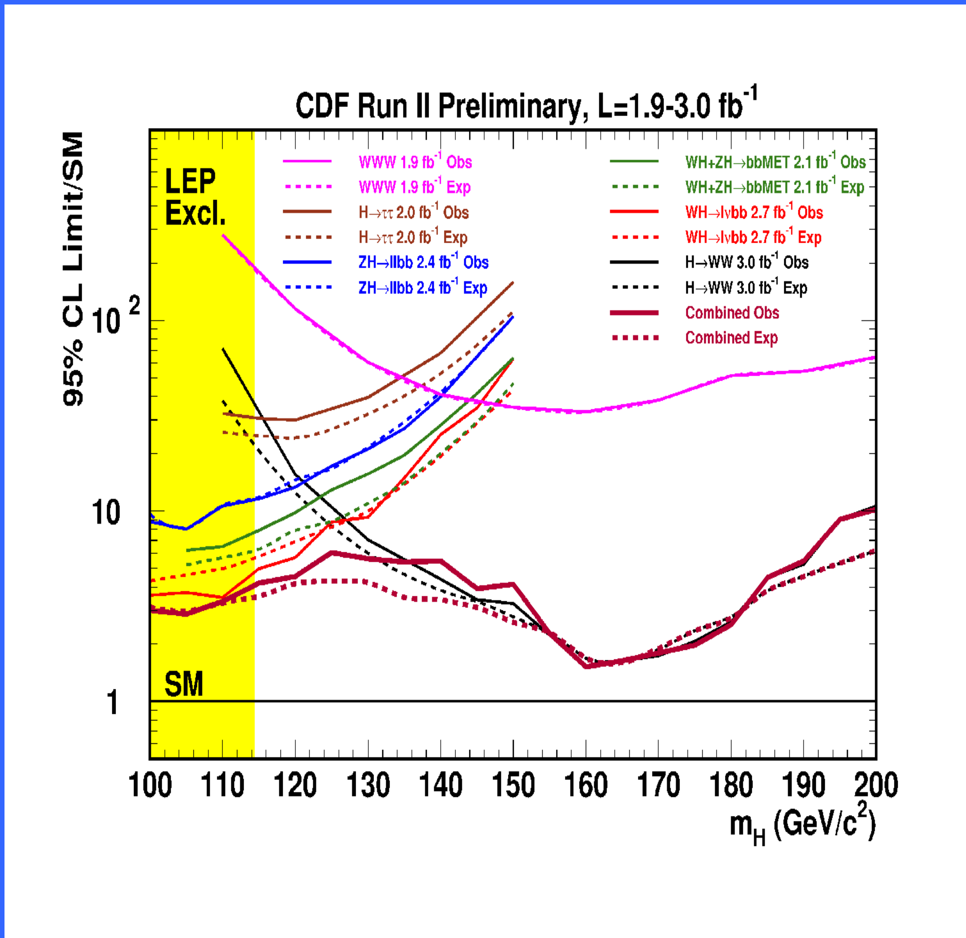


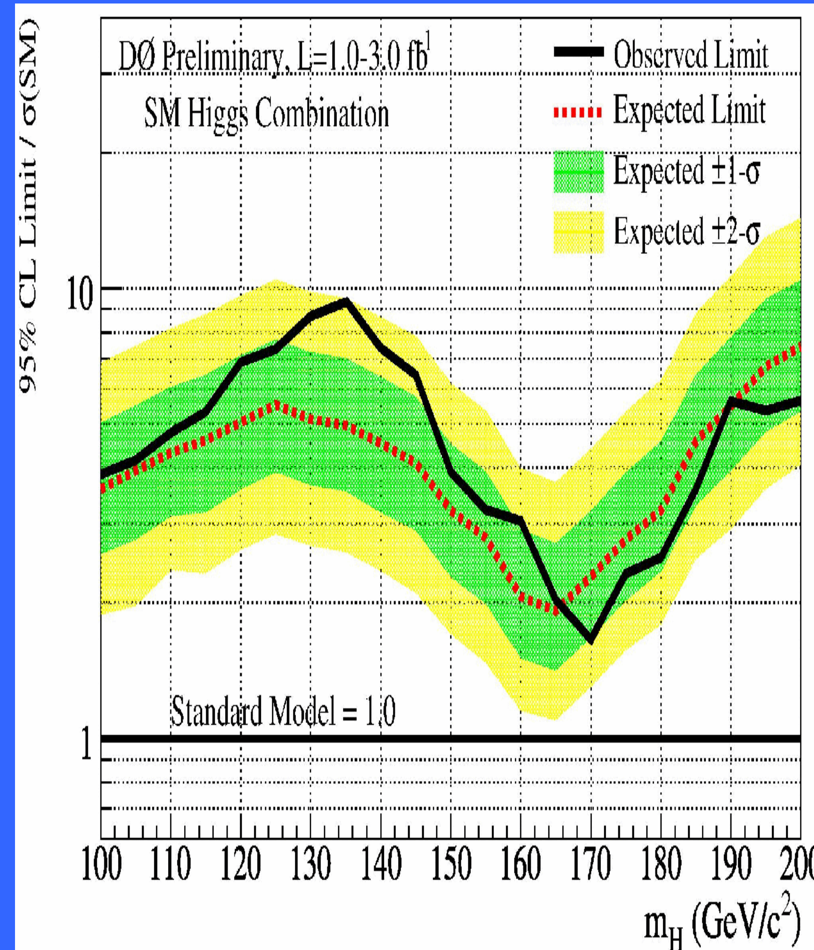
- D0 set limits: 24.3(Obs)/23.8(exp) @m_H=120 GeV

Combination Procedure

- Normalized to SM rate, we can combine σ×Br/SM statistically to improve the final result.
- Use Bayesian and Frequentist approaches:
  - Bayesian: $$\mathcal{L}(R,\vec{s},\vec{b}|\vec{n},\vec{\theta}) = \prod_{i=1}^{N_C}\prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}}/n_{ij}! \times \prod_{k=1}^{n} e^{-\theta_k^2/2}$$
  - Frequentist (CLs): $$LLR_n = 2\sum_{i=1}^{N} (s_i - n_i Log(1+\frac{s_i}{b_i}))$$
  - All systematics treated as nuisance parameters with truncated Gaussian constrain
- If the excess is significant after combination, do more checks to make sure not statistic fluctuation.
- If no excess, set 95% CL upper limit vs m_H

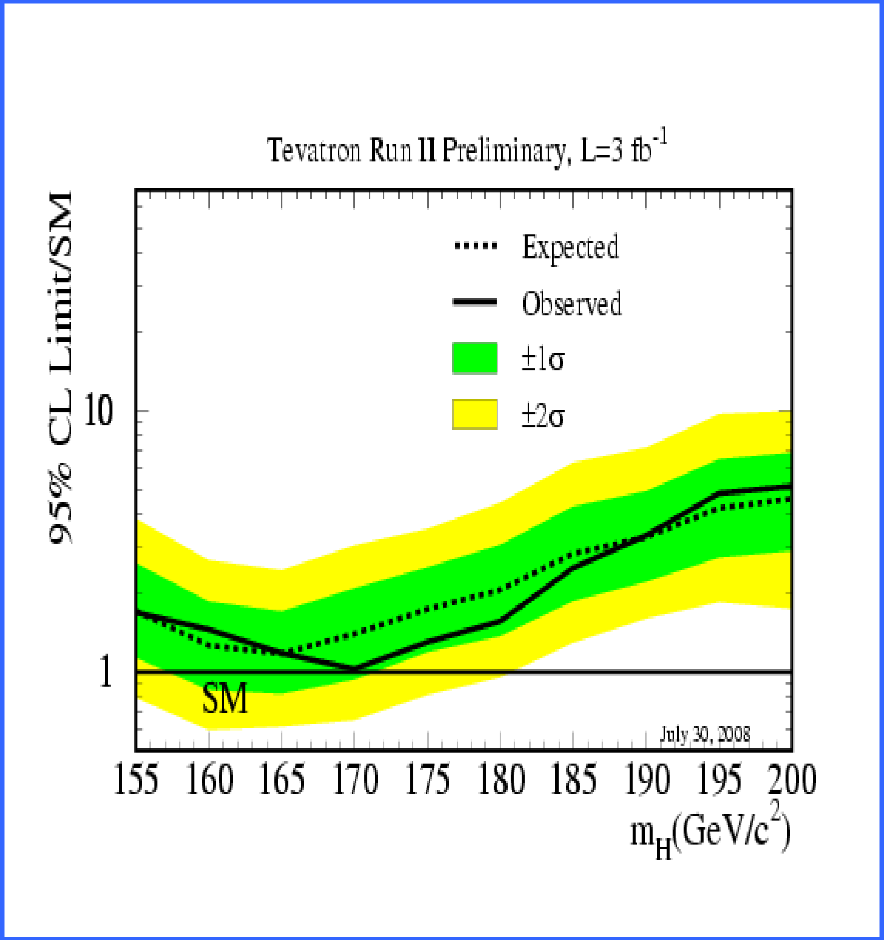
CDF and D0 Combined Limit (ICHEP08)

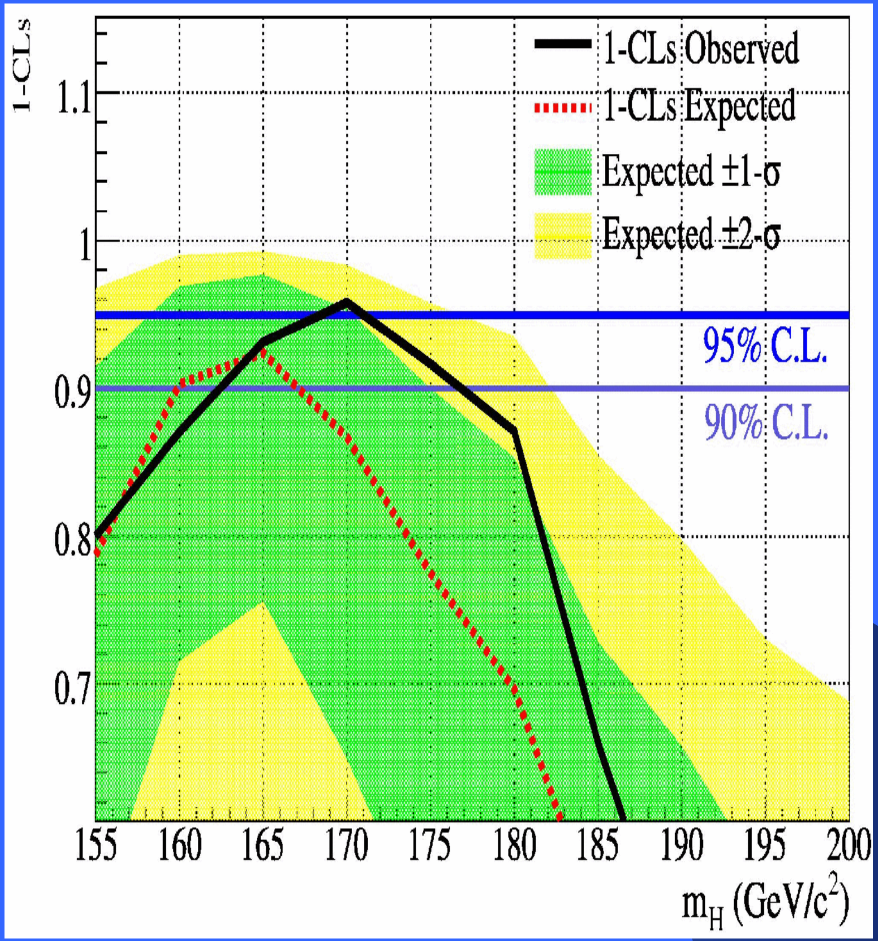




- **Both Collaborations give comparable Observed(Expected) limits:**
  - **CDF: 4.2(3.6) & 1.64(1.60) for mh=115 & 165 GeV**
  - **D0: 5.3(4.6) & 2.0(1.9) for mh=115 & 165 GeV**

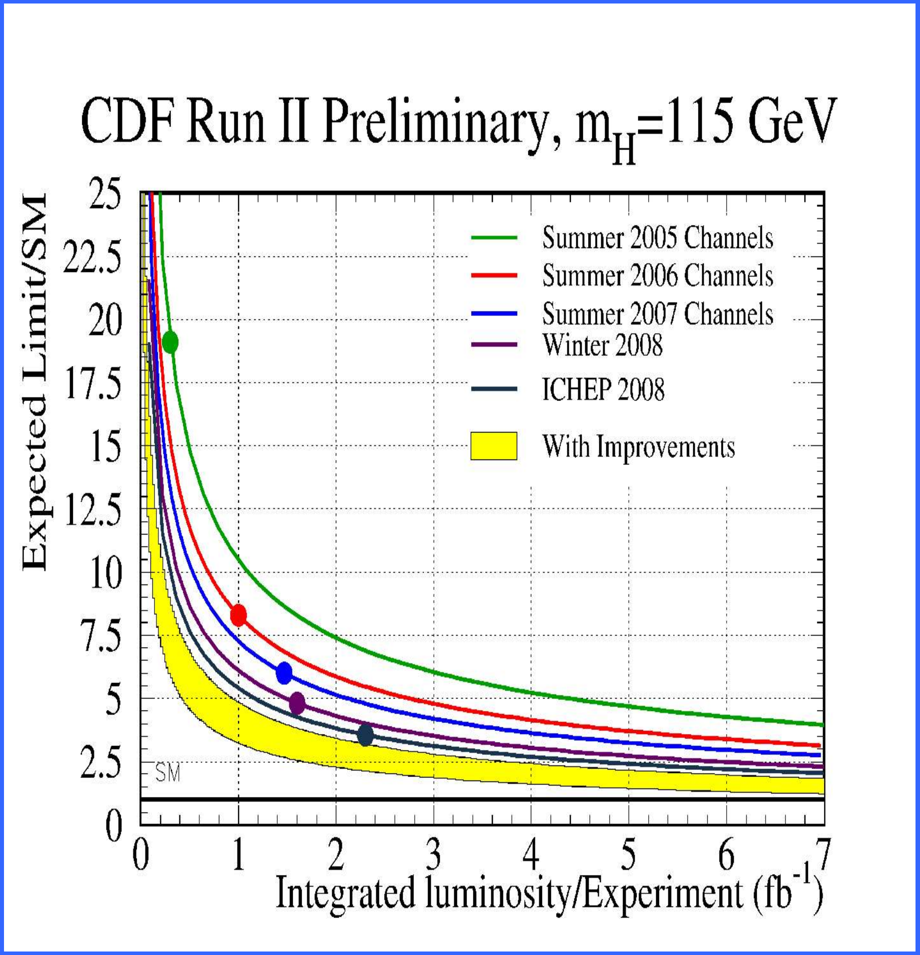
Tevatron Combined SM Higgs Limits

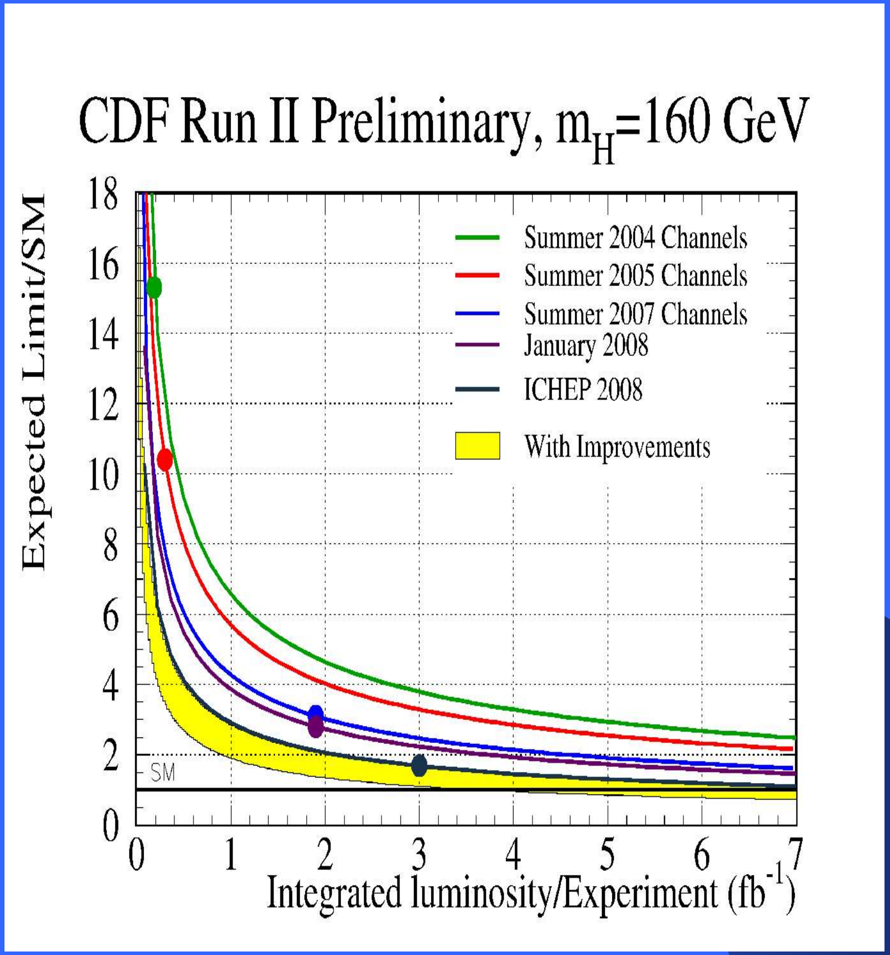




- Tevatron excluded the SM higgs mass at 170 GeV first time.
- obs/exp =0.95/1.3 x SM @ 170 and more exclusion is expected with more data.

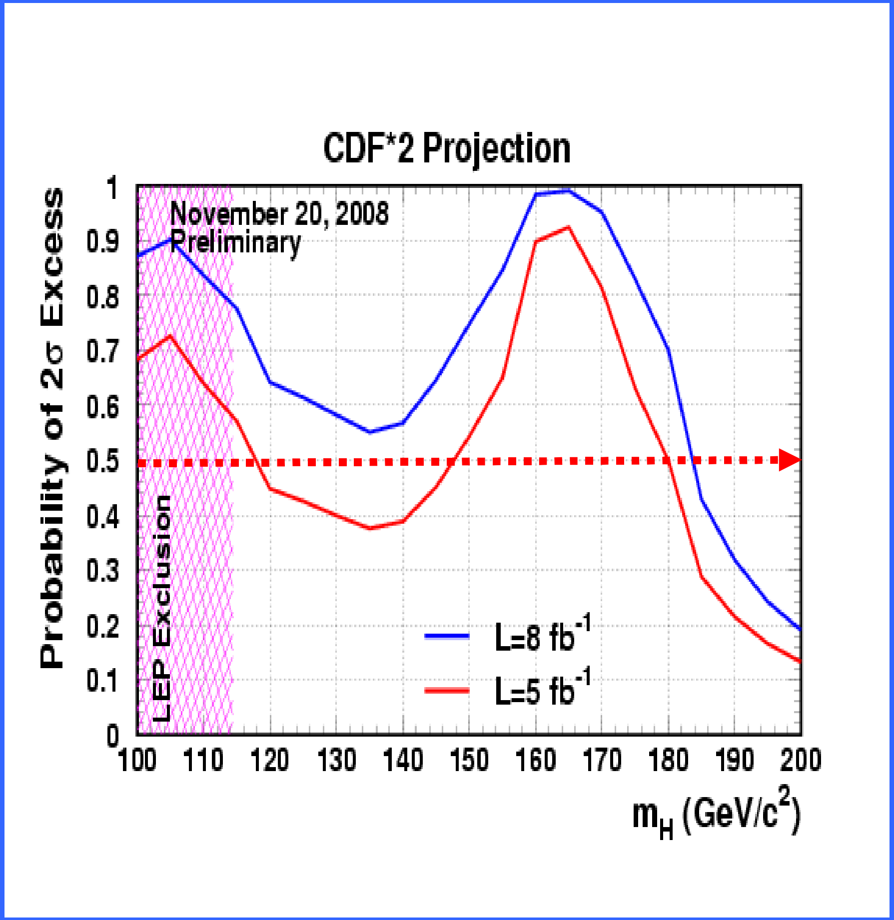
Tevatron Sensitivities

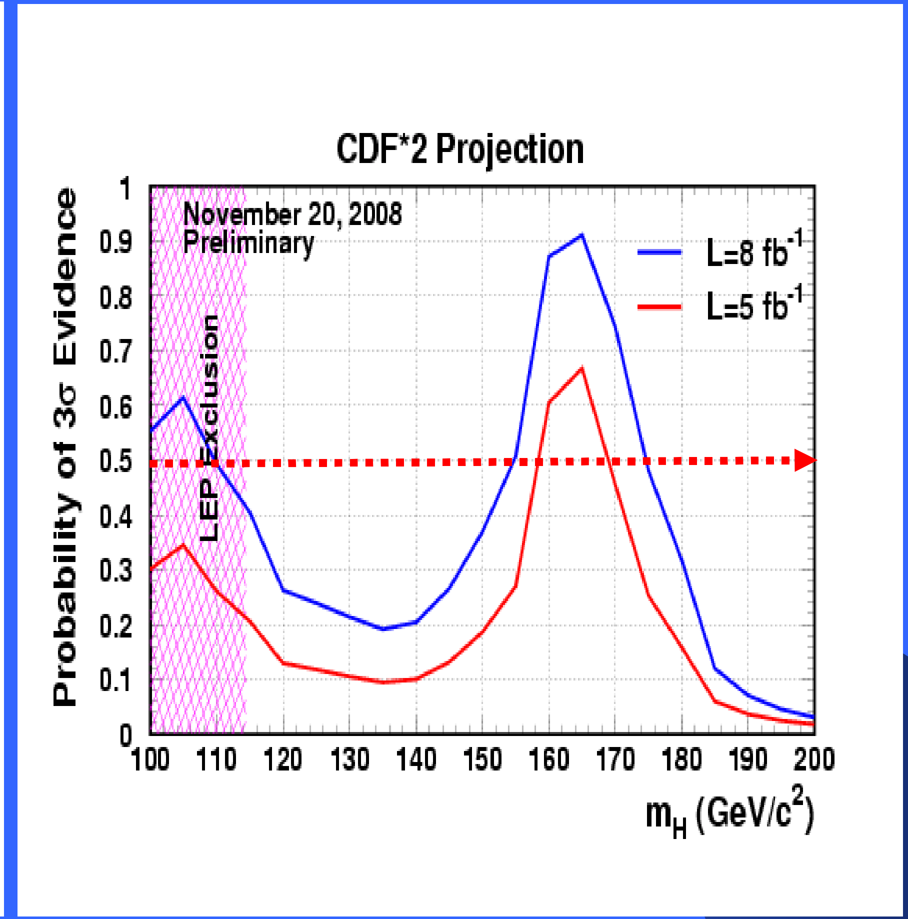




- **The Higgs sensitivity improves better than 1/sqrt(L) over time**
  - **with more data, new ideas**
  - **more advanced analysis techniques.**

Future Prospects





- With 8 fb^{-1} data, Tevatron would
  - either exclude Higgs mH<180 @ 95% C.L.
  - or find 3-σ evidence Higgs near mH=160 GeV.

Conclusions

- We have excluded the Higgs at 170 GeV for the first time and are closing in towards in low mass Higgs.
- There is no magic bullet, 10% effects matter most and no stone is left unturned.
- CDF have improved the sensitivity by a factor of 2 over the gaining of luminosity since summer 06 and expect the trend will continue in next two years.
- Another factor of 2 improvement over the current analysis by 2010 will put the Tevatron within a reach of 3 σ evidence for Higgs mass near 160 GeV
- This is very exciting time for Higgs search at Tevatron

BACKUP

Extended Lepton Coverage with Isolated Track(CDF)

- Identify high-Pt, isolated track lepton not fiducial to μ chamber
- Require $\Sigma Pt/Pt_{cand} < 0.1$
- New trigger: Met+2jets(>40)
- 25% increase in WH→lνbb acceptance with similar purity