Higgs Searches at D0

On behalf of the D0 collaboration

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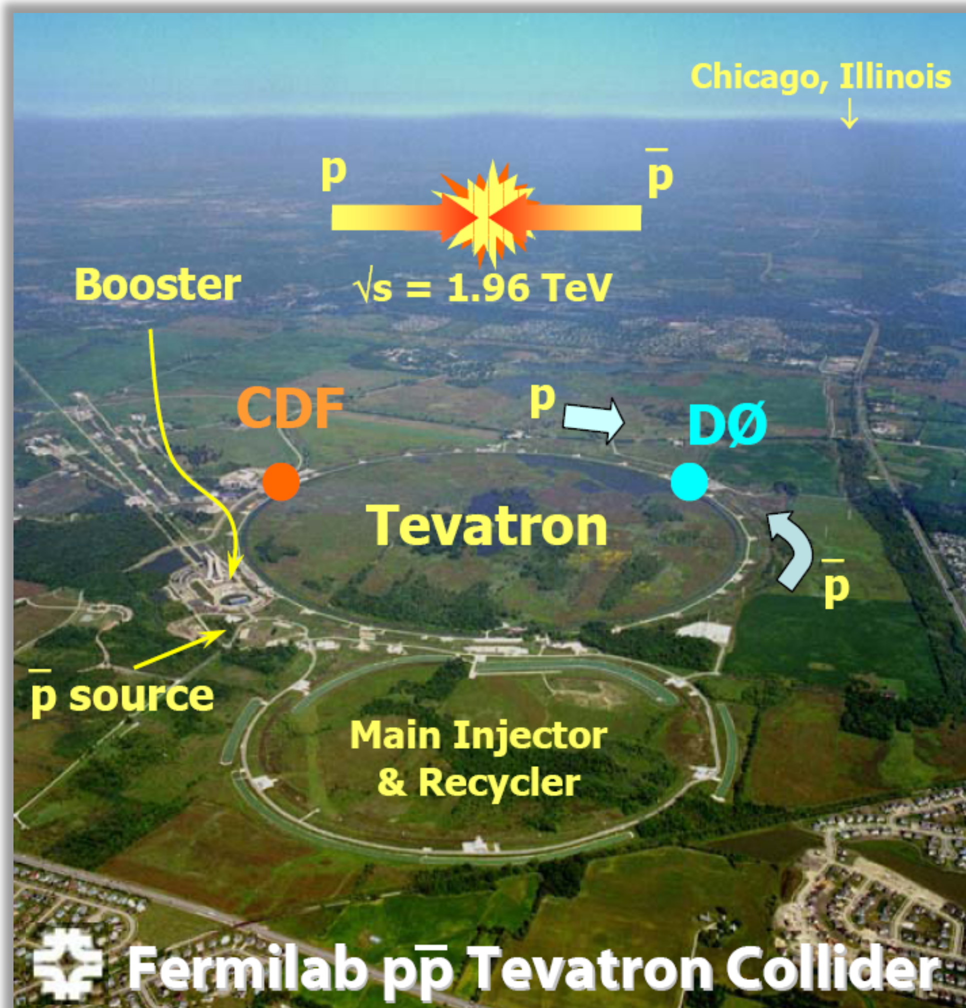
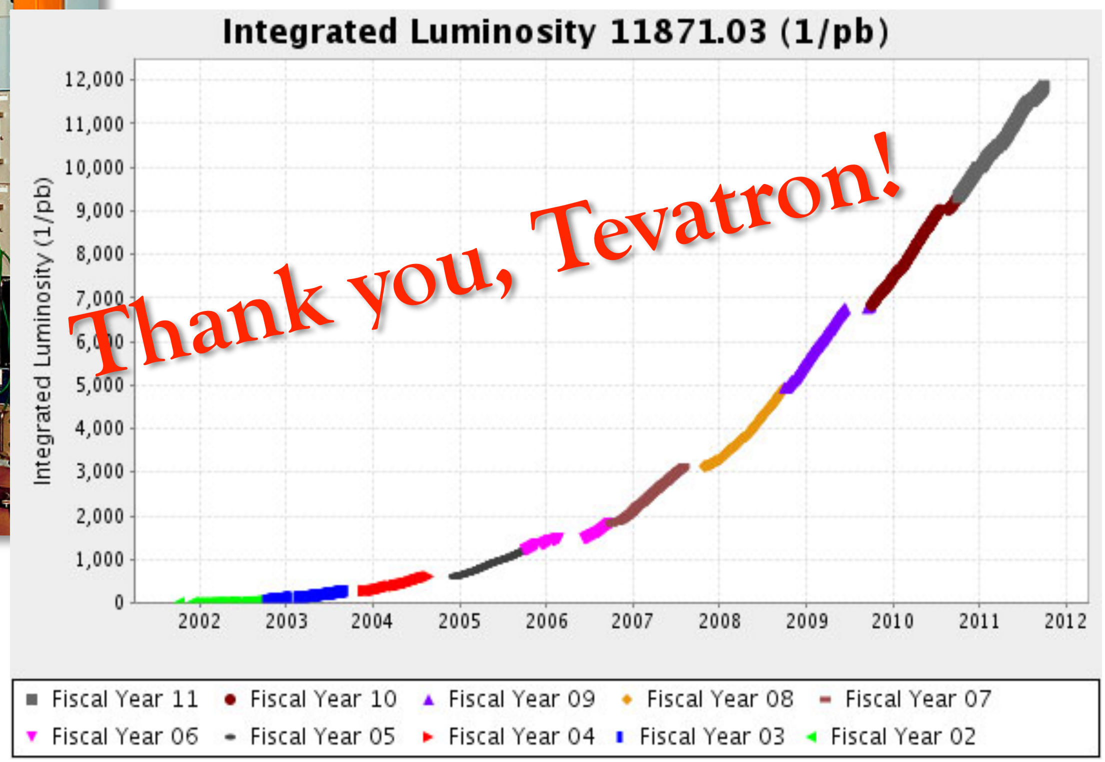
Outline of Talk

- Introduction
- Higgs Production and Decay
- Analysis Method
- Searches for the SM Higgs boson
  - $H \to WW \to l\nu l\nu$
  - $WH \to l\nu bb$
  - $ZH \to llbb$
  - $ZH \to \nu\nu bb, WH \to (l)\nu bb$
  - $H \to \gamma\gamma$
- Putting all together
- Diboson production
- Conclusions



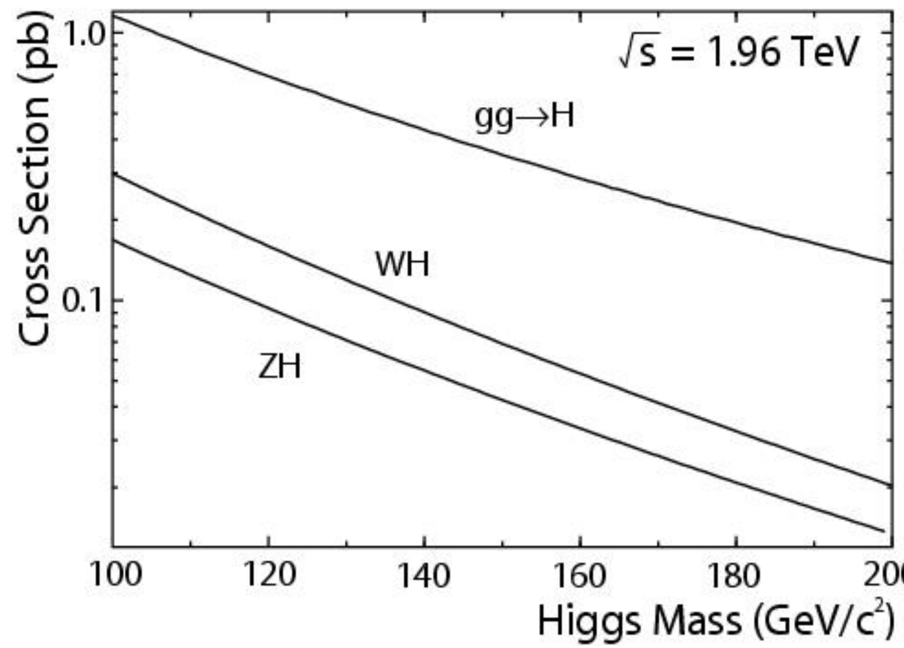
Introduction

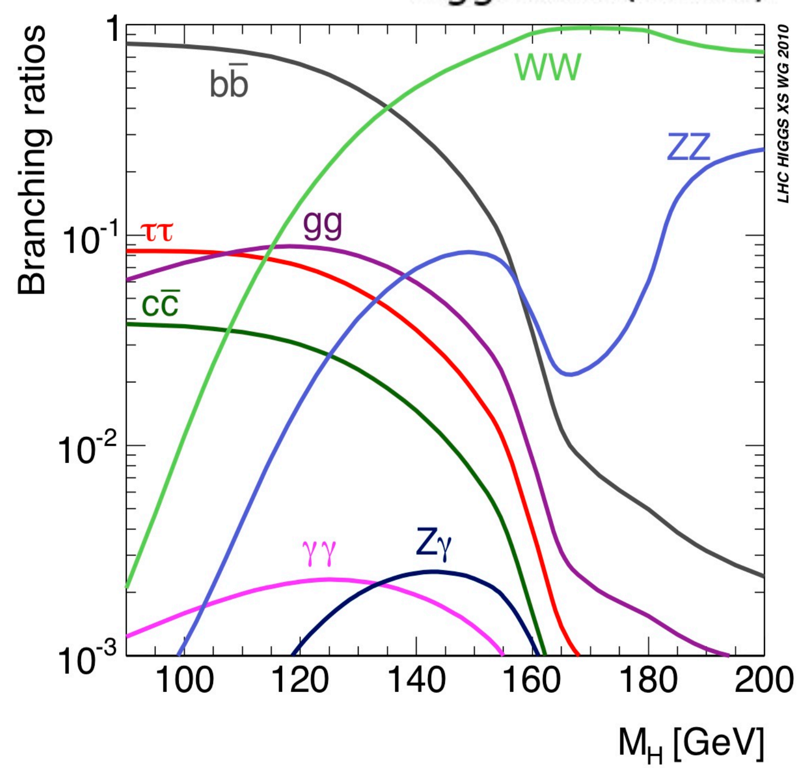
- Tevatron shut down after delivering 11.9 fb^{-1} of collisions.
- D0 recorded 10.7 fb^{-1}.
- After removing bad runs, we have 9.7 fb^{-1} of good data.



Higgs Production and Decay

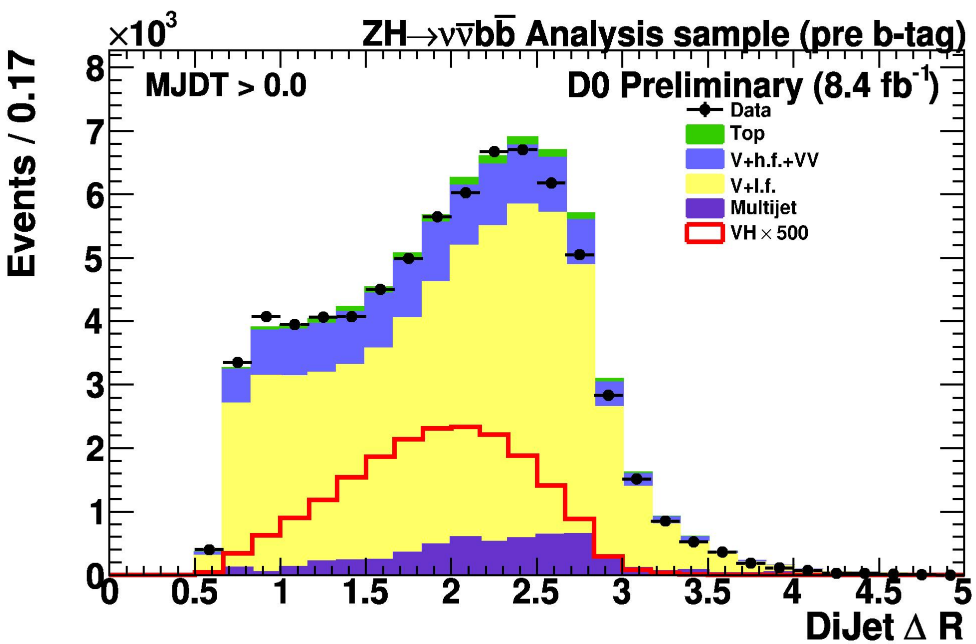
- Small production cross-sections
  - 0.1 –1 pb
- Branching ratio dictates search
- $m_H < 135$ GeV
  - gg → H → bb overwhelmed by multijet (QCD) background
  - Associated WH & ZH production with H → bb decay
- $m_H > 135$ GeV
  - gg → H → WW

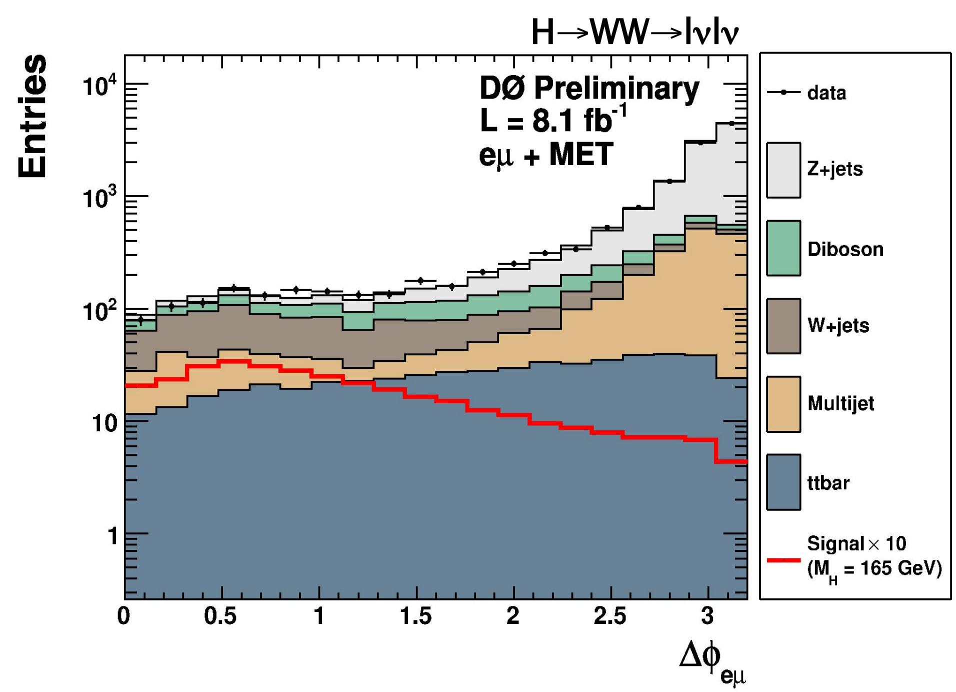




Analysis Method

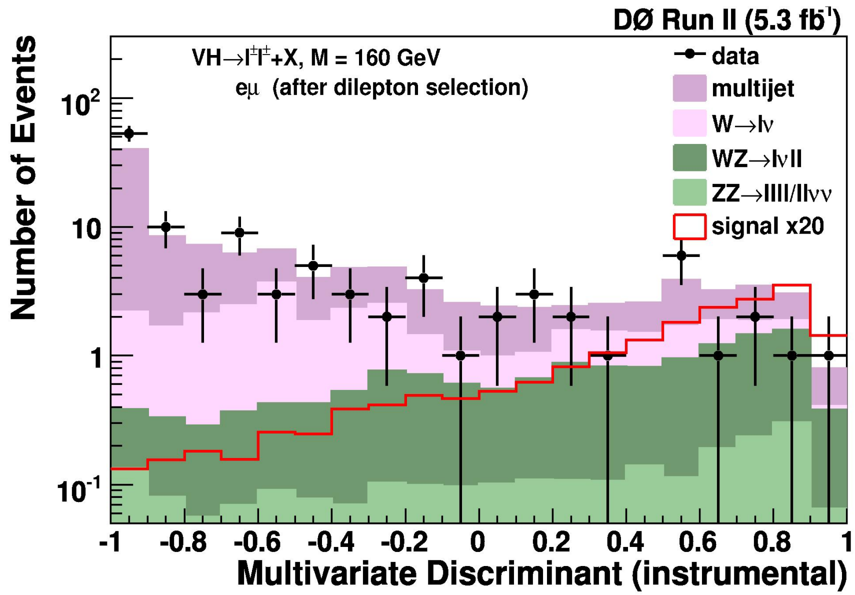
- Many years of continuing searches have built a wealth of knowledge base.
- Analyses use multivariate techniques (NN, Decision Trees, etc) to separate signal from background.
  - Input variables for MV discriminants
    - Single particle kinematic variables: p_T, η, b-tag output, MET, METsig, etc.
    - Multipartile kinematic variables: m_{jj}, $\Delta\eta_{jj}$, $\Delta\phi_{jj}$, ΔR_{jj}, dijet p_T, etc.

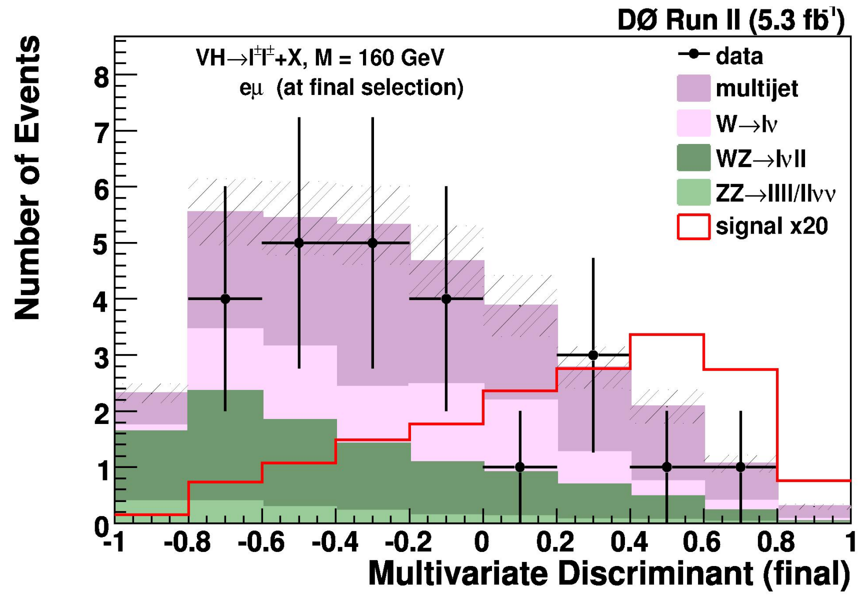




Analysis Method

- Multiple MV discriminants used
  - To reduce specific background that may hinder the performance of the final discriminant.
  - To differentiate the remaining background and signal.

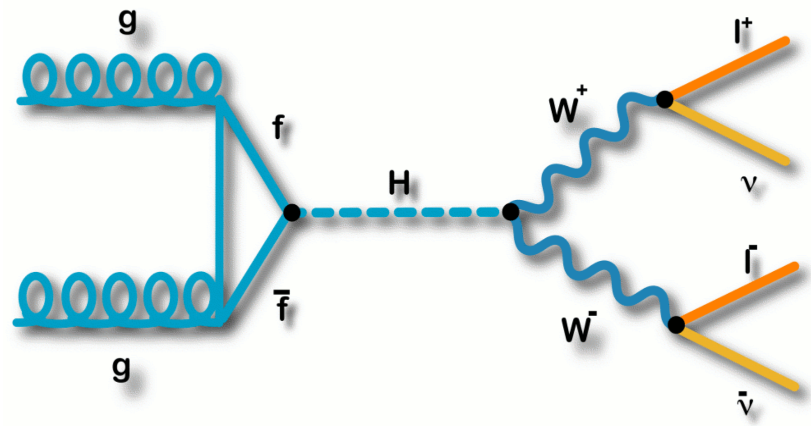


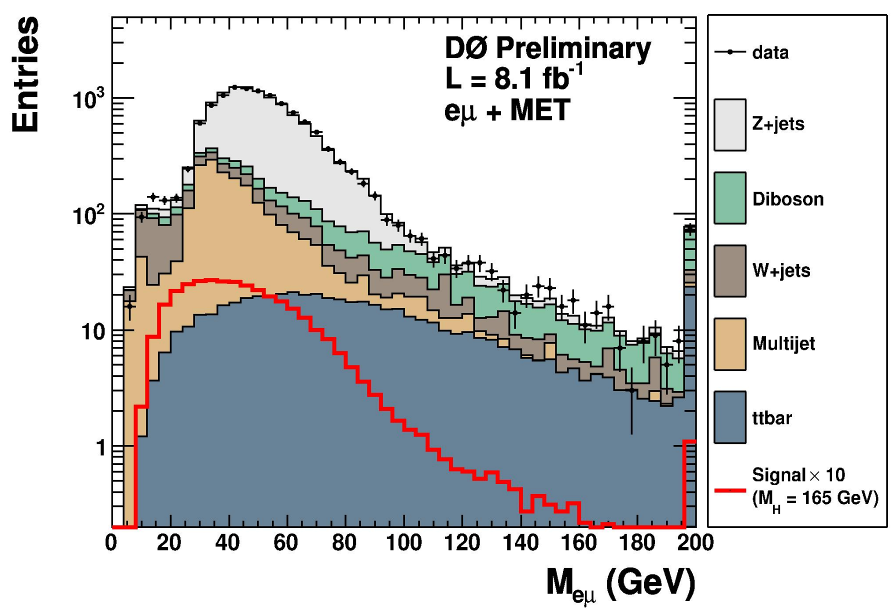


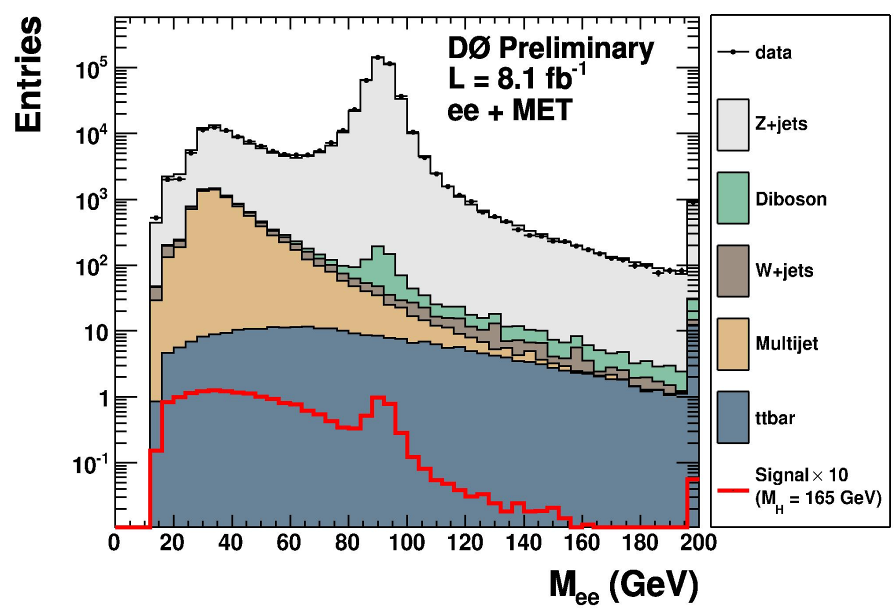
- Background modelling
  - To obtain the best possible performance from the MVA methods, the background model must describe data well.

H→WW→lνlν

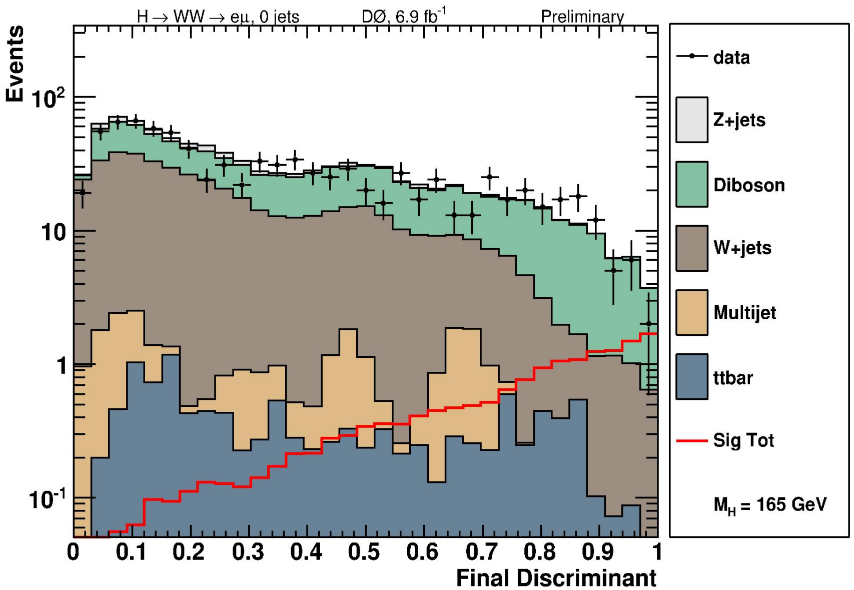
- Large cross section and small branching ratio
- Event selection
  - Two isolated leptons (oppositely charged), missing E_T(MET), 0, 1 or 2 high p_T jets
- Background
  - Z/γ, diboson, W+jets, multijet, ttbar





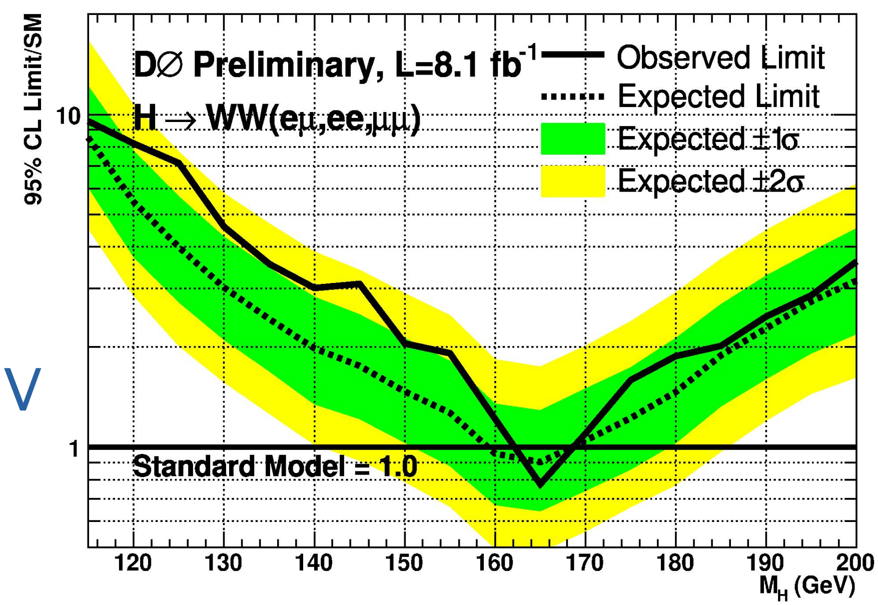


$H \to WW \to l\nu l\nu$



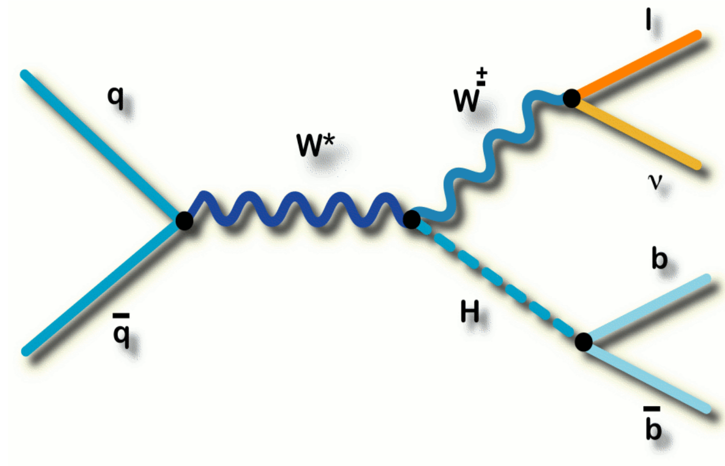
- DY DT to remove Z/γ from ee and $\mu\mu$ channels using MET, M_T^{min} and $\Delta\phi_{\mu\mu}$ etc.
- W+jets and diboson are most significant background.
  - Reduction of e-fake crucial in ee and eμ
- S/B ~1/50(eμ)

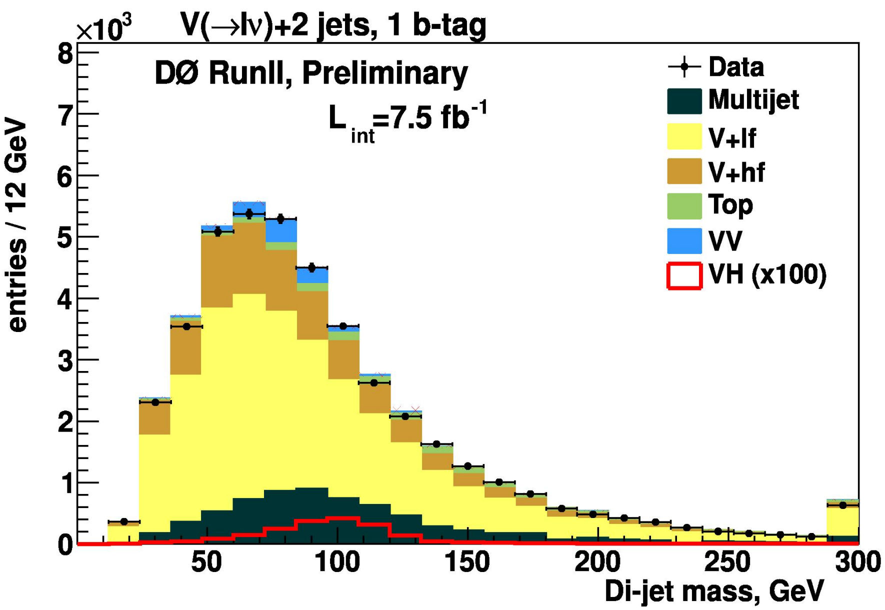
- No signal observed.
- Set upper limits on the cross section, using MV discriminant.
- SM Higgs boson with m_H=165 GeV is excluded at 95% CL.

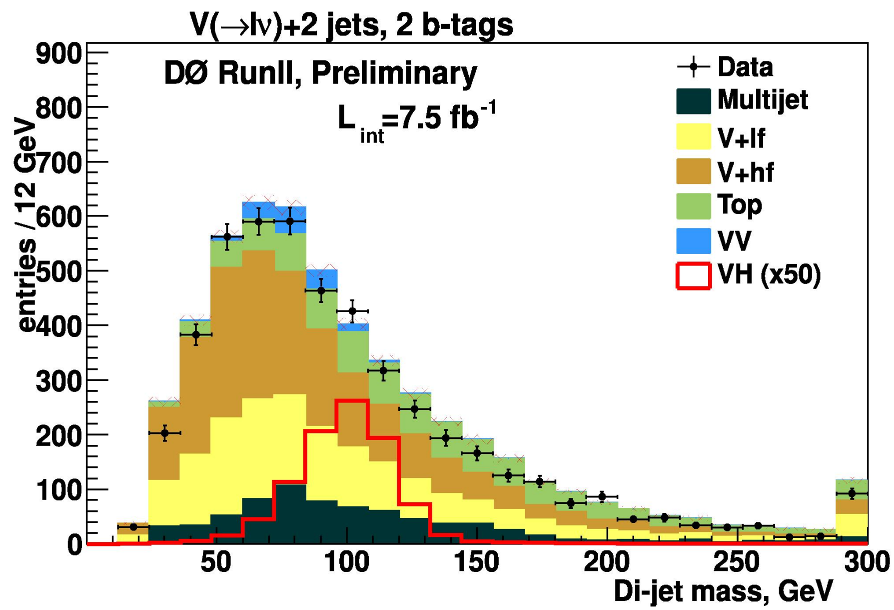


WH→lνbb

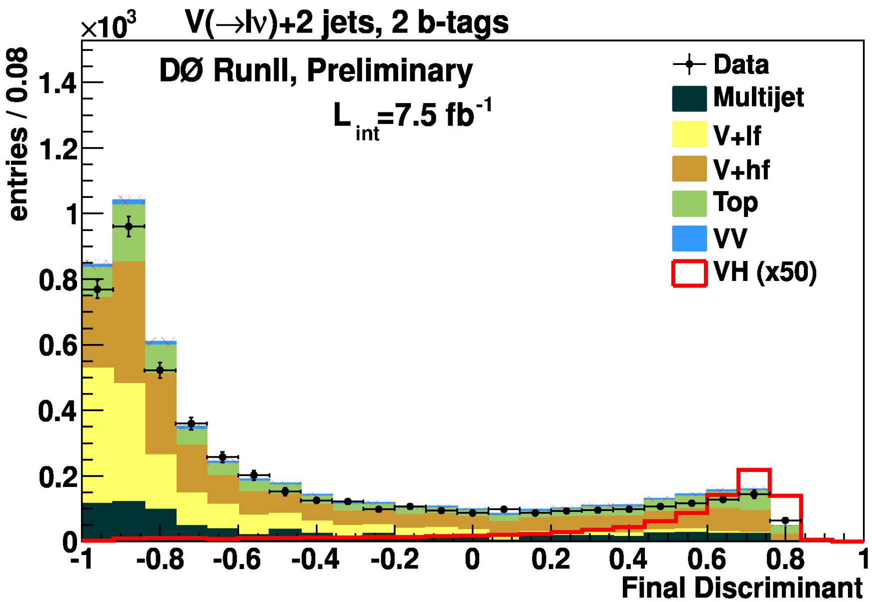
- Larger cross section than ZH
  - Use electron and muon channels
- Selection
  - Isolated single lepton, missing E_T(MET), 2 or 3 high p_T jets with 1 or 2 jets b-tagged
  - Separate 1 "tight" & 2 "loose" b-tag channels
  - S/B~1/50(double tag)

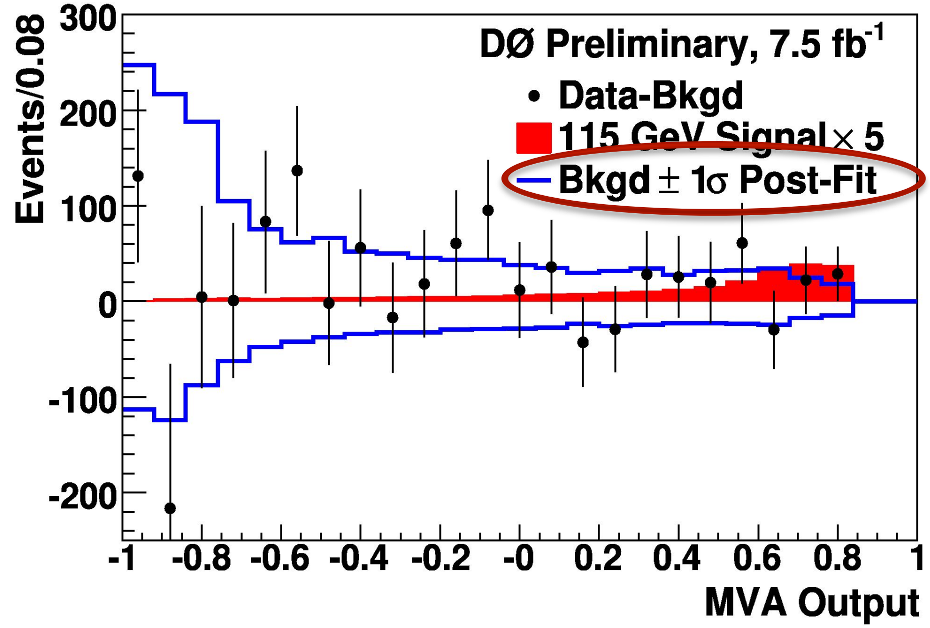




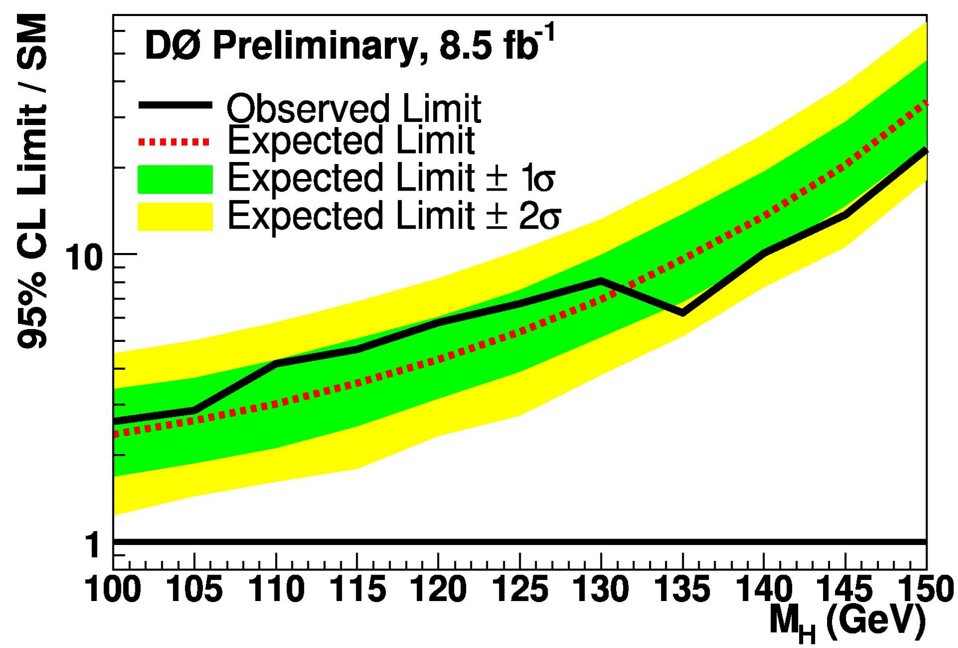


WH→lνbb



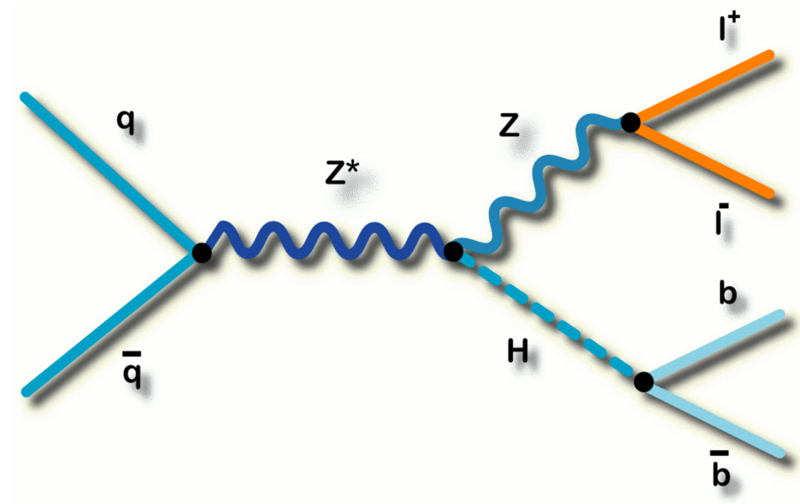


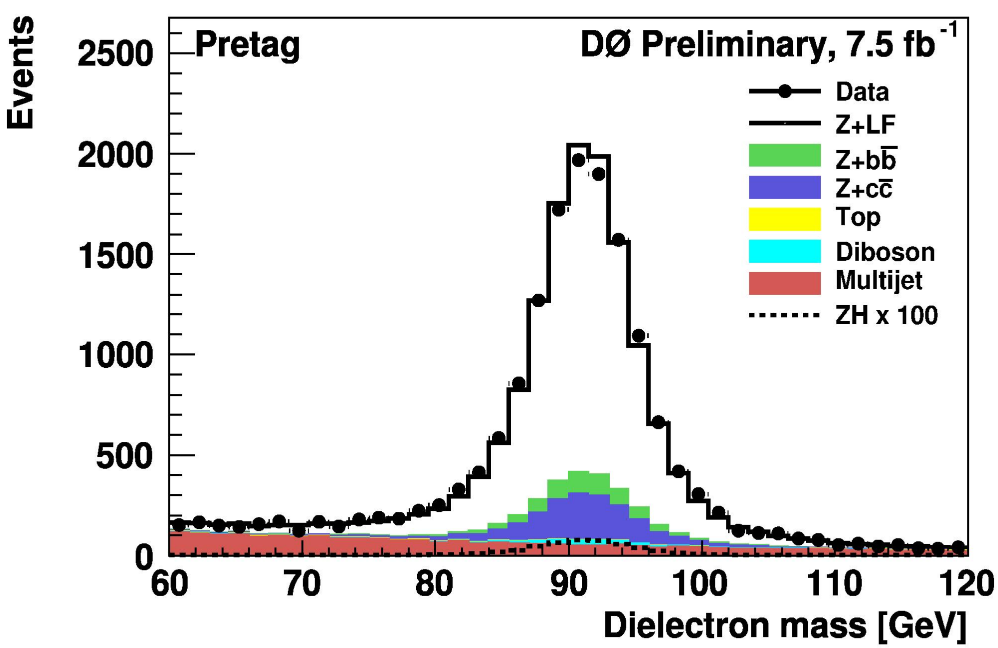
- No significant excess
- Cross section limits derived using BDT.
- Exp(Obs) limit for m_H=115 GeV is 3.5(4.6)xSM.

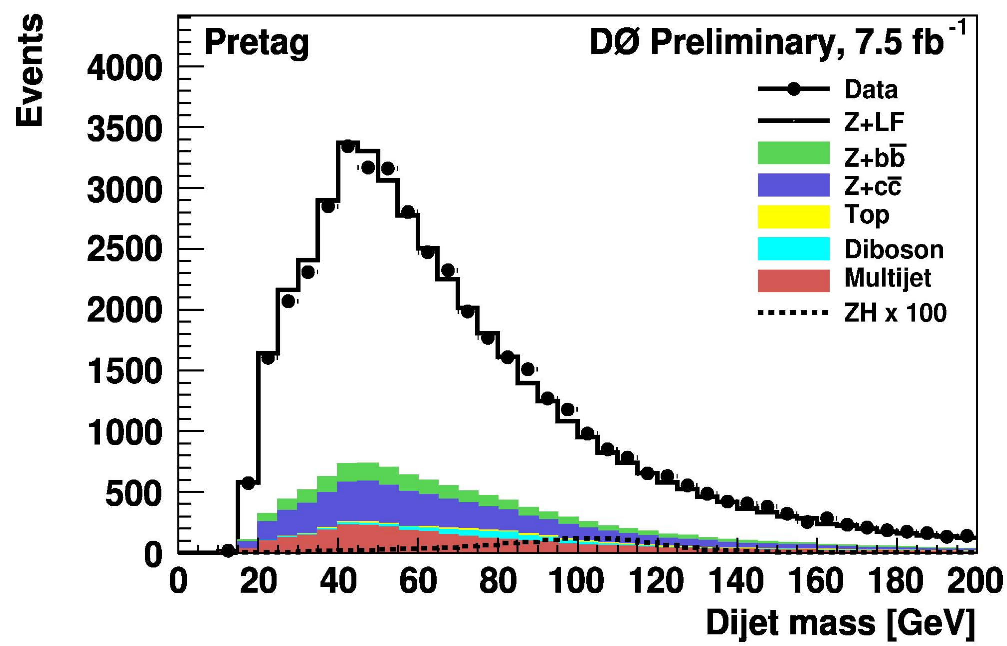


ZH→llbb

- Cleanest channel with all final state particles detected, but low cross section x BR
- Selection:
  - 2 Isolated leptons
  - 2 or 3 high p_T jets with 1 or 2 jets b-tagged
  - S/B~1/20(double tag)

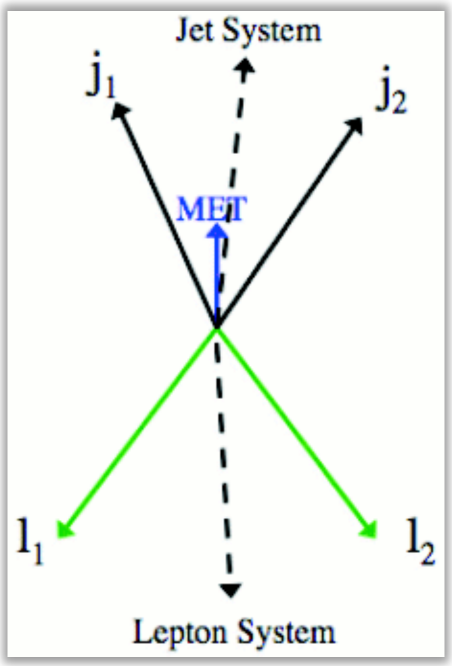


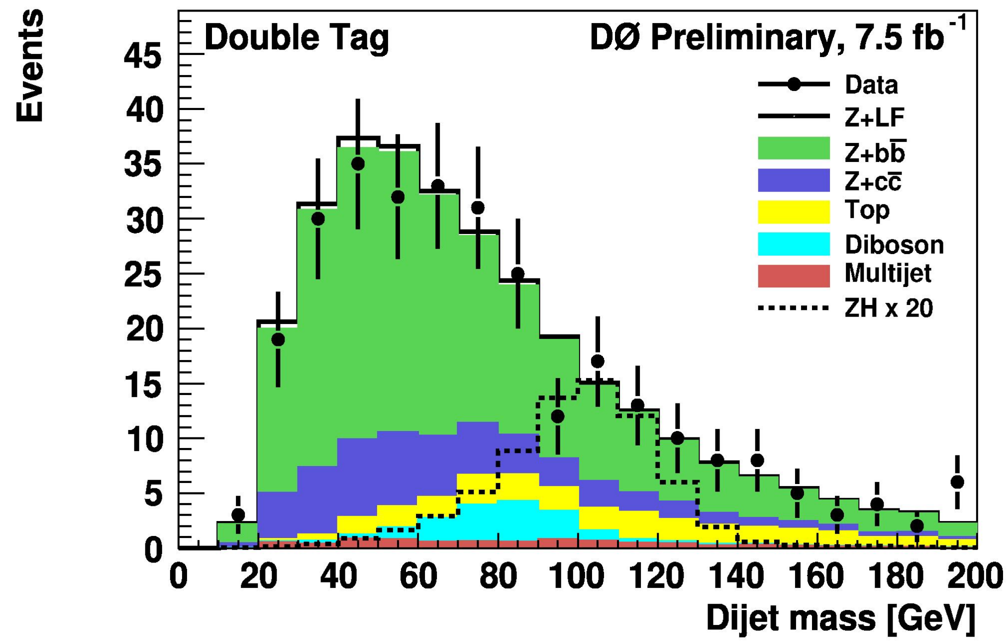


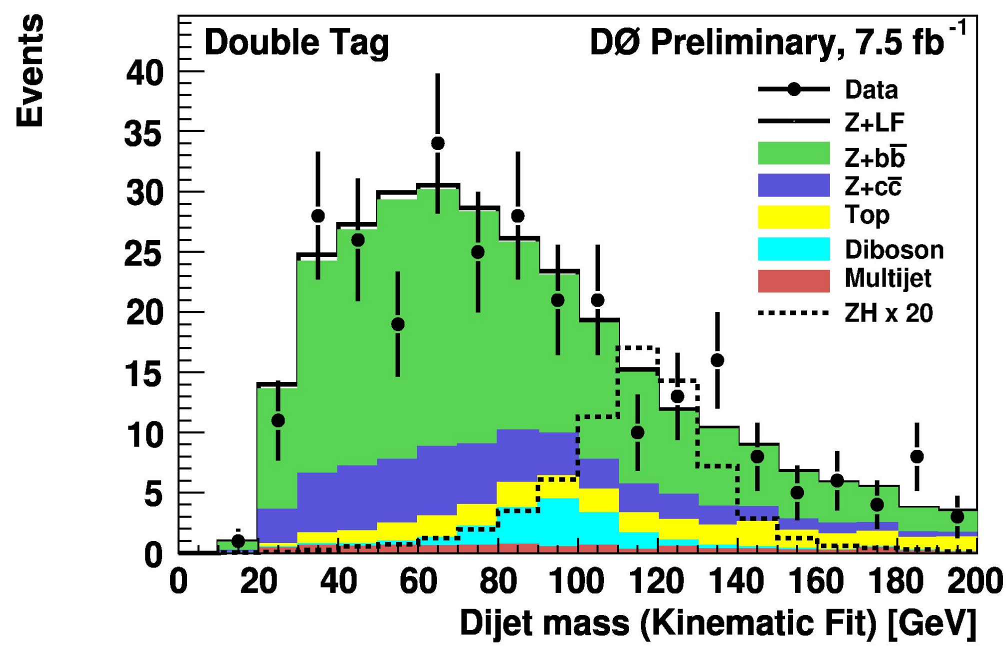


ZH→llbb

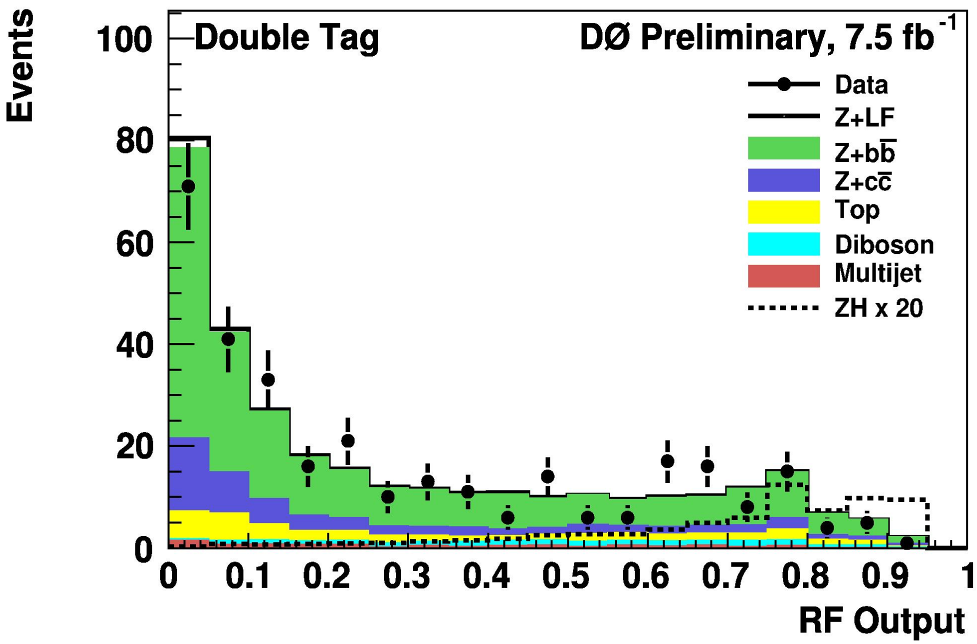
- Improving dijet mass resolution
  - Likelihood fit to the 4 vectors of 4 final state particles
  - MET and Z mass constraints
  - Energy transfer functions from MC and angular resolutions.



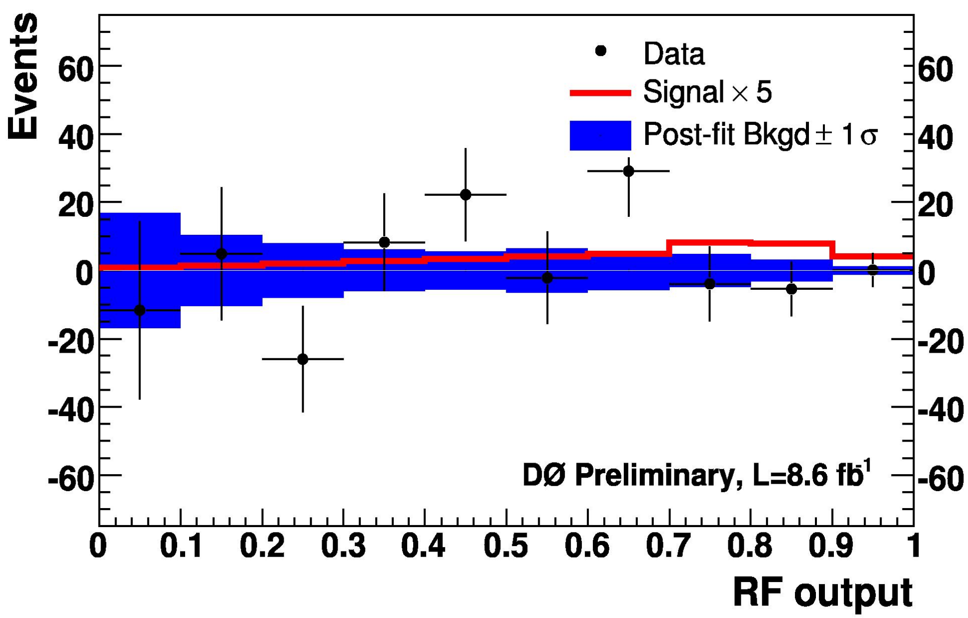


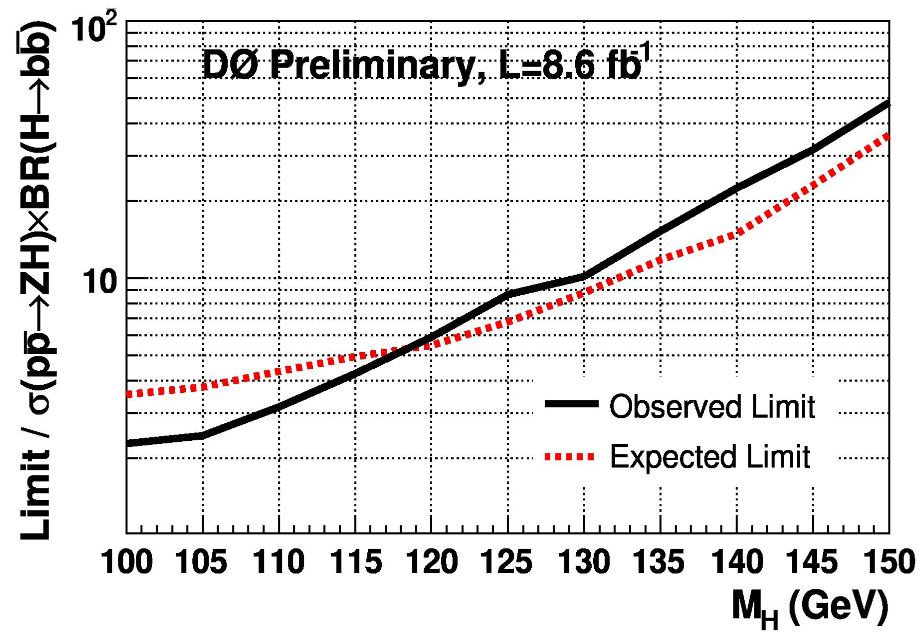


ZH→llbb



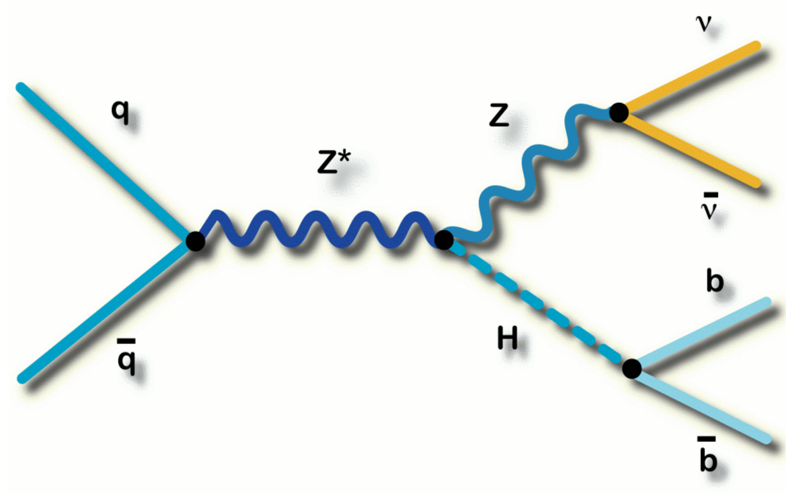
- Random Forest of Decision Trees to separate signal from background
- Exp(Obs) limit for m_H=115 GeV is 5.0(4.3)xSM.

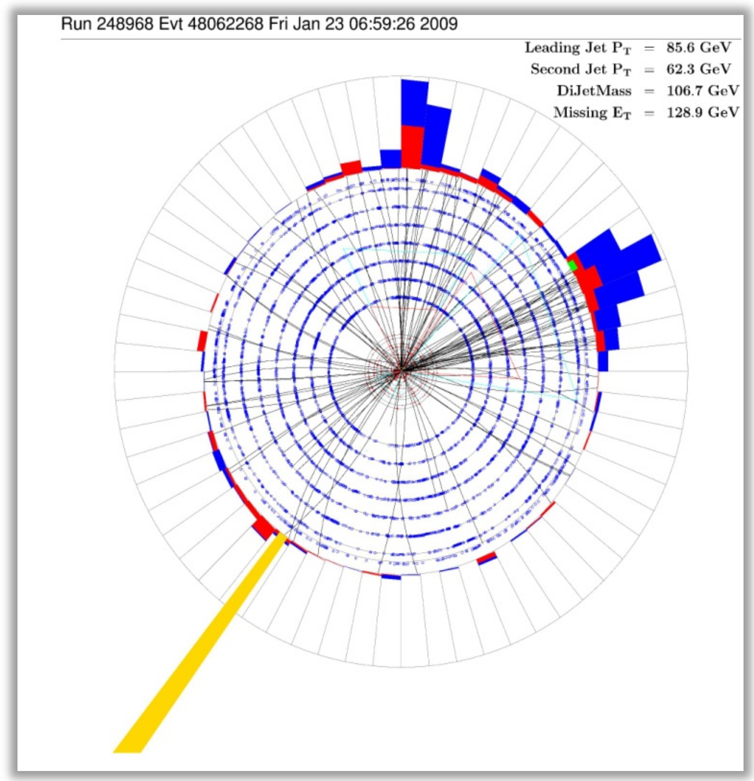




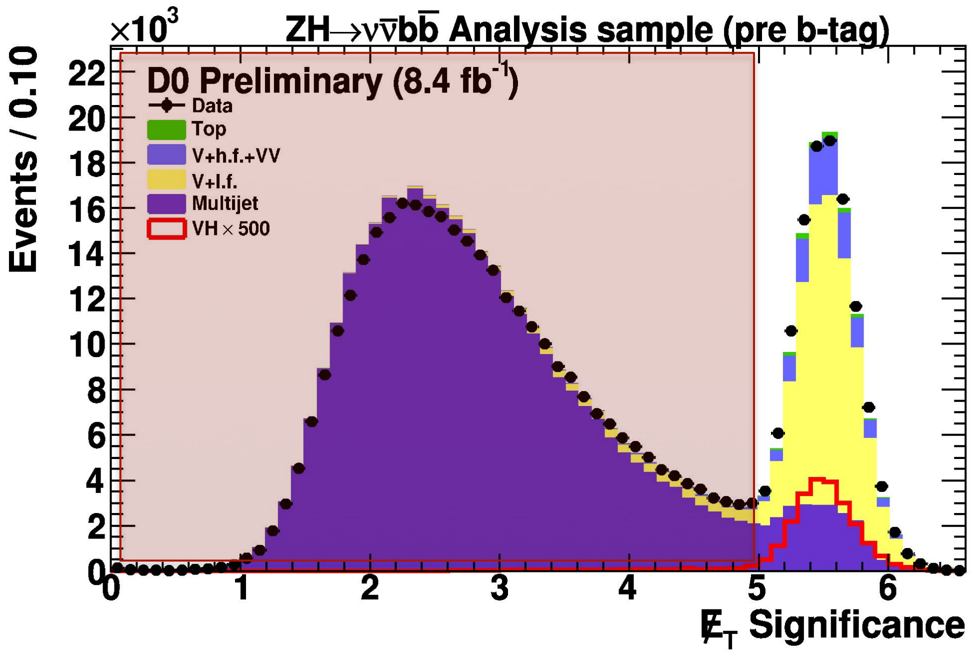
$ZH \rightarrow \nu\nu bb, WH \rightarrow (l)\nu bb$

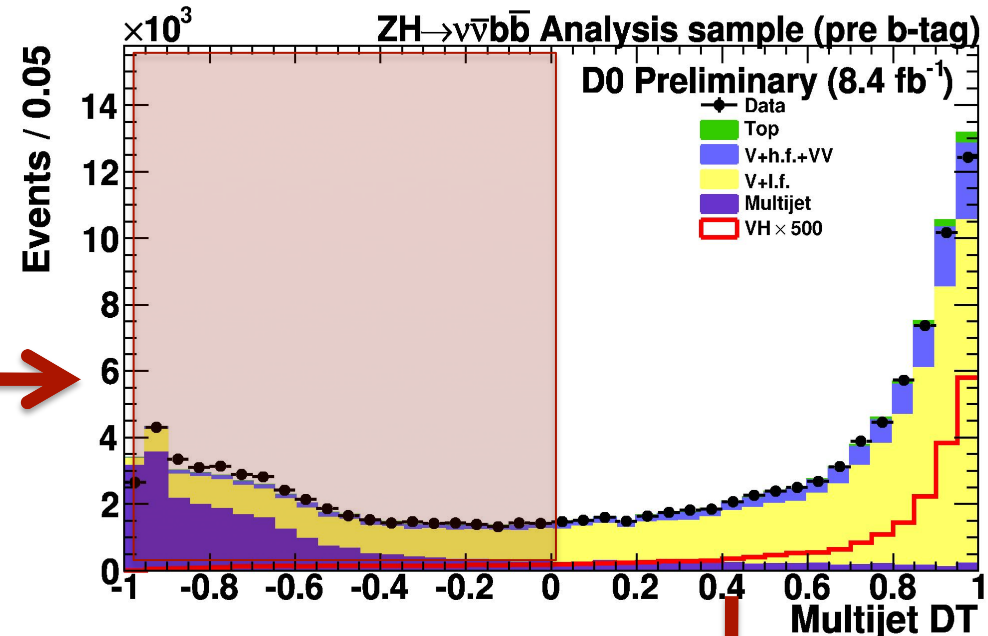
- Large cross section x BR & acceptance
  - No visible lepton & only jets
  - Large contribution from WH (~50 %)
- Selection
  - Two jets (not back-to-back: $\Delta\phi(j_1,j_2)<165^o$)
  - Large MET (not aligned in ϕ with jets)
  - MET calculated from calorimeter energy and calculated from tracks
  - Scaler sum of jet $P_T>80$ GeV
  - MET>40 GeV, METsig>5
- Samples
  - EW ($W\rightarrow\mu\nu$+jets) control sample
  - MJ control sample
  - Signal sample

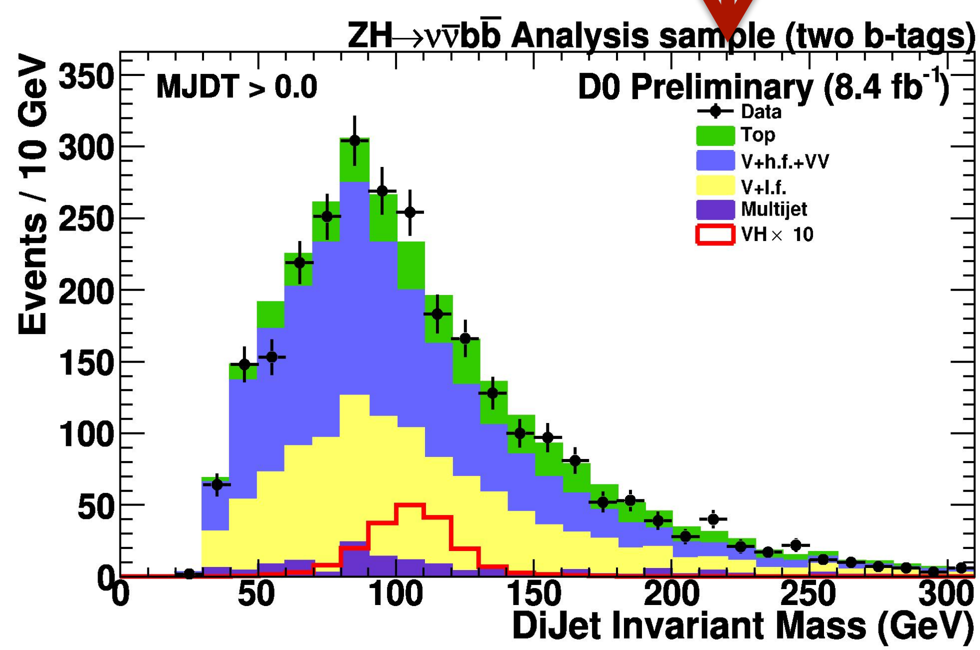




ZH→ννbb, WH→(l)νbb



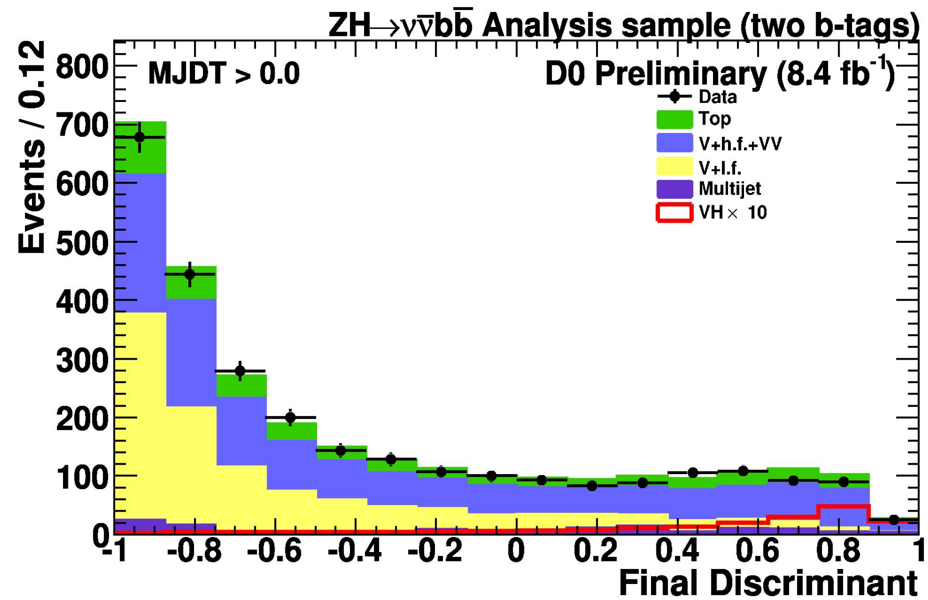


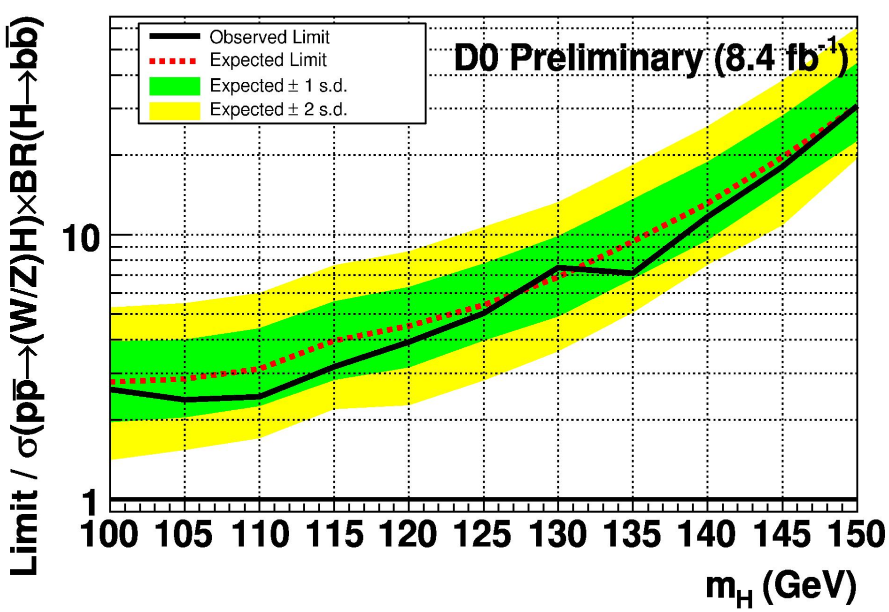


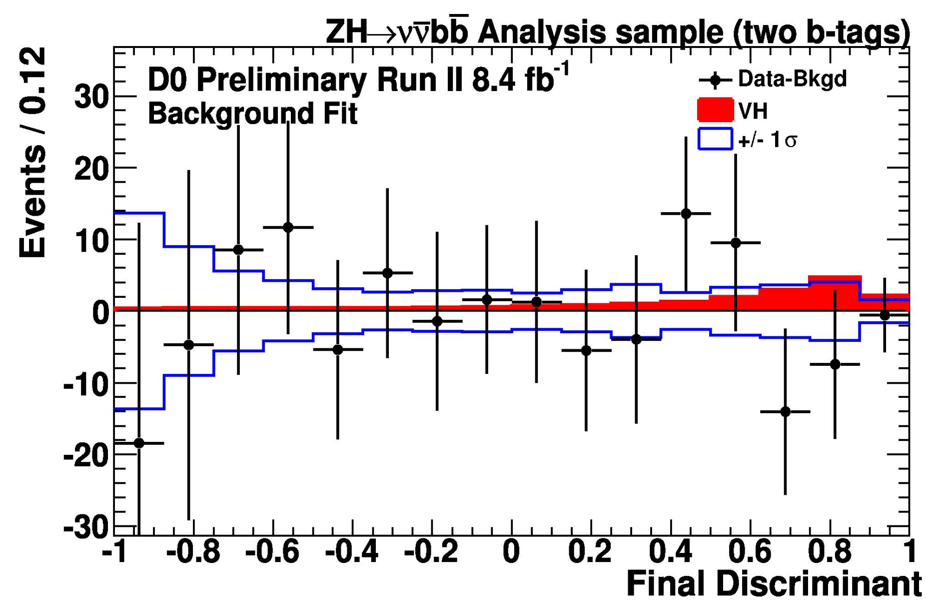
- Background rejection
  - Specialized DT for multijet background rejection
  - S/B~1/20 for m_H=115 GeV

ZH→ννbb, WH→(l)νbb

- No significant signal observed.
- Cross section limits derived using BDT.
- Exp(Obs) limit for m_H=115 GeV is 4.0(3.2)xSM.

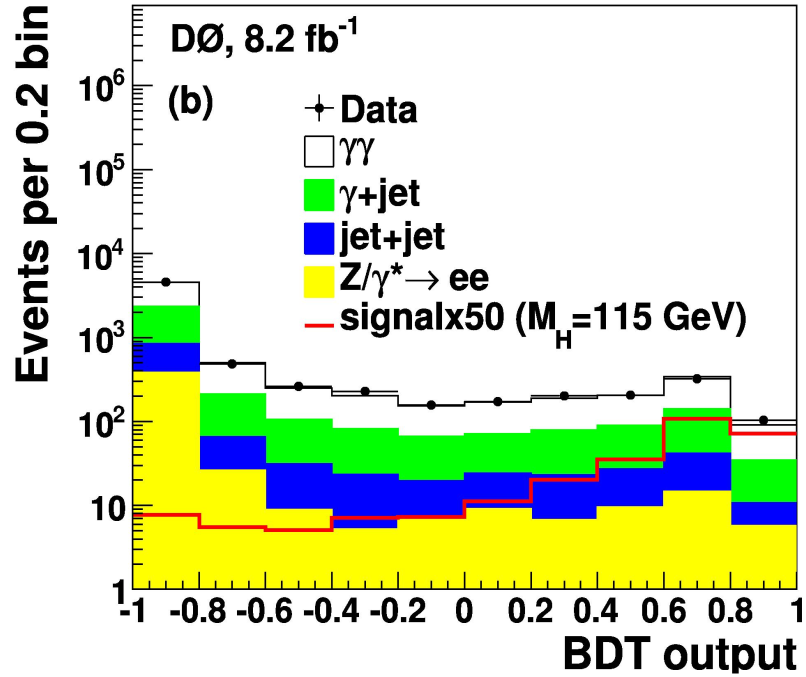


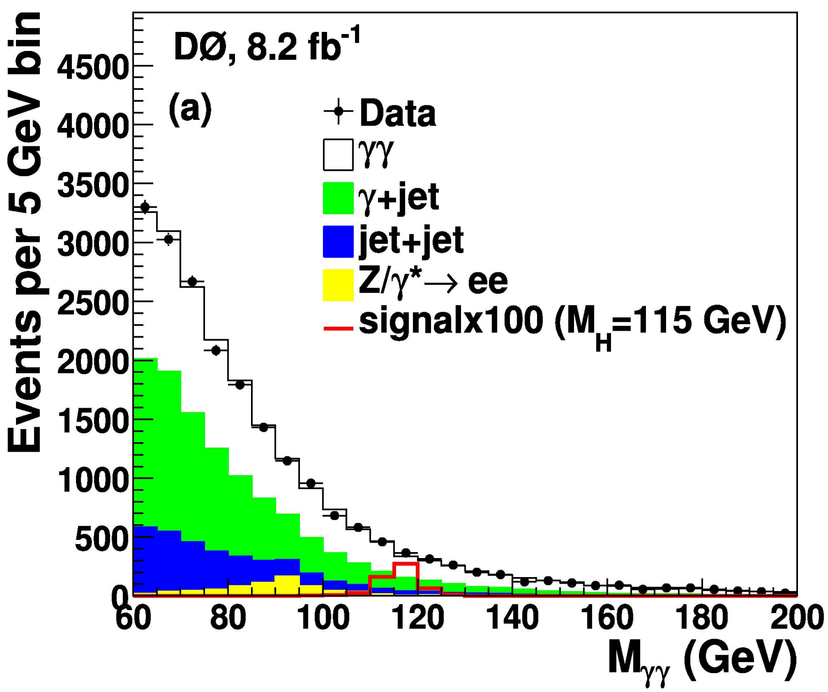


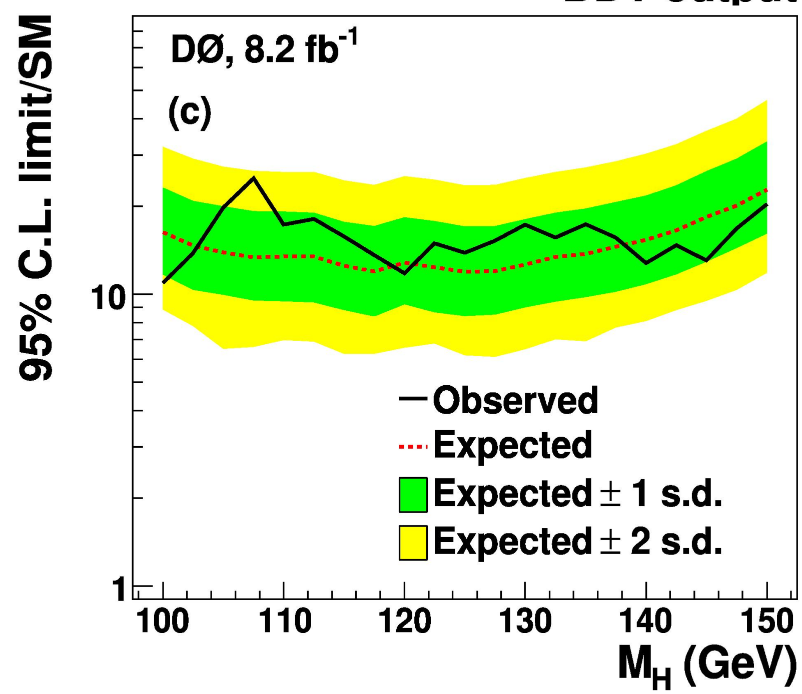


$H \rightarrow \gamma\gamma$

- Small BR (~0.2% for $110 < m_H < 140$ GeV)
- Clean signal with a narrow resonance
- S/B~1/100



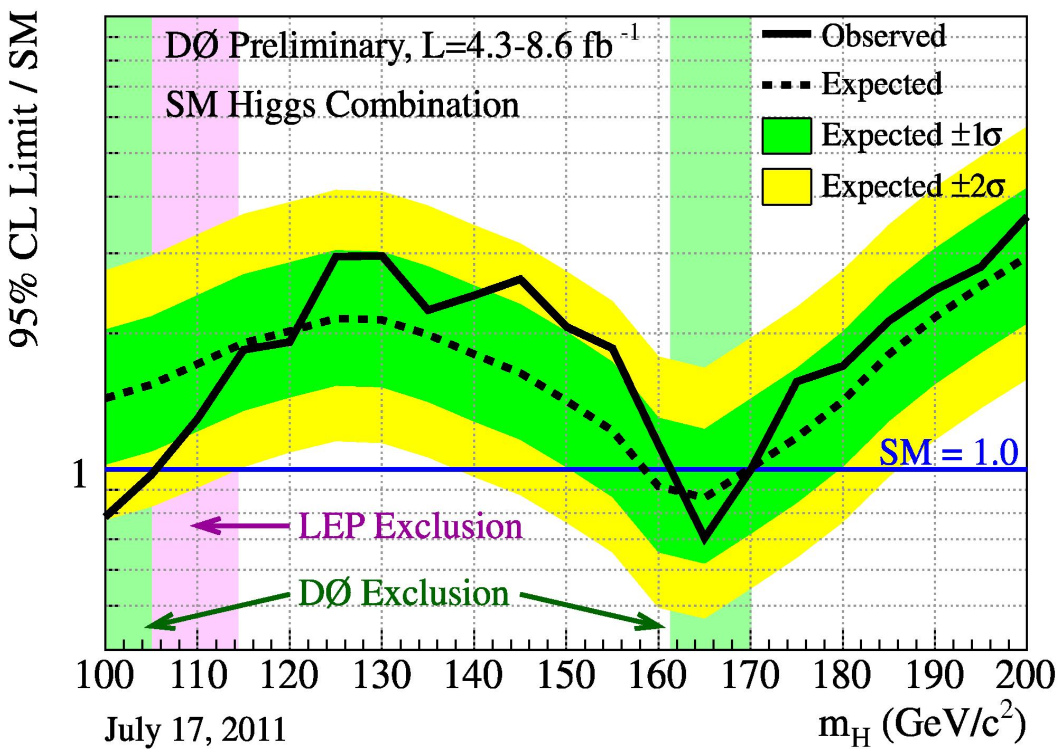




Putting all together

- Combine across channels within D0.
  - H→WW→lνlν, H→WW→lνqq for high mass
  - VH→l±l±X for intermediate mass
  - WH→lνbb, ZH→ννbb, ZH→llbb, H→γγ, etc for low mass

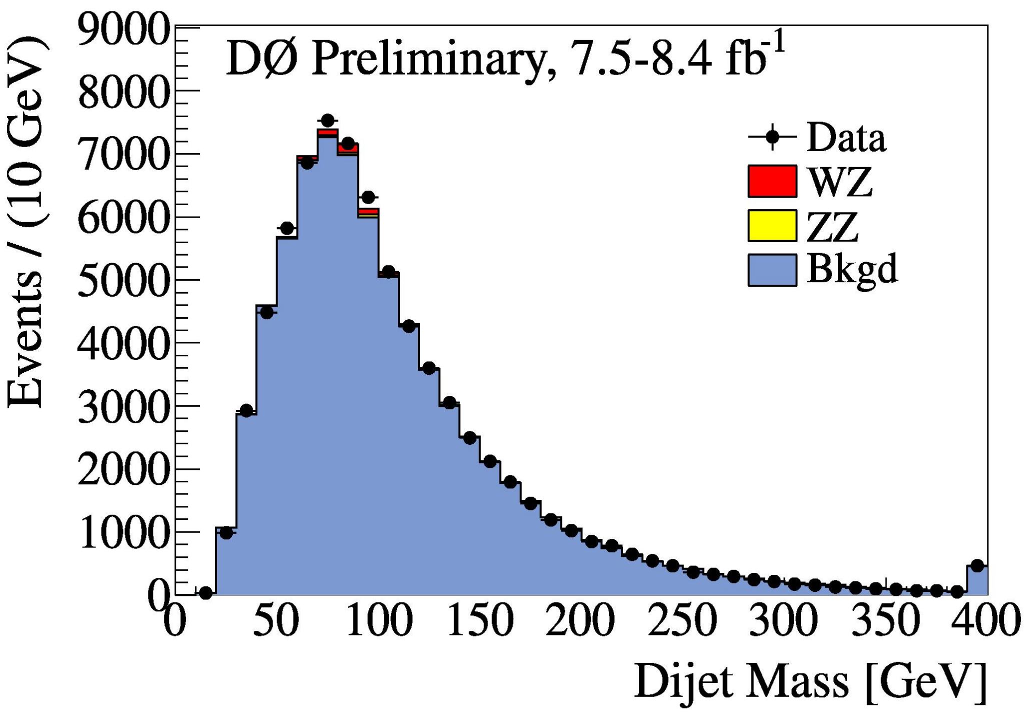
channel	Lumi (pb^{-1})
WH→lνbb	8.5
ZH→ννbb	8.4
ZH→llbb	8.6
H+X→μτ+<2j	7.3
H+X→lτjj	4.3
H→WW→lνlν	8.1
H→WW→lνqq	5.4
VH→l±l±X	5.3
H→γγ	8.2

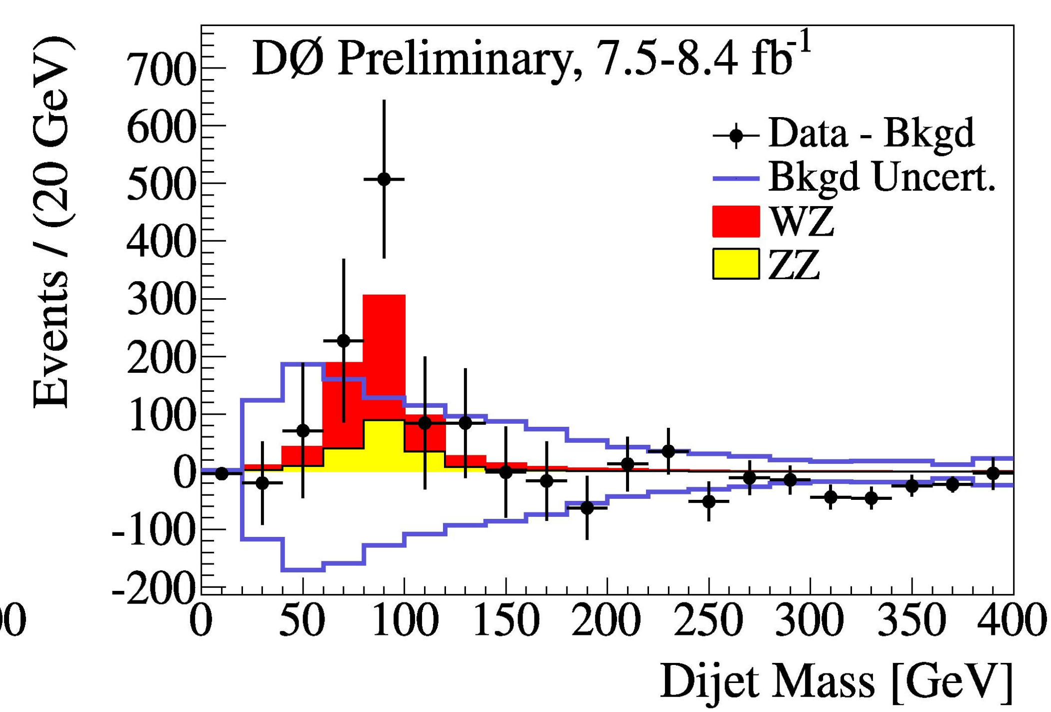


- None of the single analyses can exclude at low mass
- With the combination, mH<105 GeV is excluded.

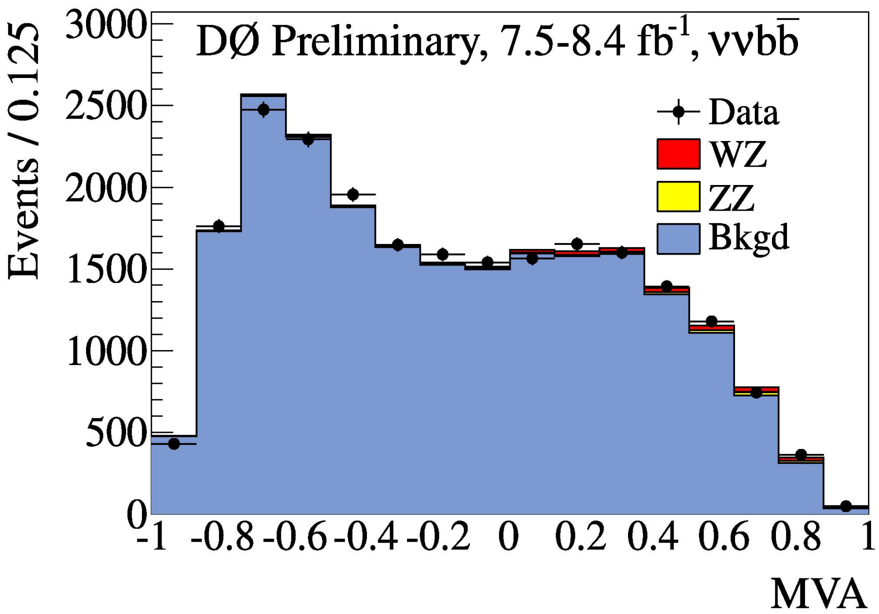
Diboson production

- WZ/ZZ with 2 b jets in final states
  - WH→lνbb, ZH→ννbb+WH→(l)νbb, and ZH→llbb with H→bb replaced by Z→bb
- Using the same search method as the W/ZH with 2 b jets in final states.
  - Validation of the low mass Higgs search method.

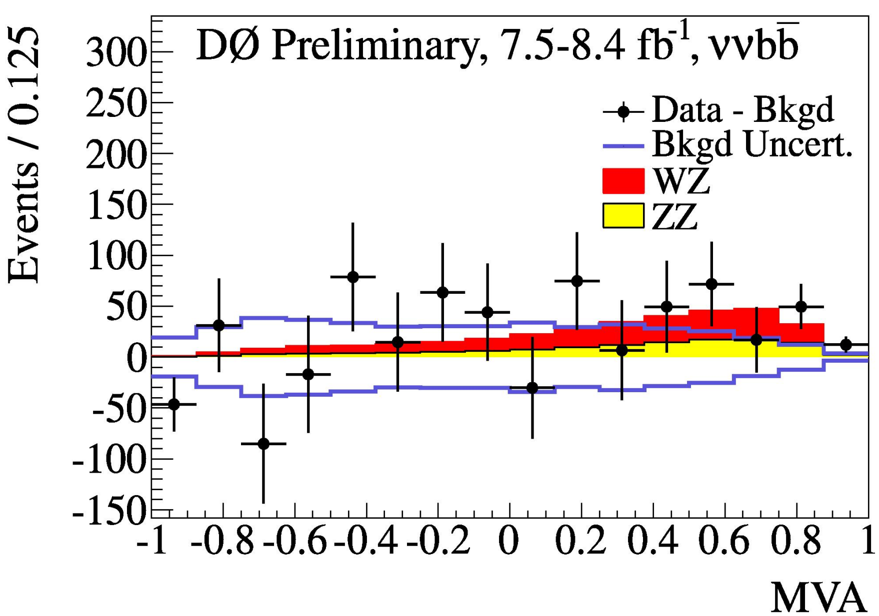


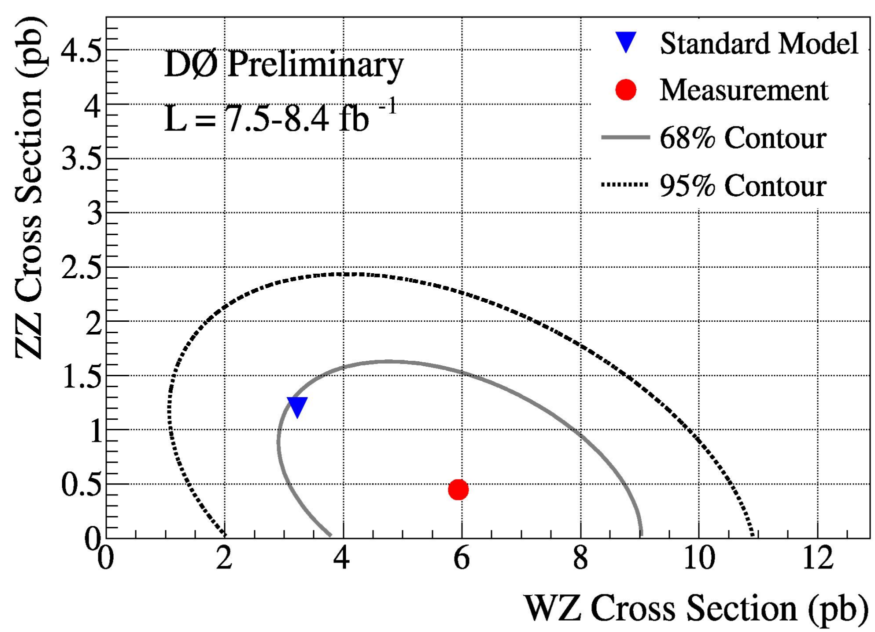


Diboson production



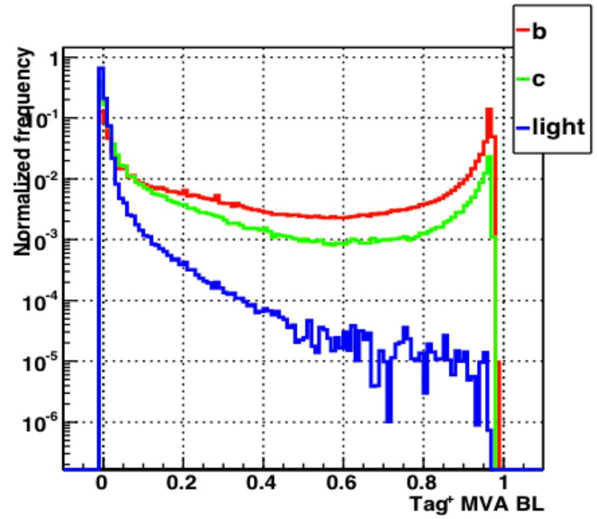
- Our measurement:
  $\sigma(VZ)=5.0\pm1.0(\text{stat})^{+1.3}_{-1.2}(\text{syst})$ pb
- NLO prediction: $\sigma(VZ)=4.4\pm0.3$ pb

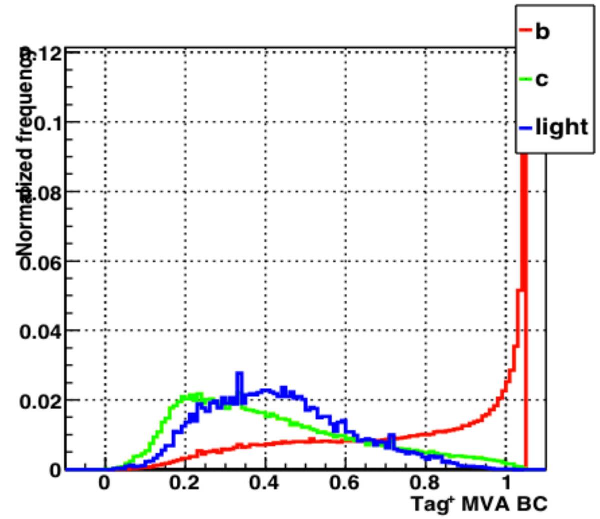




We are not done yet

- Improvements in analysis
  - Algorithm improvements for high luminosity running conditions.
  - Improved b-tagging (flavor separator)





  - Jet energy resolution
    - Treat HF jets differently from light jets
  - Improved systematics
    - Major source of degradation in sensitivity
    - Need better understanding of W/Z+HF jets properties, including cross sections
  - New channels are coming online
    - VH→tri-leptons, VH→lνjjjj, etc

Conclusions

- Tevatron shutdown brought to a very successful collider run at Fermilab to an end.
  - Over 12fb^{-1} delivered, 11fb^{-1} recorded and 10 fb^{-1} for analysis.
- Higgs search analyses have matured.
  - Analysis techniques have improved.
  - Good understanding on the limiting factors and working on further improvements.
- Results with the full dataset, with additional channels, are coming soon.