# Update on the search for H→WW at the Tevatron


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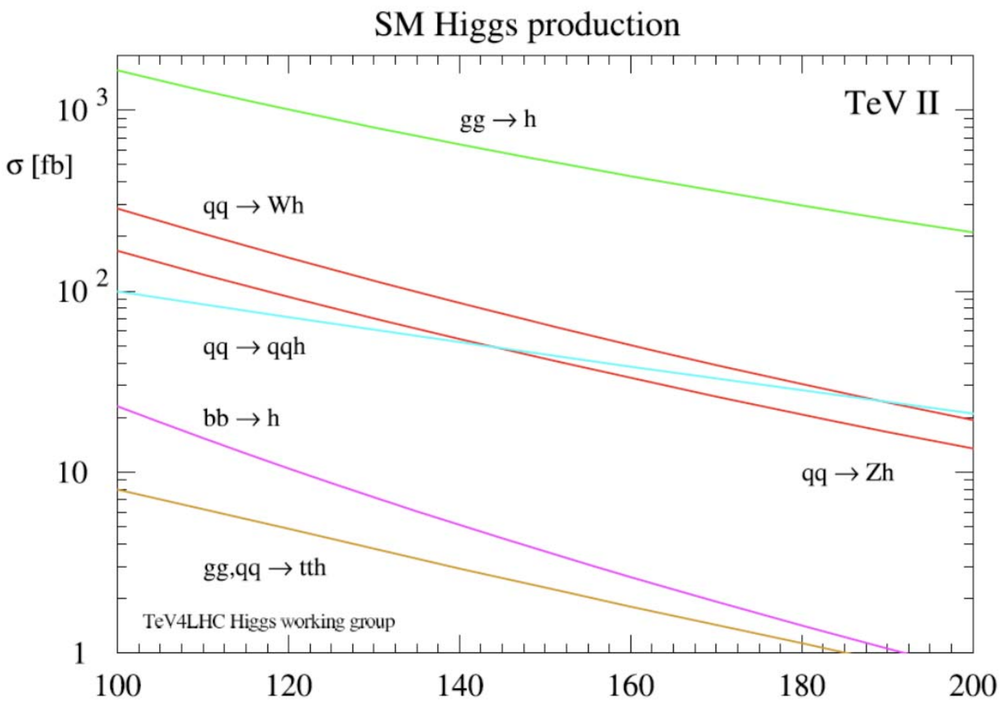
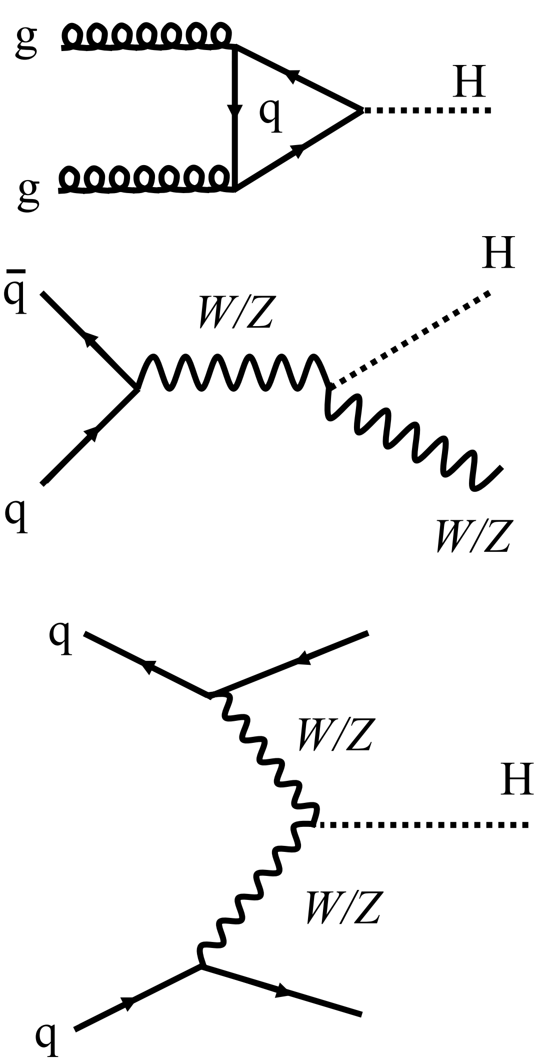
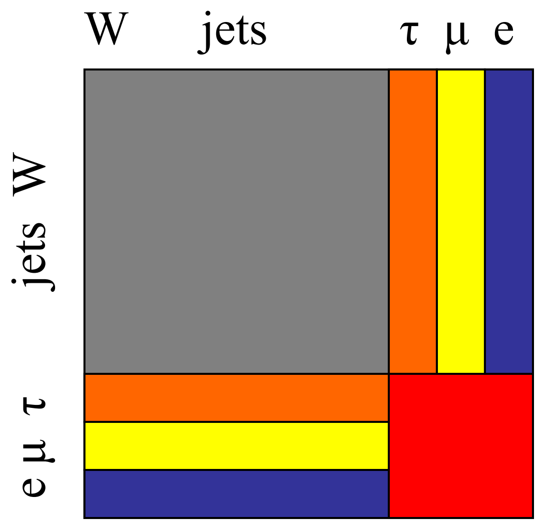
# Higgs production at the Tevatron



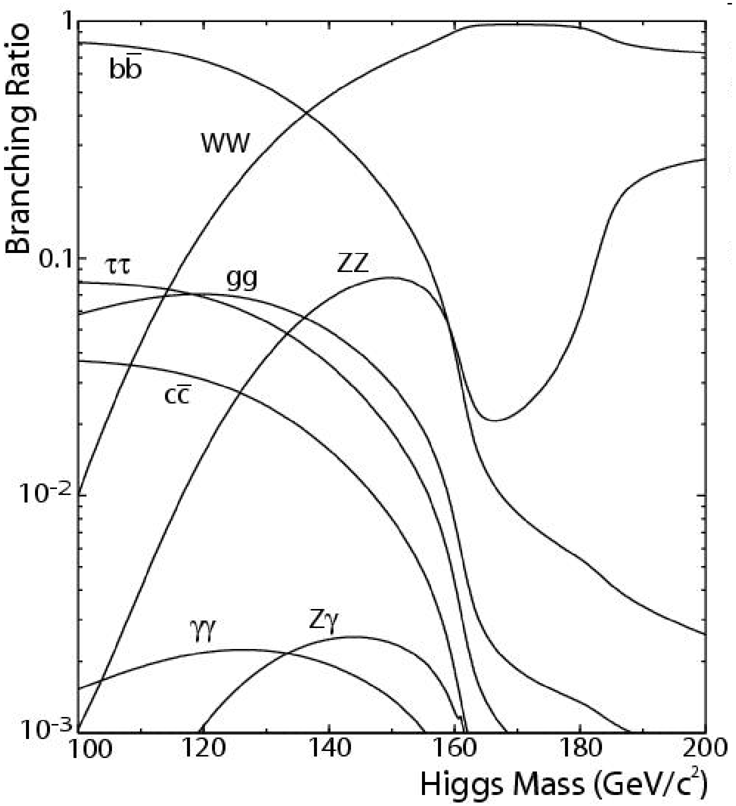



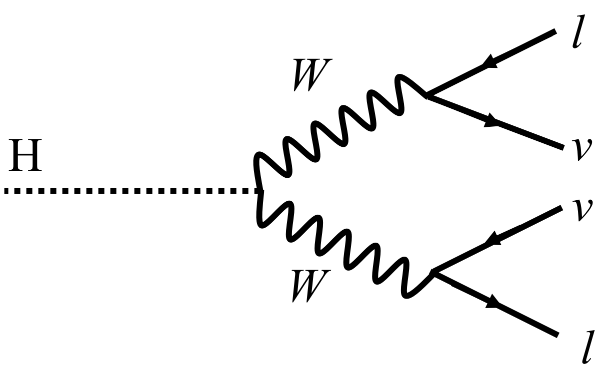

Gluon fusion easily dominates
the other production mechanisms

# Higgs final states




Branching ratio of the $W$s

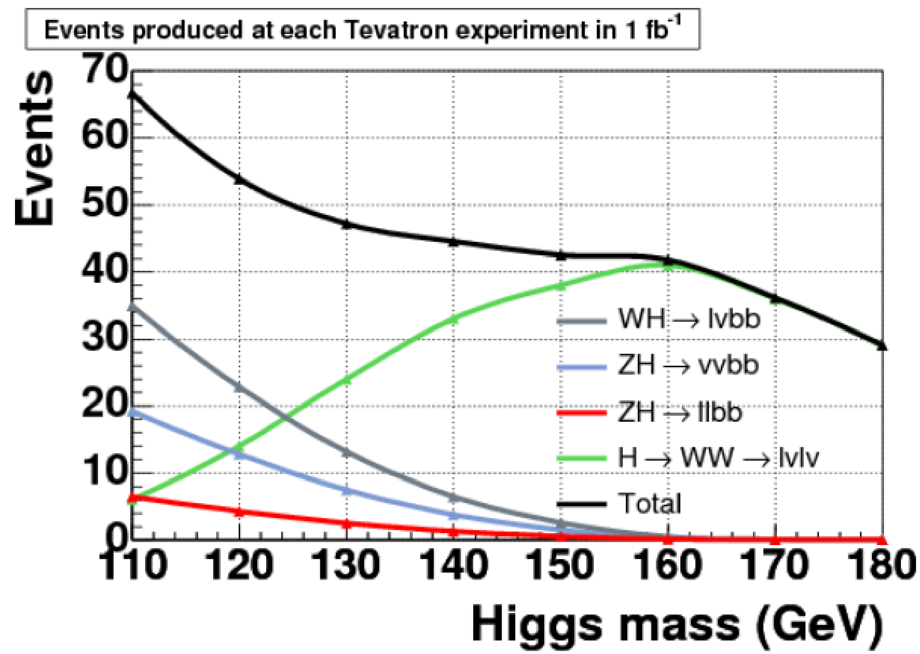



Our event selection is simple: two high $p_T$ leptons and missing transverse energy

# The analysis strategy

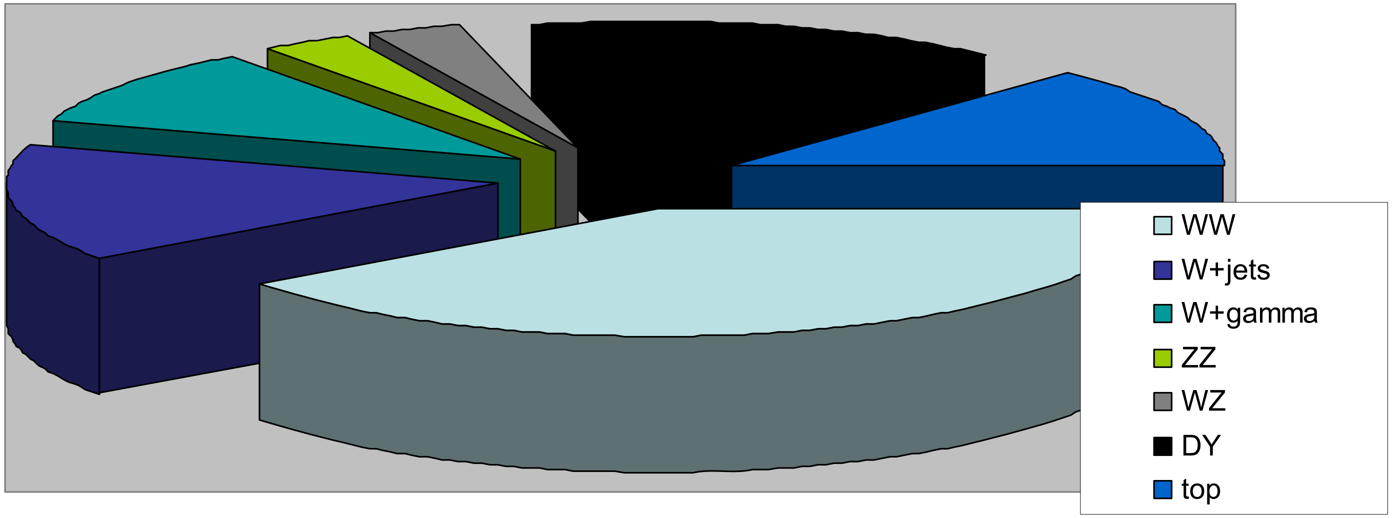
1. Cast a wide net, we seek to make the analysis as inclusive as possible to maximize signal
2. Put great effort into making sure background model is accurate, checking against control regions in data
3. Use multivariate techniques to separate signal from background based on event kinematics




Expect only about 10 events per experiment at 165 $GeV/c^2$ after trigger, reconstruction, and event selection

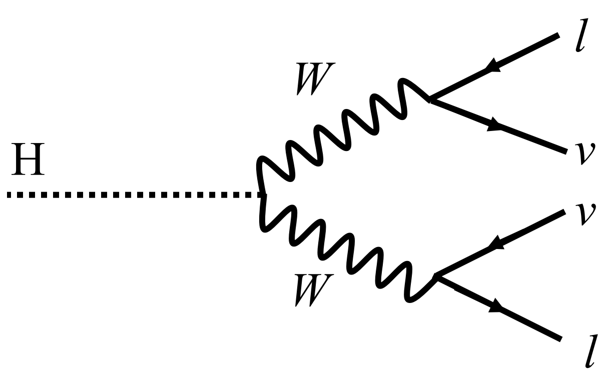
# Standard Model backgrounds

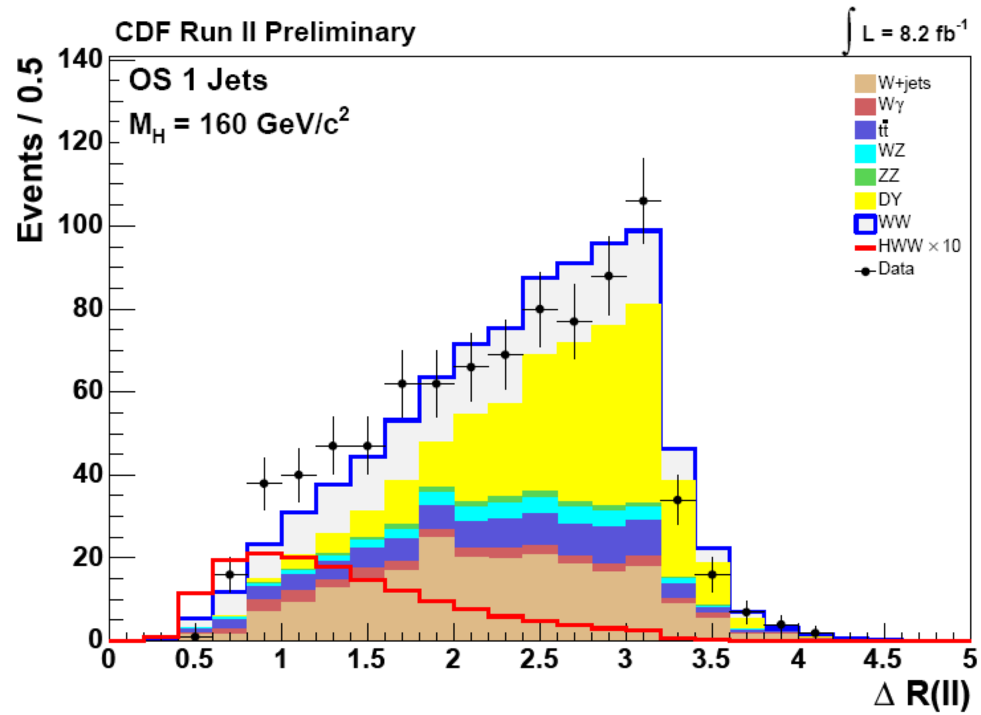
- Our backgrounds are *WW*, *WZ*, *ZZ*, Drell-Yan, W+$\gamma$, *W*+jets, and top
- We need to separate out a small signal from a large background
- Even in CDF’s most sensitive channel, we still only have S/B~0.01 after preselection cuts



# An example of kinematic separation

- As previously mentioned we take advantage of kinematics to separate signal out
- For example, $\Delta R = \sqrt{(\Delta\varphi)^2+(\Delta\eta)^2}$ between leptons is a measure of spatial separation

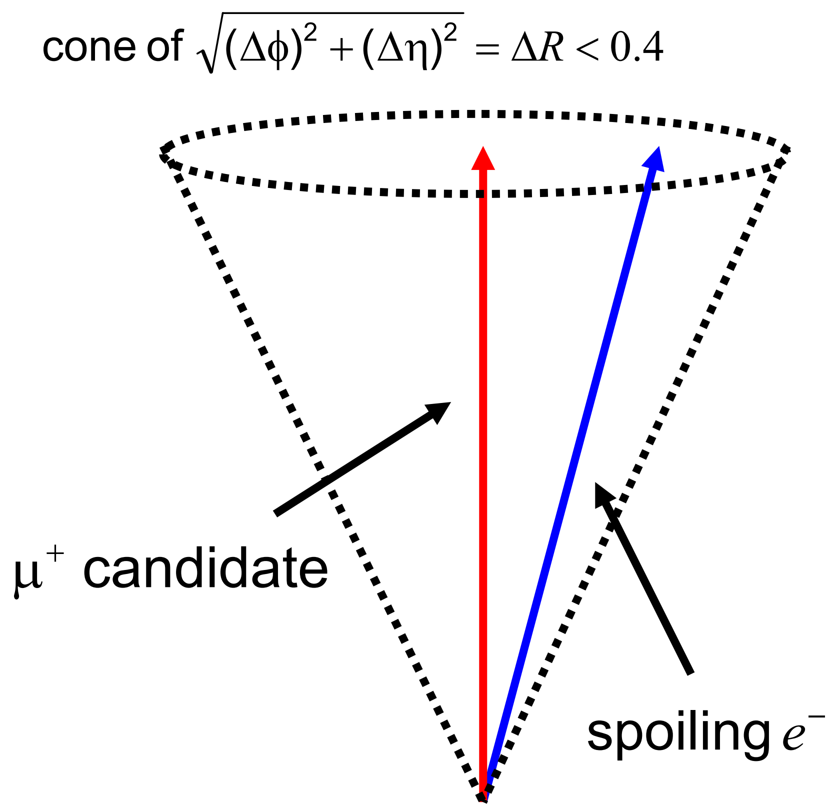



$\Delta R$ separates the red Higgs signal from the many backgrounds

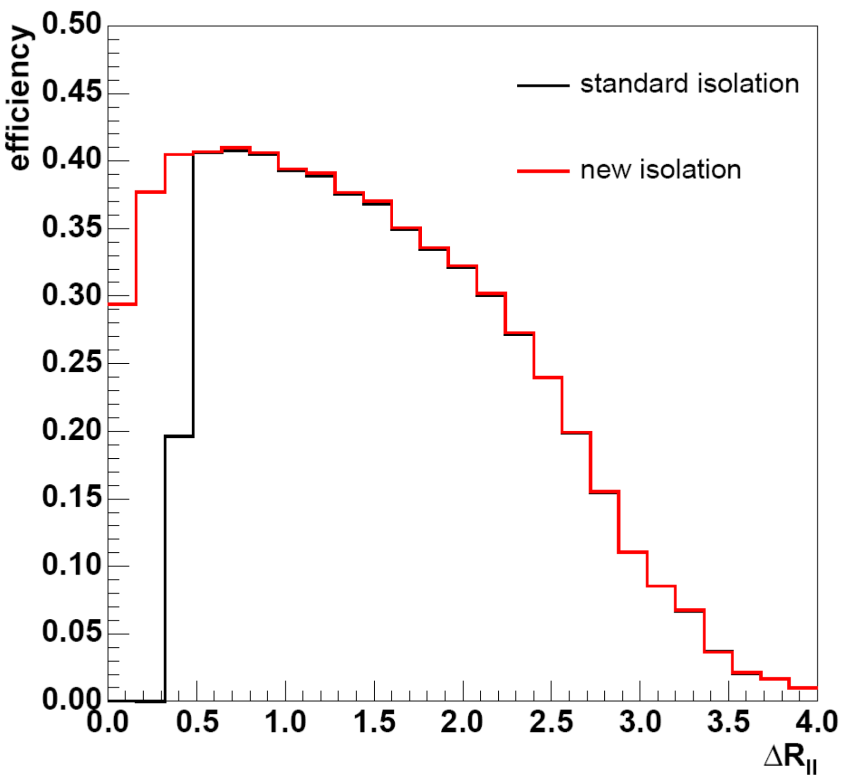
# Improvements from CDF

- Maximizing acceptance is the goal, motivates the improvements
- The largest improvement came from recalculating the isolation
- CDF also adds in likelihood based forward electrons
- Also have the usual increase in data

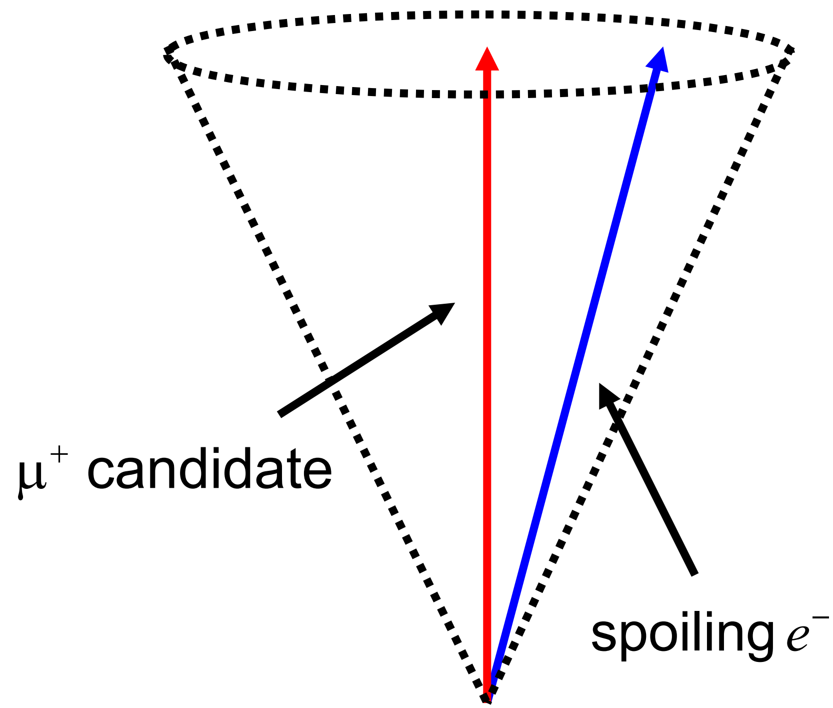


# The new isolation

- With the leptons being close together in $\Delta R$ , mutual isolation spoilage is possible
- CDF reevaluates the isolations, removing likely electron or muons from the cone

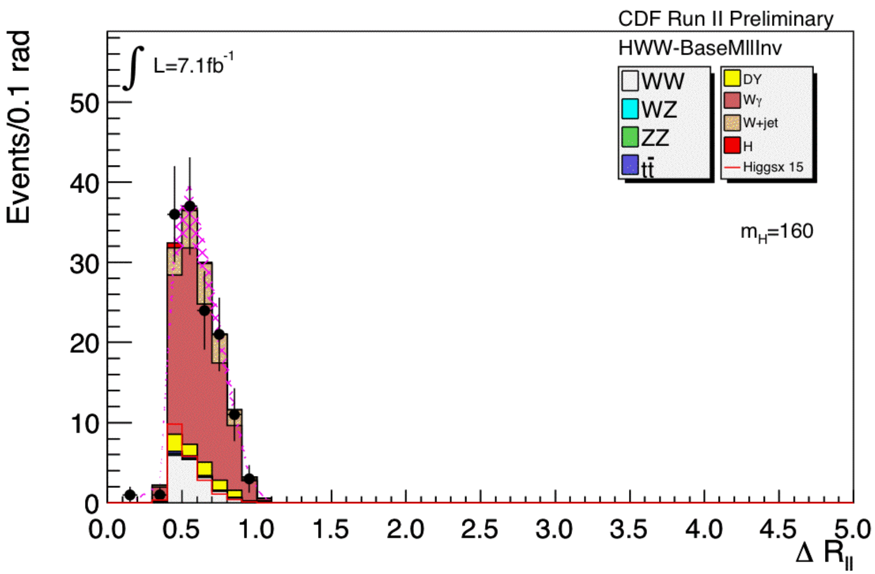



cone of $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = \Delta R < 0.4$

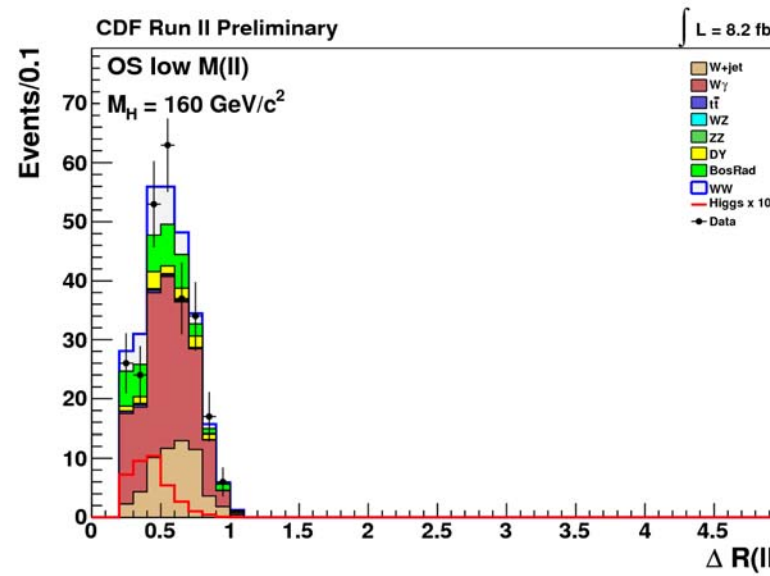



$$Isolation = \frac{E_T^{cone} - E_T^{from\ muon}}{E_T^{muon}}$$

# The new isolation's impact




Before

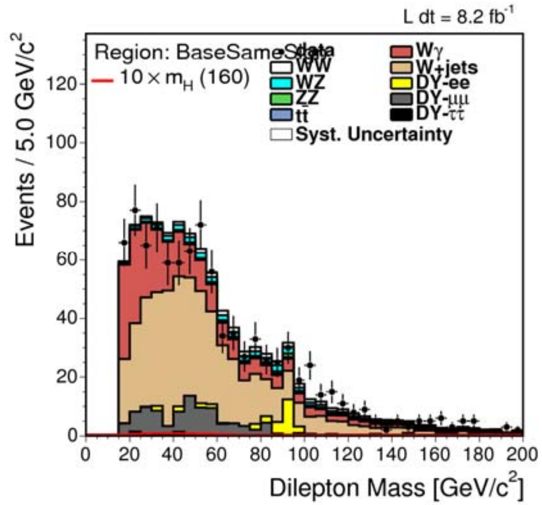



After

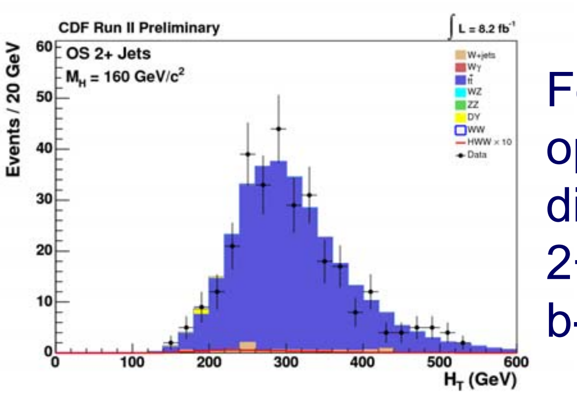
This improved our sensitivity in our low Mll channel by a factor of 3!

# Cross-checking the background modeling

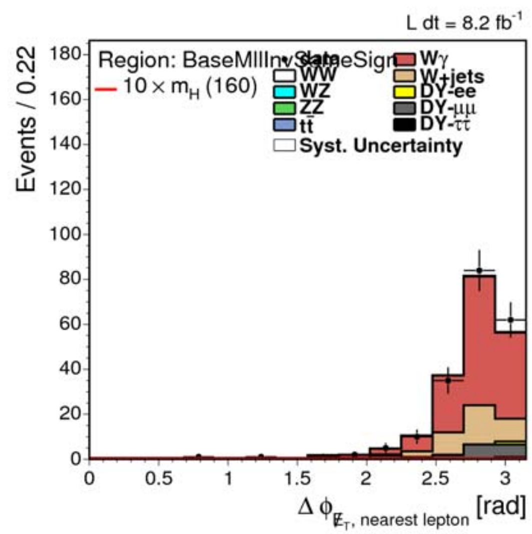
- For each background, we preferably have a control region to check our modeling of it
- Not always possible, for *WW*, *WZ*, and *ZZ* we are not able to define a region, rely on cross-section measurement




For *W*+jets, use same-sign dileptons



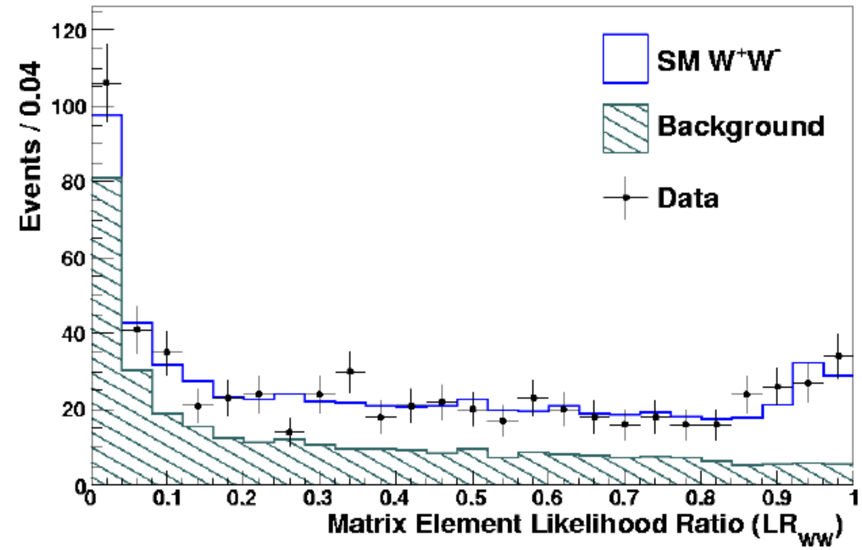

For top, use opposite-sign dileptons, 2+jets and a b-tag



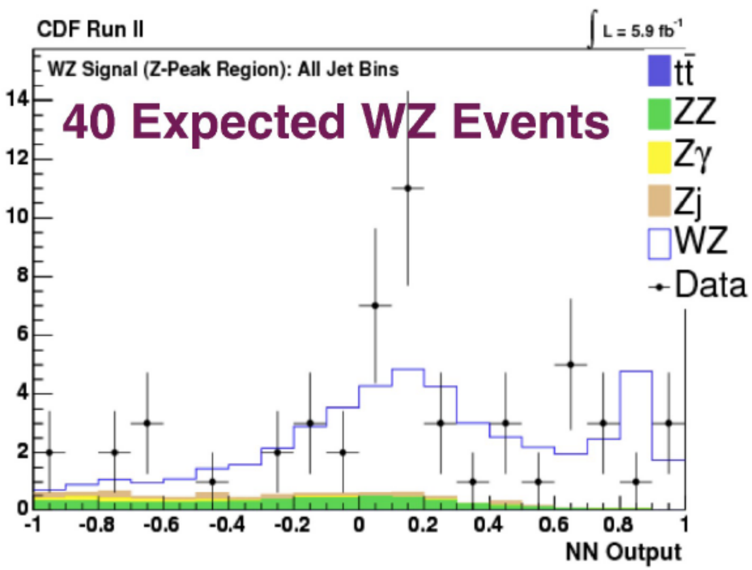

For *W*+γ, use same-sign dileptons for $M_{ll} < 16$ GeV/c$^2$

# Diboson cross-sections

- Measuring diboson cross-section provides a powerful indication the analysis is working
- Same analysis techniques are used as in the $H \rightarrow WW \rightarrow l\nu l\nu$ search




$$\sigma(pp \rightarrow WW) = 12.1 \pm 0.9\,(\text{stat.})\,^{+1.6}_{-1.4}\,(\text{syst.})\,[\text{pb}]$$

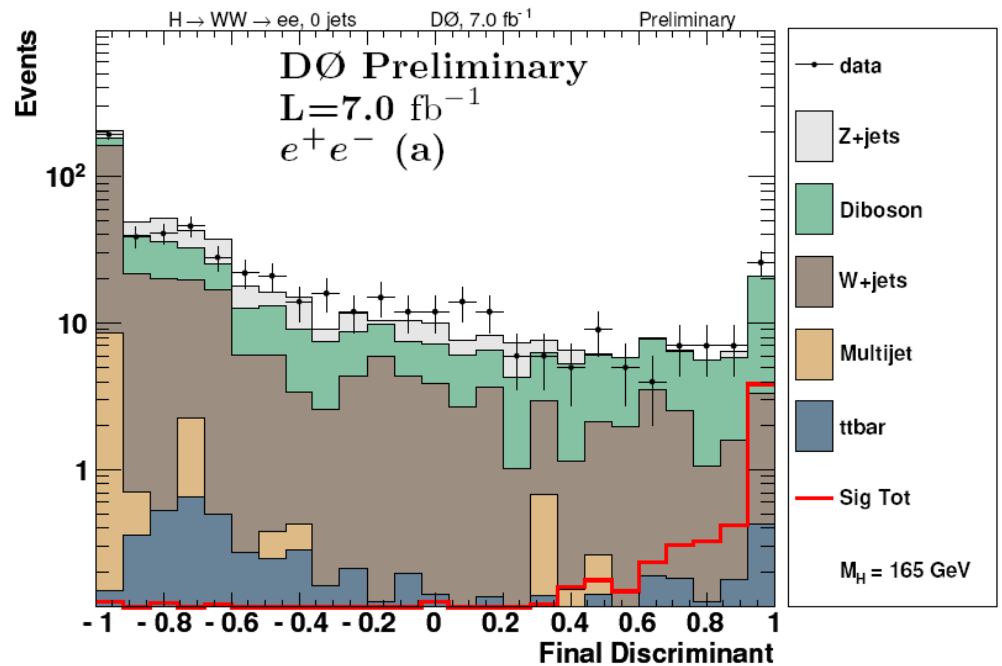



$$\sigma(pp \rightarrow WZ) = 3.7 \pm 0.6\,(\text{stat.})\,^{+0.6}_{-0.4}\,(\text{syst.})\,[\text{pb}]$$

Both measurements agree very well with theory

# Multivariate discriminants

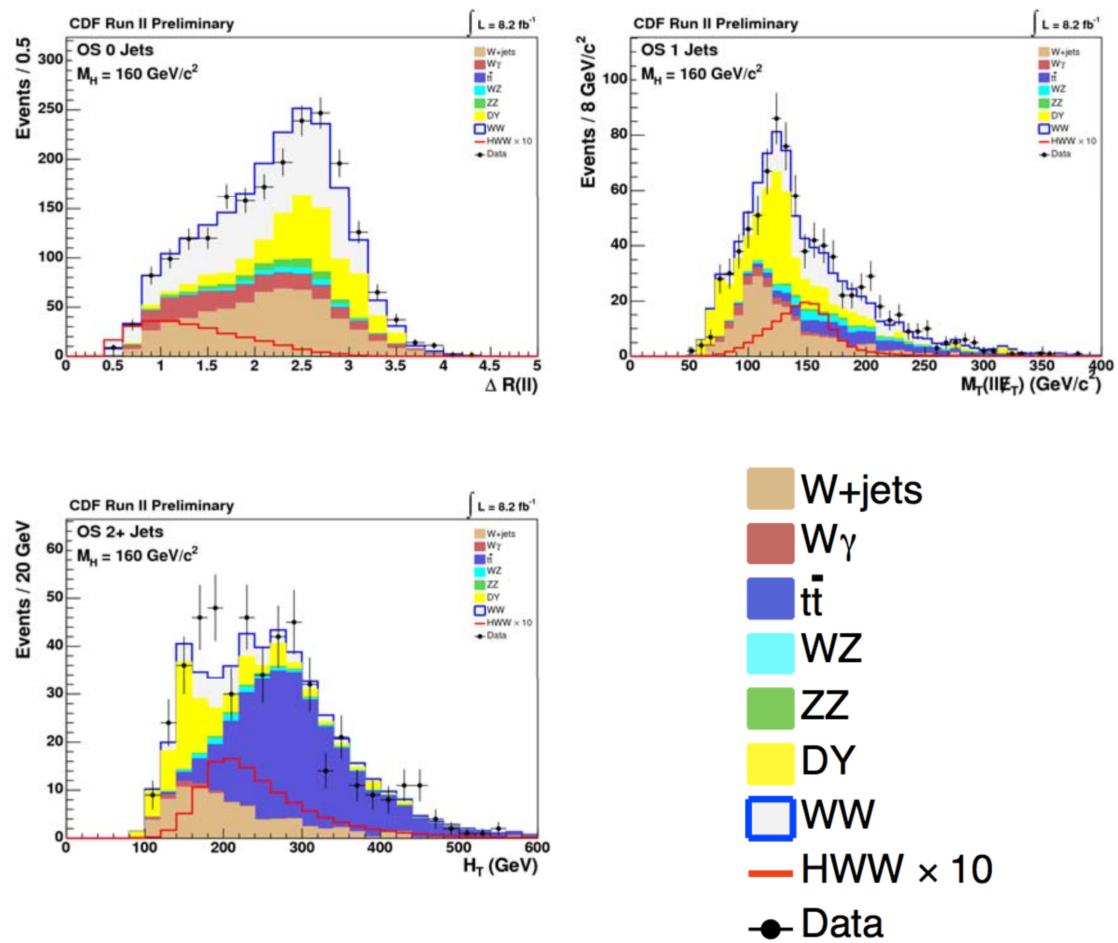
- Using chosen event kinematics, we create BDTs (DØ) or NNs (CDF) trained on background and signal models
- Data gets fed in to create a final discriminant which can be used for a limit
- Allows roughly a 10-20% improvement over a traditional cut based analysis



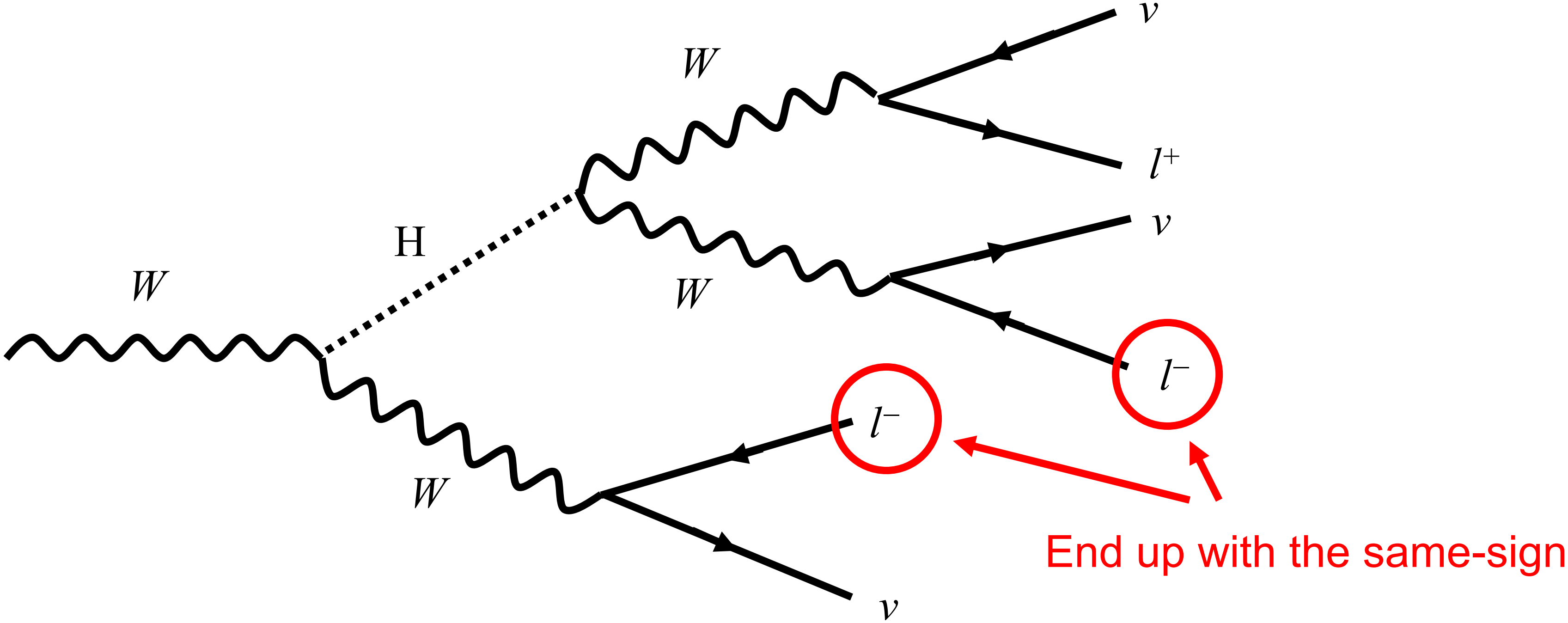

The red Higgs signal gets separated from backgrounds

# Getting the best sensitivity

- We can greatly increase our sensitivity by dividing the data into different channels
- Allows us to take advantage of different signals and backgrounds in the different channels
- Discriminants are optimized for signal, background, and kinematics unique to each channel



# Not exclusively opposite-sign




Both CDF and DØ have same-sign channels that take advantage of associated production

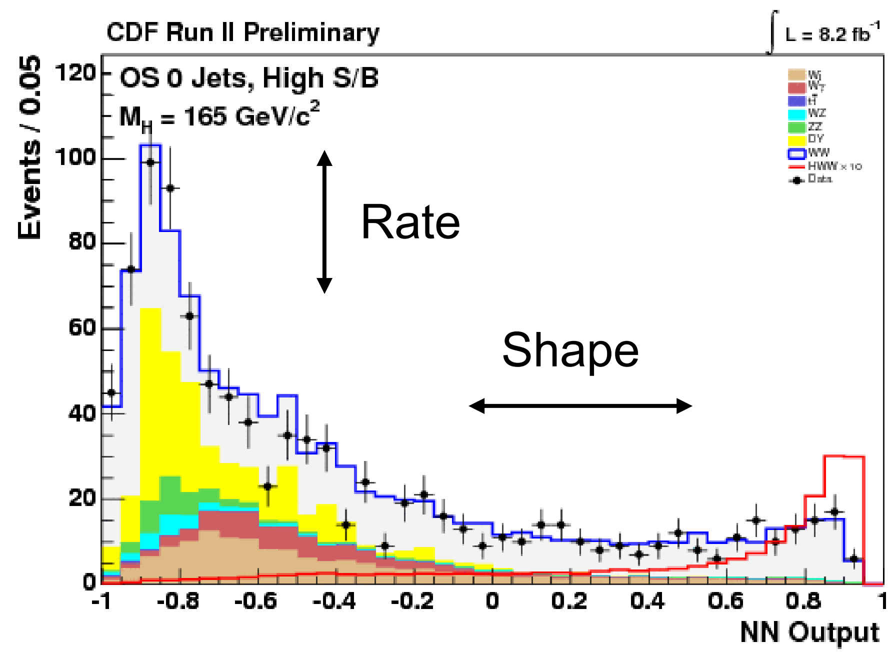
# The channels used by CDF

| Channel | Main Signal | Main Background | Most Important kinematic variables |
|---|---|---|---|
| OS dileptons, 0 Jets | $gg \to H$ | WW | $LR_{HWW}$, $\Delta R_{ll}$, $H_T$ |
| OS dileptons, 1 Jet | $gg \to H$ | DY | $\Delta R_{ll}$, $m_T(ll,E_T)$, $E_T$ |
| OS dileptons, 2+ Jets | Mixture | t-tbar | $H_T$, $\Delta R_{ll}$, $M_{ll}$ |
| OS dileptons, low $M_{ll}$, 0 or 1 Jet | $gg \to H$ | $W+\gamma$ | $p_T(l2)$, $p_T(l1)$, $E(l1)$ |
| SS dileptons, 1+ Jet | $WH \to WWW$ | W+Jets | $E_T$, $\sum E_T^{jets}$, $M_{ll}$ |
| Tri-leptons, no Z candidate | $WH \to WWW$ | WZ | $E_T$, $\Delta R_{ll}^{close}$, Type(lll) |
| Tri-leptons, Z candidate, 1 Jet | $ZH \to ZWW$ | WZ | Jet $E_T$, $\Delta R_{lj}$, $E_T$ |
| Tri-leptons, Z candidate, 2+ Jets | $ZH \to ZWW$ | Z+Jets | $M_{jj}$, $M_T^H$, $\Delta R_{WW}$ |
| OS dilepton, electron + hadronic tau | $gg \to H$ | W+Jets | $\Delta R_{l\tau}$, $\tau$ id variables |
| OS dilepton, muon + hadronic tau | $gg \to H$ | W+Jets | $\Delta R_{l\tau}$, $\tau$ id variables |

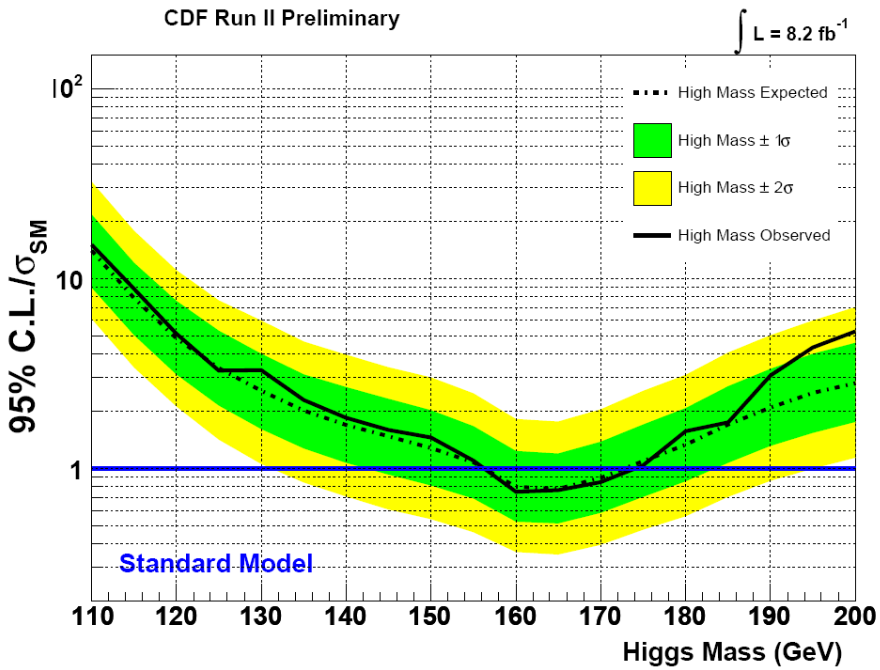
What I'm focusing on today, see other talks for details on the rest

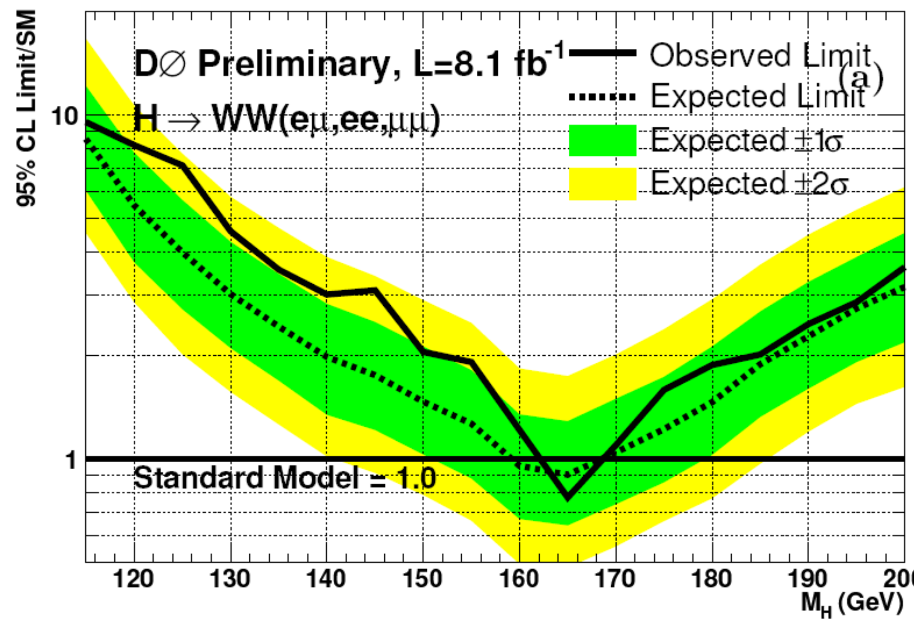
# Systematic uncertainties

- There are two categories of systematics impacting the final discriminant, shape and rate (normalization)
- The uncertainties get accounted for as nuisance parameters in the final fit and limit calculations



# The limits from the two experiments

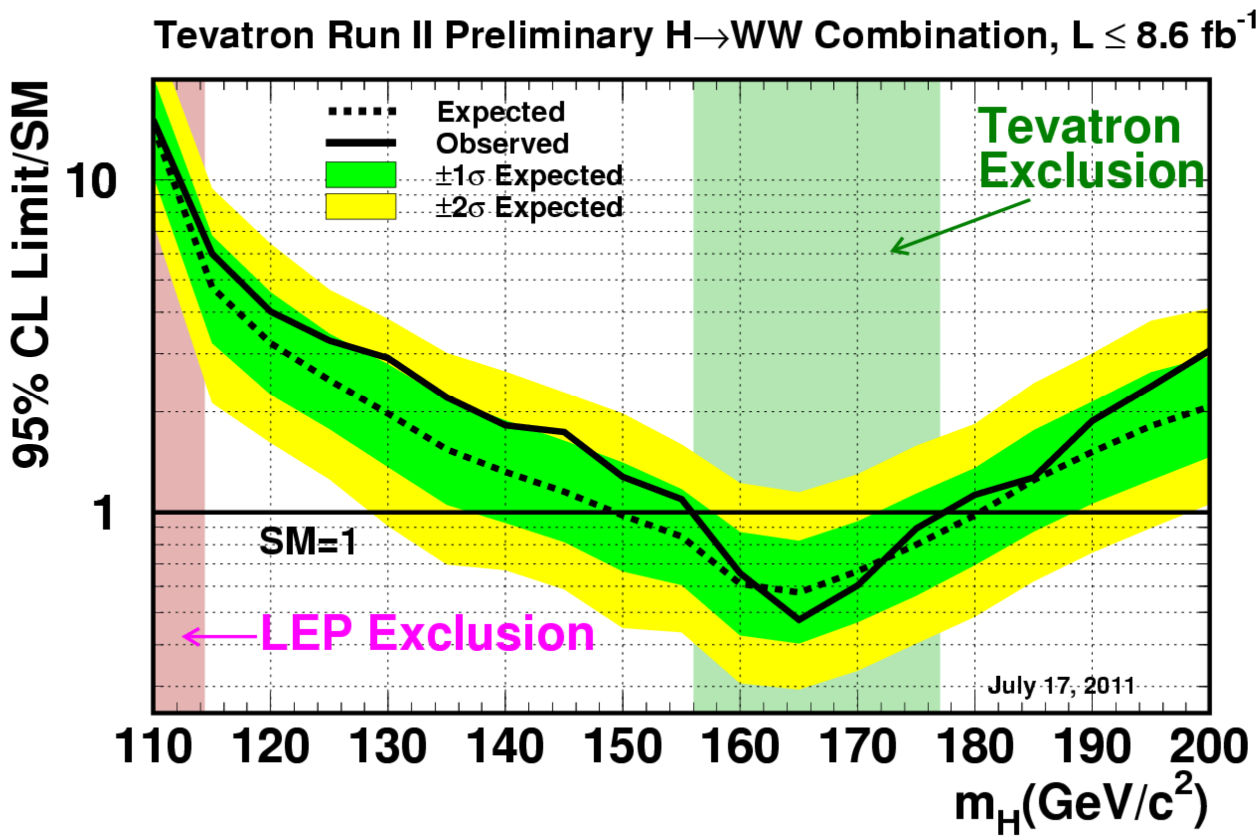



CDF sets a 95% CL limit from 156-175 GeV/$c^2$

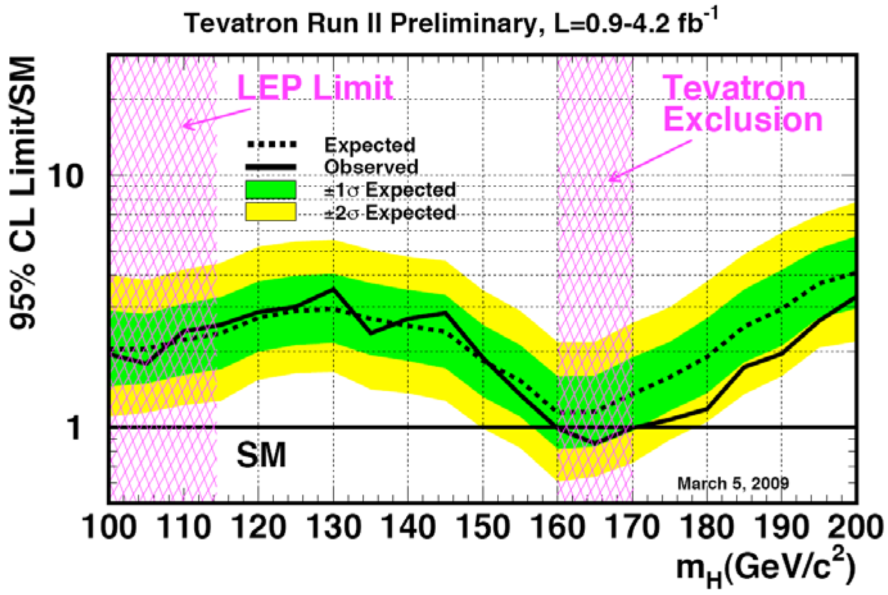
DØ sets a 95% CL limit from 163-168 GeV/$c^2$

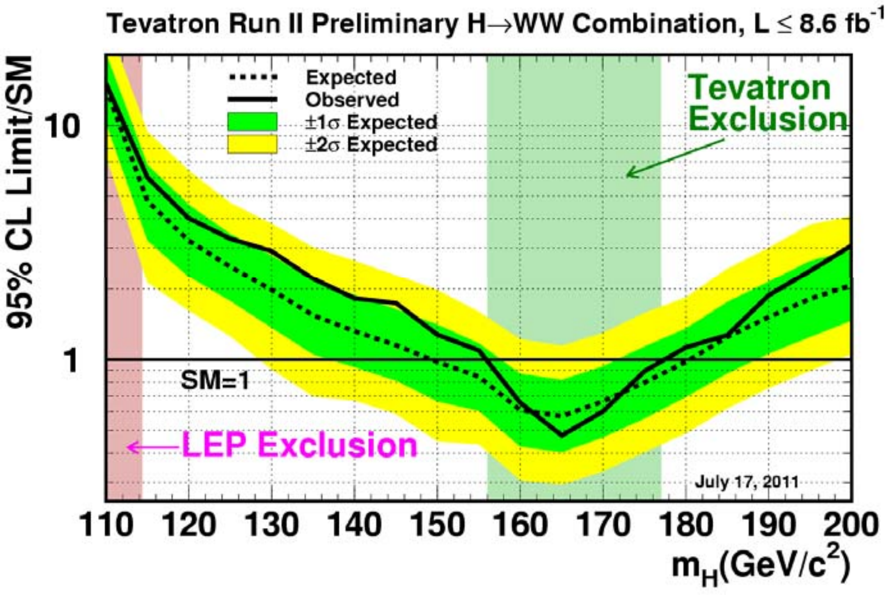
# The combined limits




CDF and DØ ruled out the range of 156-177 GeV/$c^2$ at the 95% confidence level

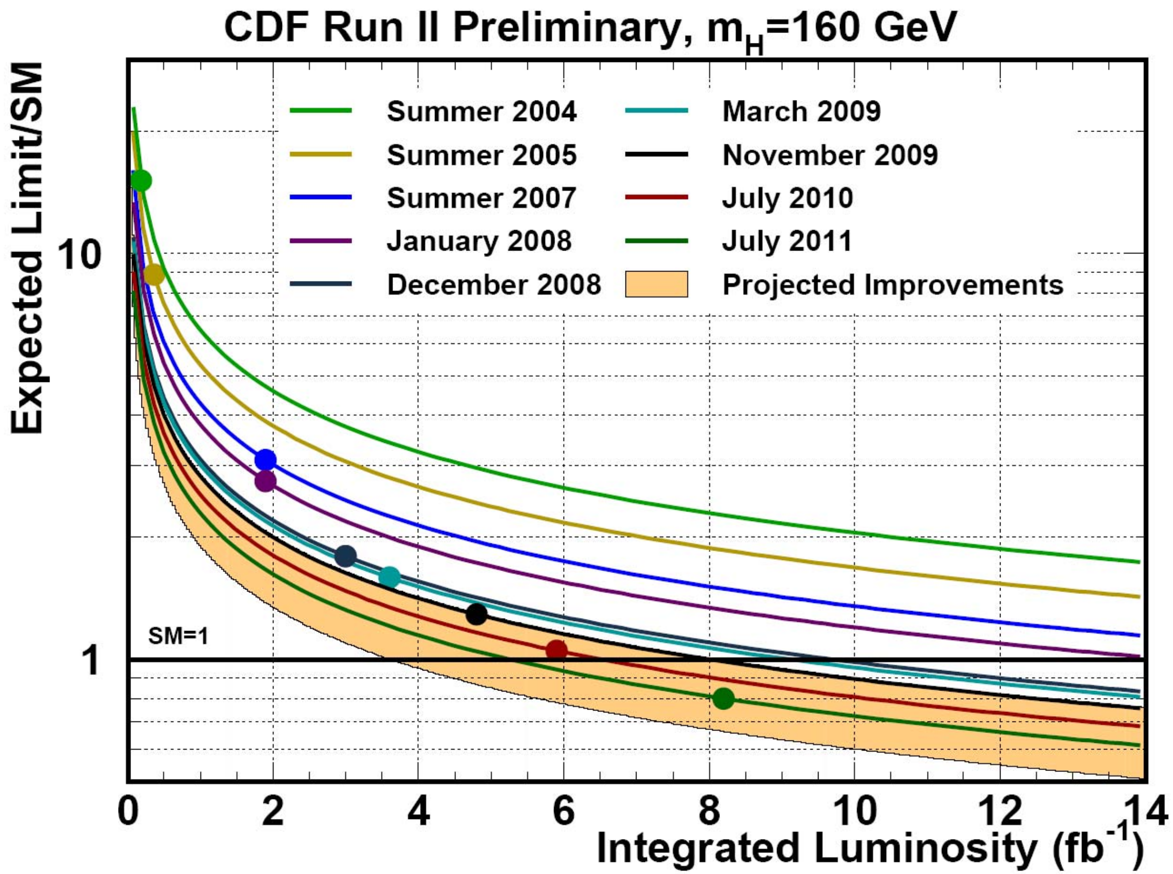
# Compare to last DPF in 2009




Huge improvement, left plot is even full combination compared to just $H \rightarrow WW$ on the right

# Cataloging improvements




We have done very well to lower the limit with both data and analysis improvements

# Conclusions and Outlook

- The high mass Higgs search at CDF and DØ have been very successful
  - Drove first exclusion since LEP
- We now have welcome competition from ATLAS and CMS
- We are trying to help out at low mass as much as we can
  - Sensitivity goes down to 130 $GeV/c^2$
  - Want to exclude as much of 100-185 $GeV/c^2$ as possible
- Looking for one final update with both improvements and the utilization of the final data set from the Tevatron