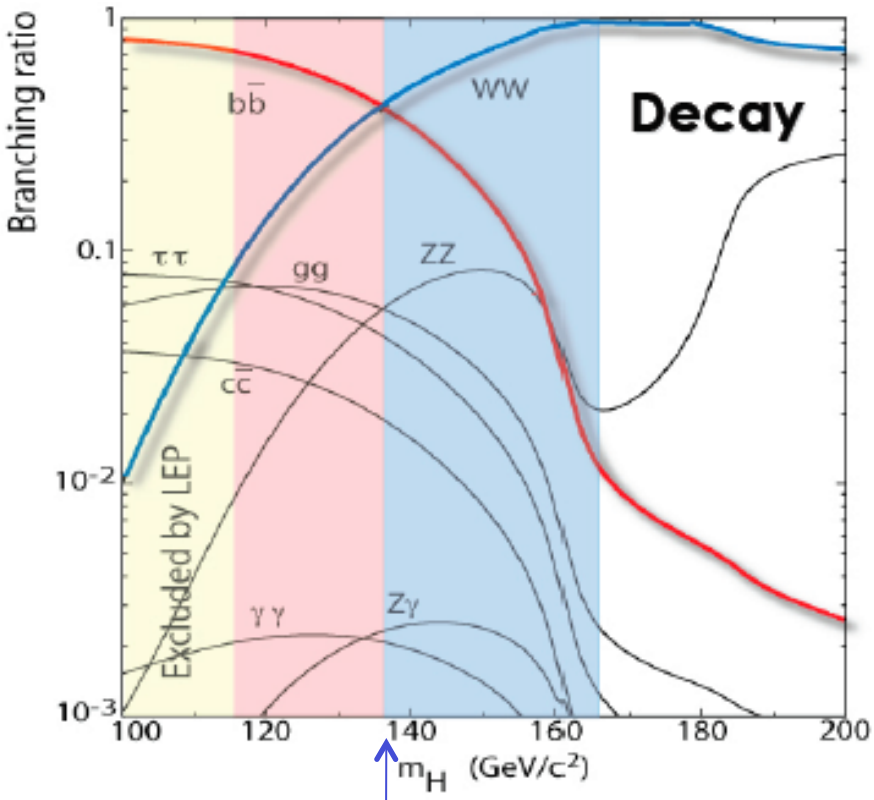
Tevatron High-mass Higgs Searches

Eric James
Fermi National Accelerator Lab
for the CDF and D0 collaborations

July 29th, 2011
Higgs Hunting 2011 Workshop

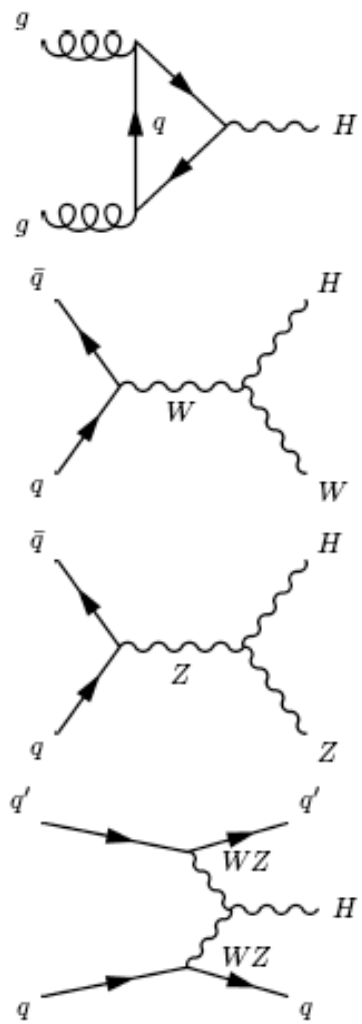
Higgs Decay

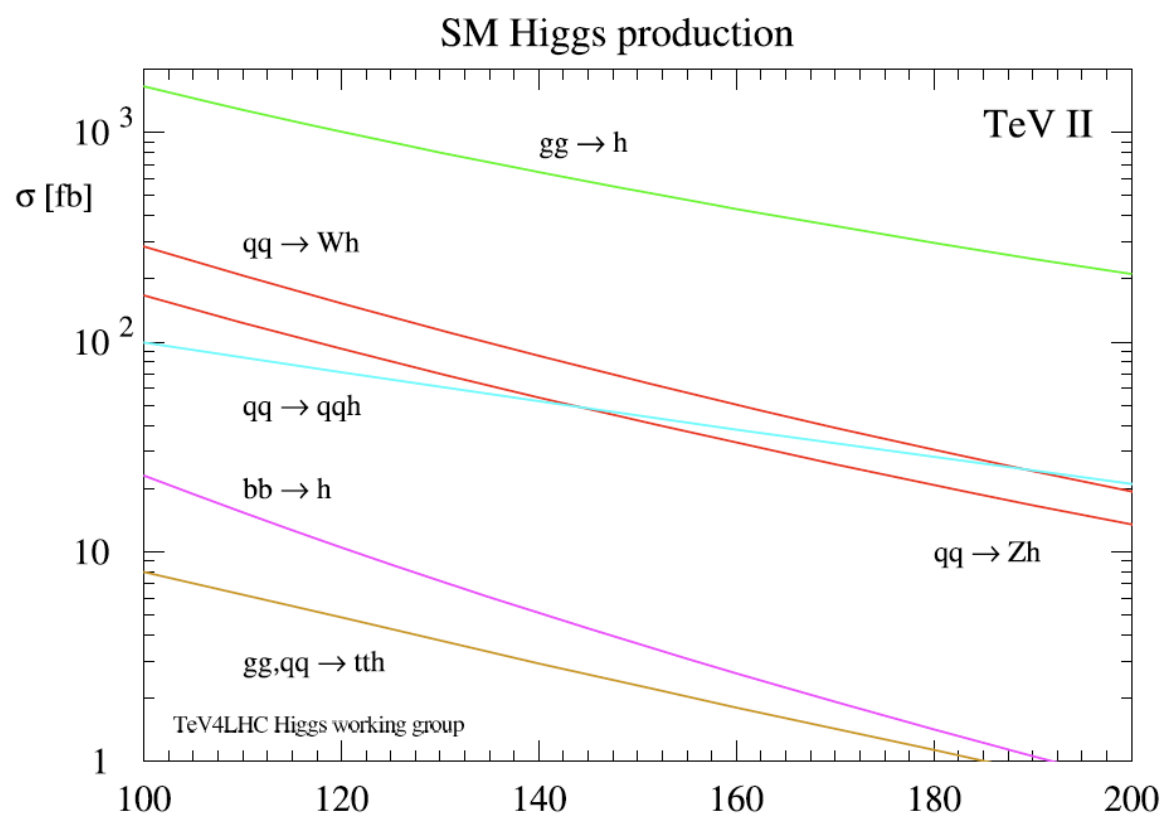


Cross-Over Point
(m_H ~ 135 GeV)

- Low Mass
  - Focus on H→bb
  - Also H→ττ and H→γγ
- High Mass
  - Focus on H→WW
  - Also H→ZZ

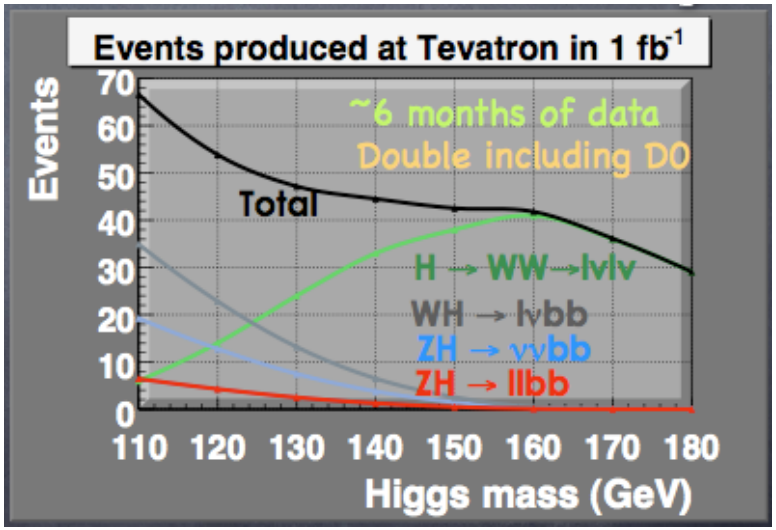
Higgs Production at Tevatron





General Analysis Approach

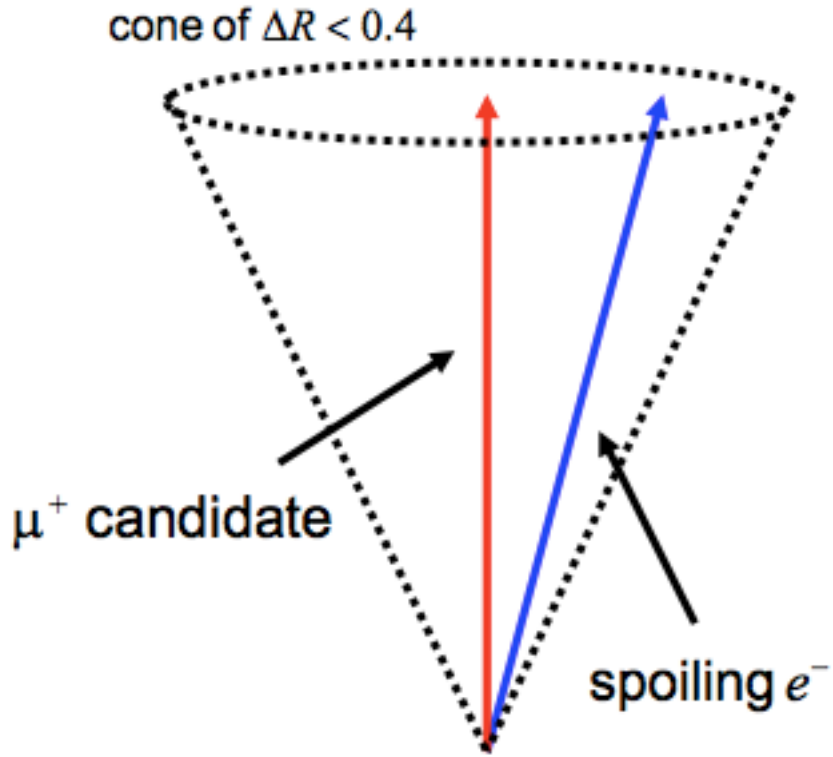
- Step #1 : Select an inclusive event sample that maximizes the acceptance for a potential Higgs signal
- Step #2 : Carefully model all backgrounds and cross check using control regions in data
- Step #3 : Use advanced analysis tools to separate signal from background based on event kinematics



Each Tevatron experiment expects to reconstruct/select roughly 8 events per fb^{-1} for $m_H = 150$ GeV/c^2

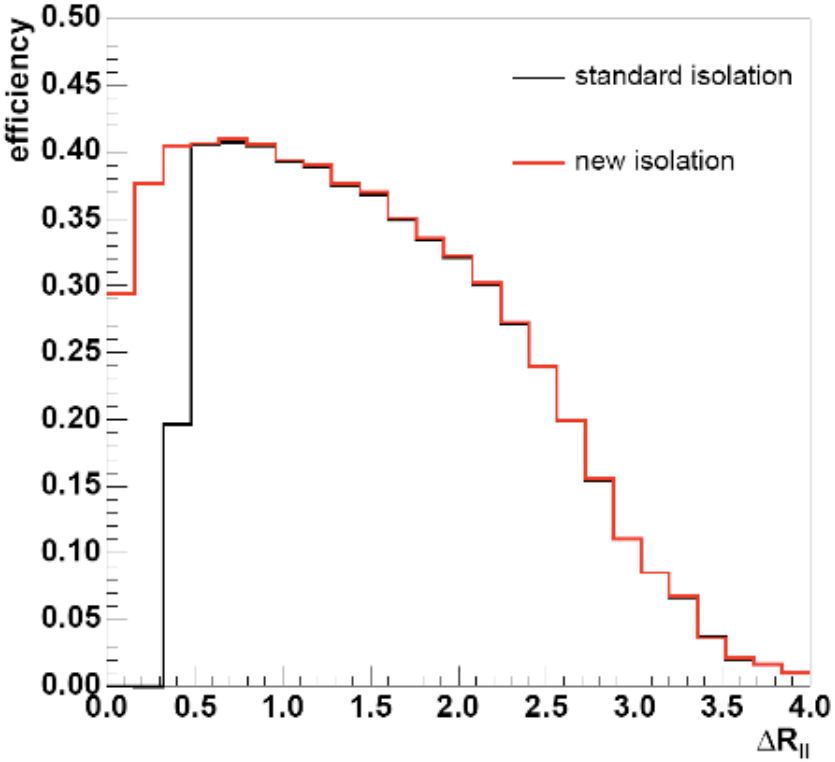
H→WW→lνlν Higgs Search

- Basic event selection : two high p_T leptons and large missing E_T
- Maximizing detector lepton acceptance is critical
- Still a few tricks up our sleeves



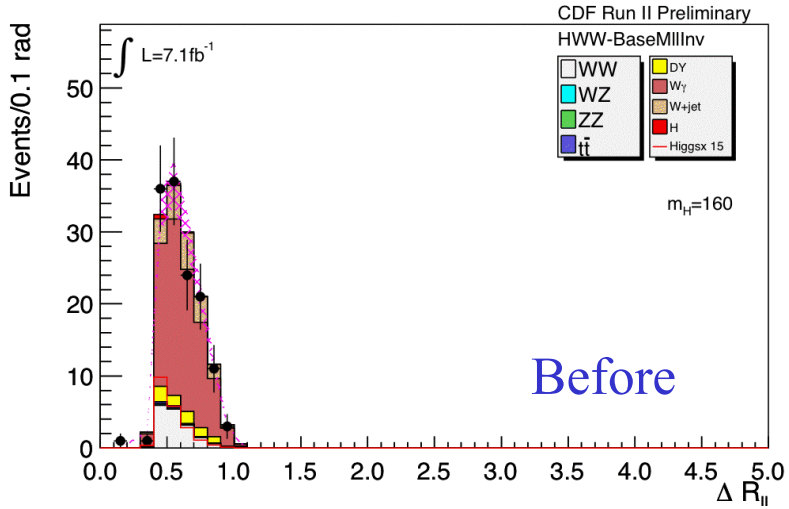
Recovering Nearby Lepton Pairs

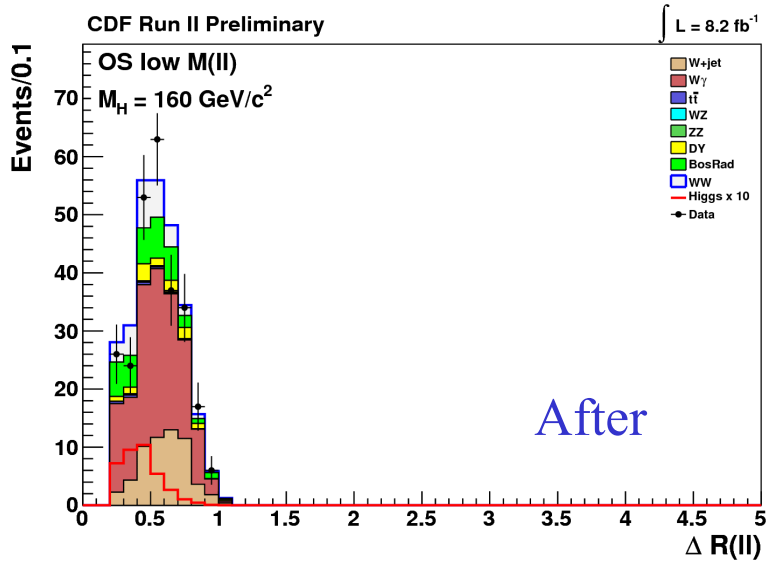
- CDF modified its isolation algorithms to prevent self-spoiling of nearby lepton pairs
- The recovered events lie in our highest S/B region



Recovering Nearby Lepton Pairs

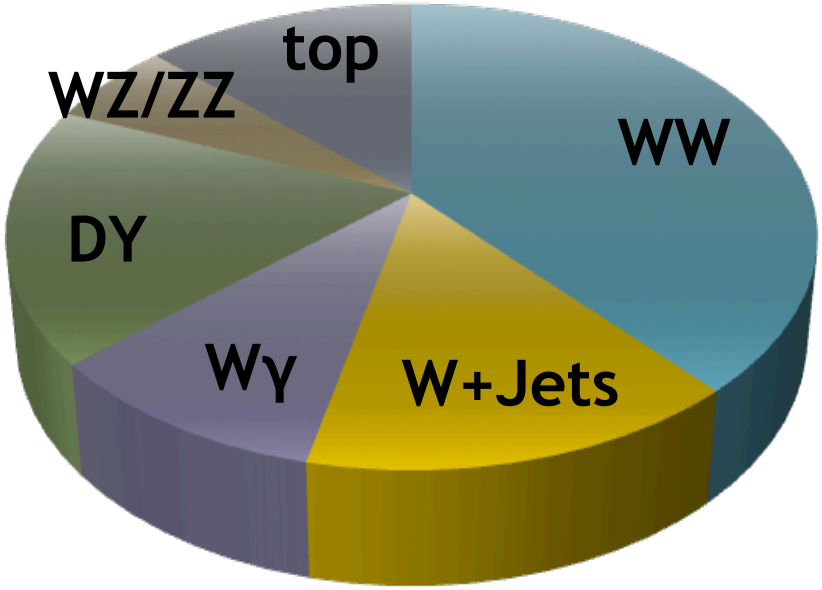
- Expected limits in CDF low-M_{ll} channel improved by more than a factor of three!





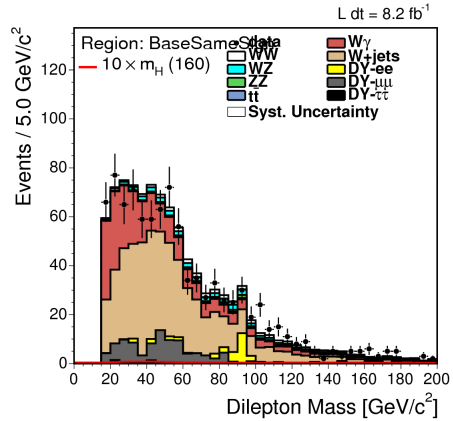
SM Backgrounds

- Need to separate small potential signal from large SM background contributions in our search channels
- Based on inclusive selection criteria S/B ~ 0.015 in the most sensitive search channels

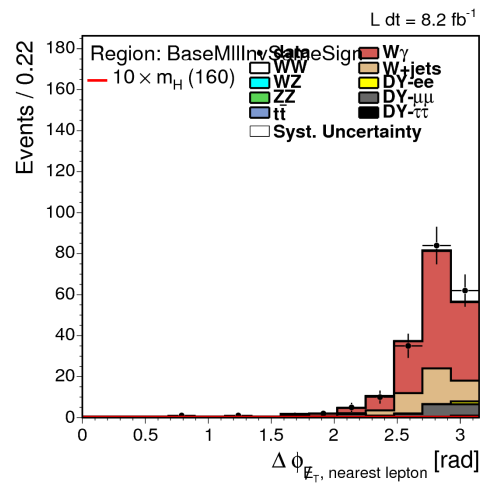


Validating Background Models

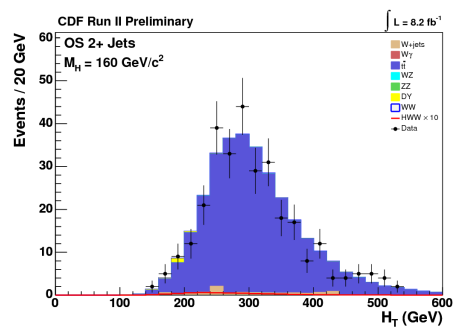
- We define specific control regions to test modeling for each individual background (whenever possible)
- In the case of dibosons (WW, WZ, and ZZ), we are not able to define specific control regions so we use cross section measurements to validate our modeling of these processes – more on this later



W+jets : same-sign dileptons



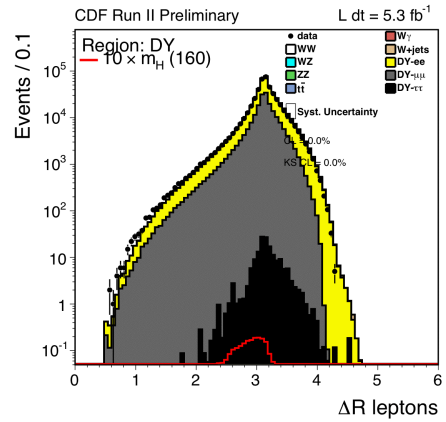
W+γ : same-sign dileptons (low M_{ll})



t-tbar : opposite-sign dileptons, 2+ jets, b-tag

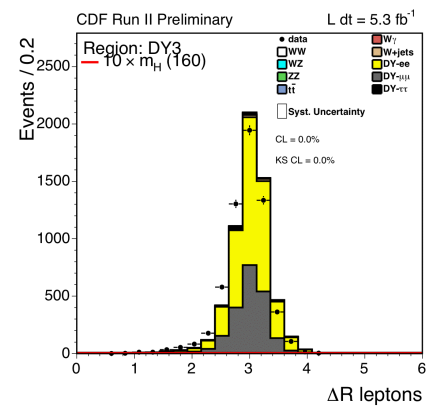
Background Model Tunings

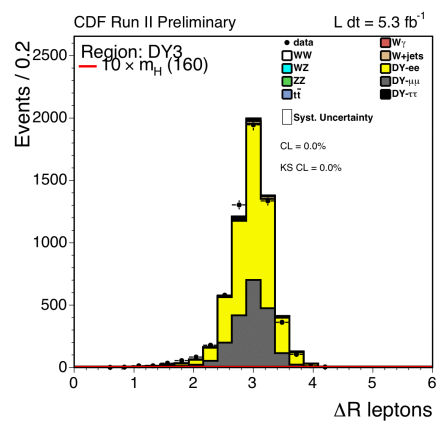
- In certain cases the MC modeling is insufficient and additional tunings are required
- Intermediate missing E_T region shows data/MC disagreement
- Determine MC tuning in control region and apply to signal region



Inclusive Sample

Intermediate missing E_T region

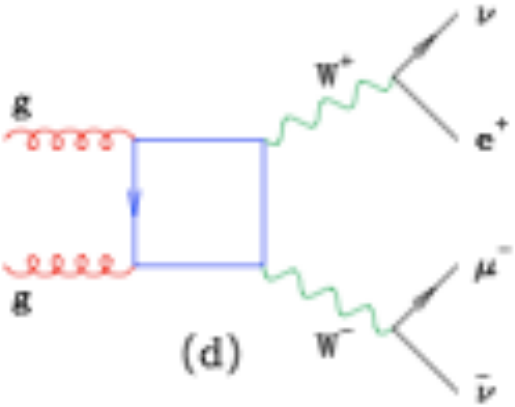


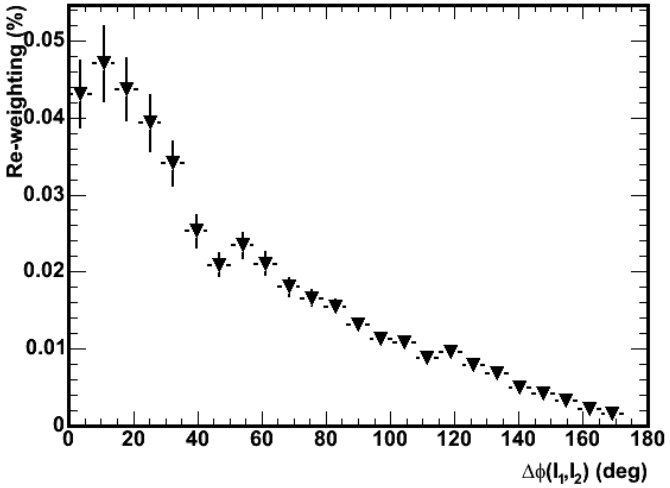


After tuning

Special Considerations

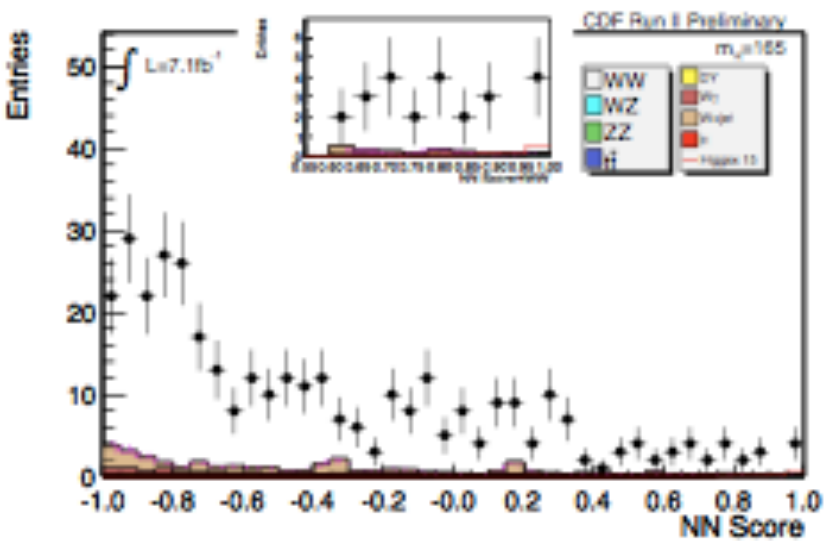
- Also need to concern oneself about potential background events in odd regions of phase space that could mimic a Higgs signal
- Classic example is WW production through box diagram (small Tevatron cross section but events are more signal-like)





Special Considerations

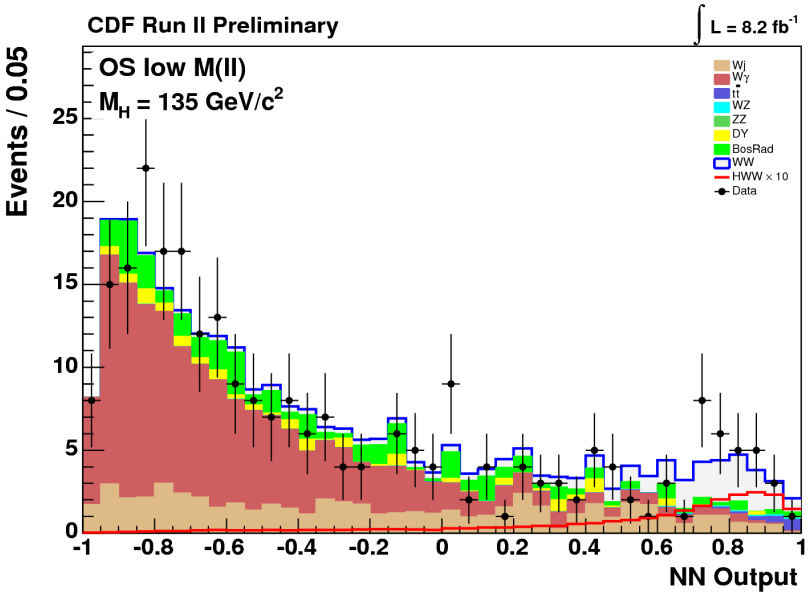
- Low-M_{ll} DY background events also sit in an very odd region of phase space
  - High P_T leptons with low opening angle
  - Large missing E_T implies mismeasured high E_T jets
- Find that a large fraction of these events come from standard dijet production where Z boson is radiated off a final state quark (not accounted for in Pythia)



Low M_{ll} intermediate missing E_T control region

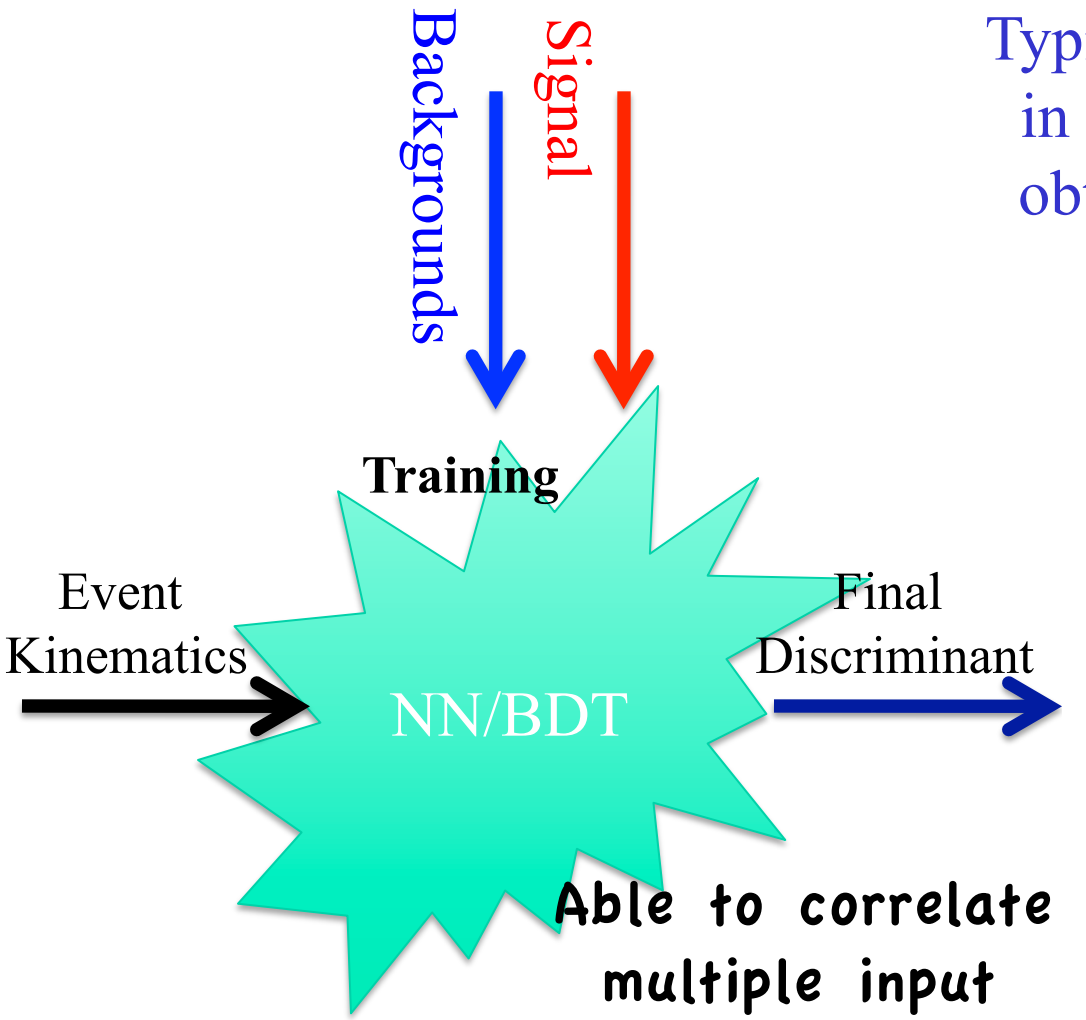
Special Considerations

- Still working to obtain a good MC model for this special class of DY events
- Instead, data events in control region are used to obtain a model for signal region events (using a MC-based extrapolation)

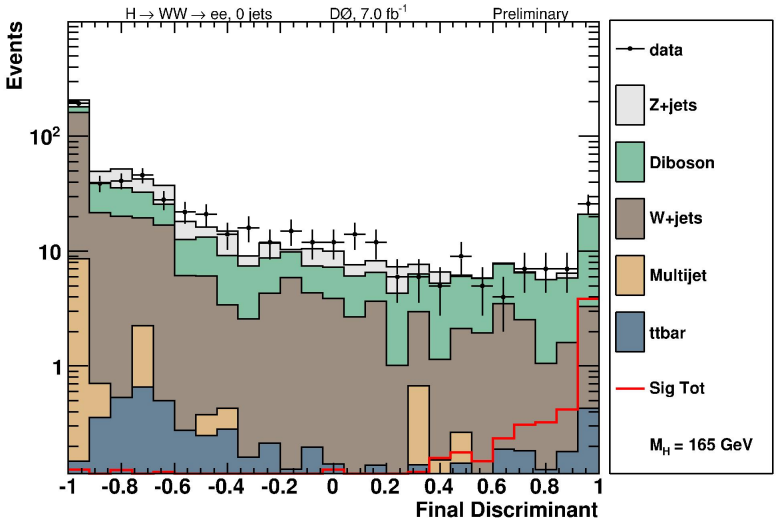


Low M_{ll} signal region

Final Discriminates



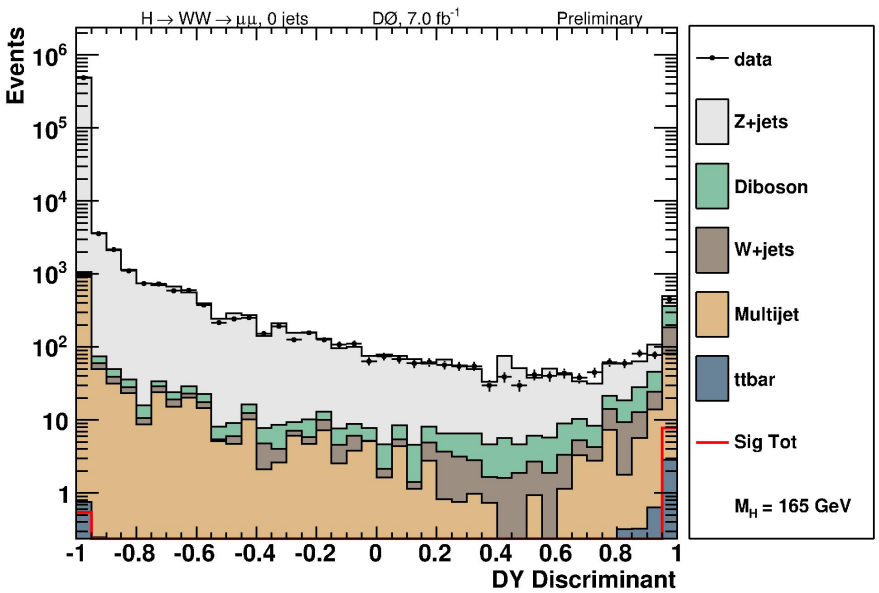
Typically these add 10-20% in sensitivity beyond that obtained from optimized, cut-based analysis



Able to correlate multiple input variables

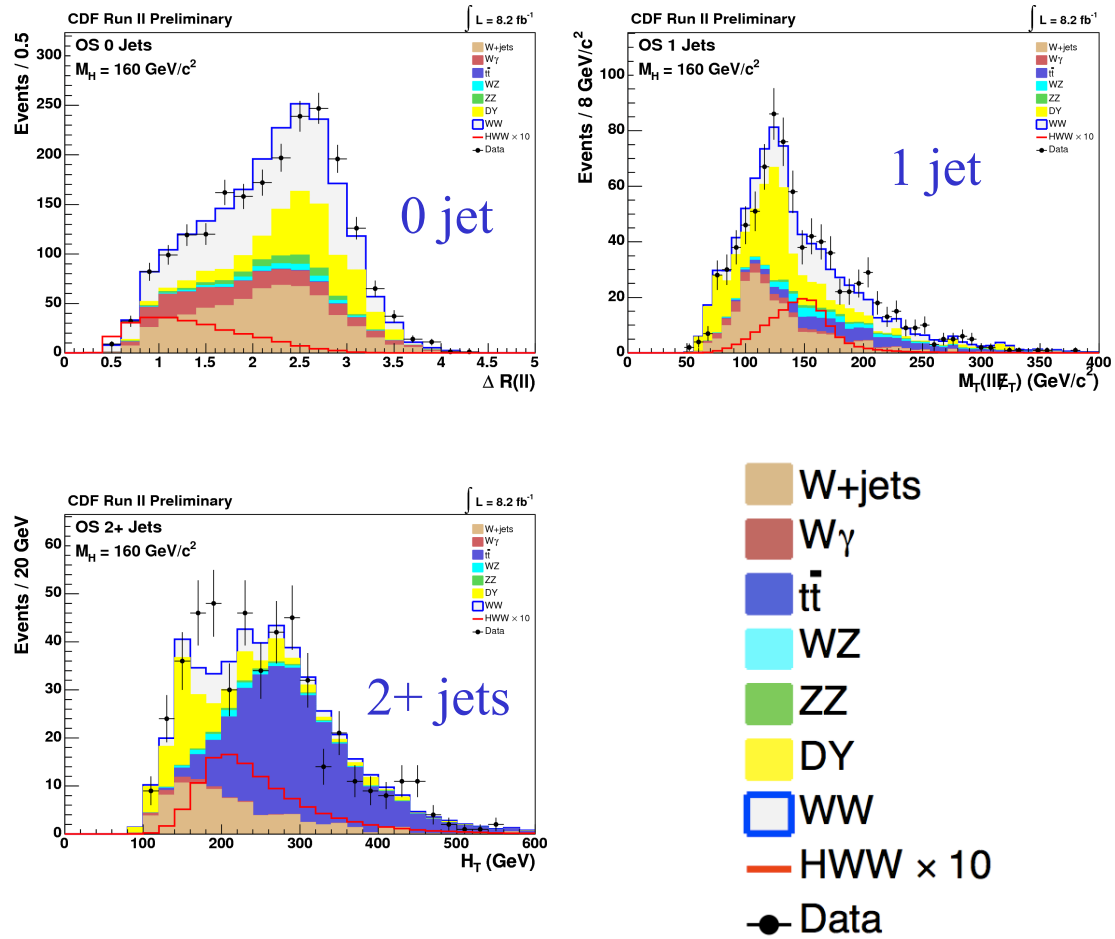
Multi-Layer Discriminants

- Several layers of multivariate discriminants are used in some cases to reduce large background components contained within inclusive candidate samples (with minimal loss of potential signal acceptance)
- In this case, DY in the D0 $H \rightarrow WW \rightarrow \mu\nu\mu\nu$ channel

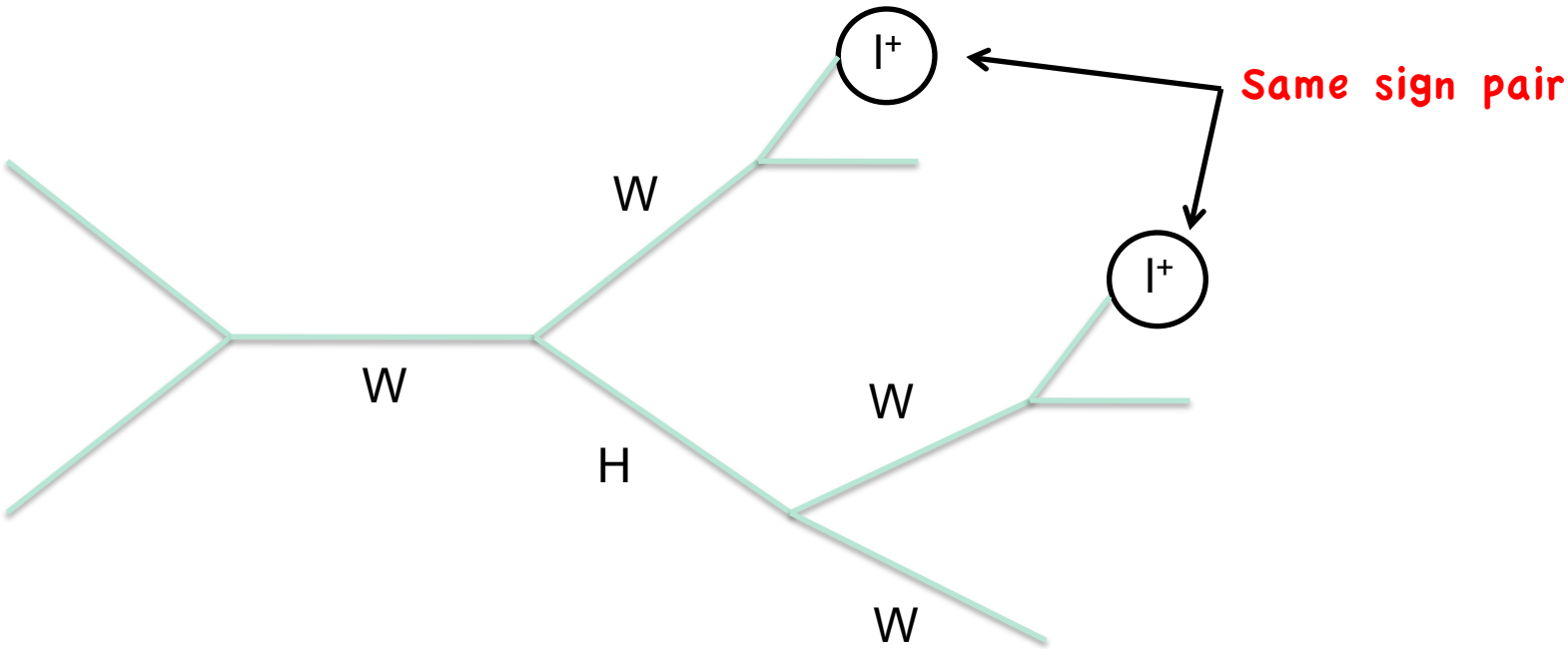


Maximizing Sensitivity

- We optimize search sensitivity by dividing events into multiple analysis channels
- This allows us to use separate, optimized discriminants for each channel based on
  - specific signal contributions
  - specific background contributions
  - specific event kinematics



Leave no Higgs Events Behind



Both CDF and D0 both include events with same-sign leptons and events with hadronic tau candidates. CDF also separates out tri-lepton events for separate analysis

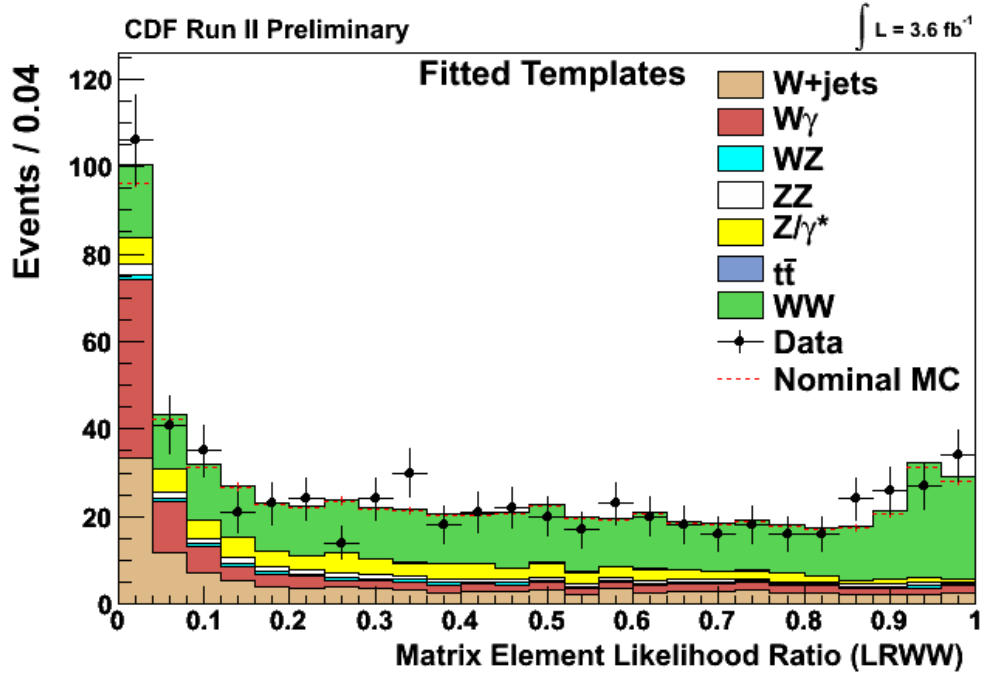
High Mass Search Channels

Channel	Main Signal	Main Background	Most Important kinematic variables
OS dileptons, 0 Jets	gg→H	WW	LR_{HWW}, ΔR_{ll}, H_T
OS dileptons, 1 Jet	gg→H	DY	ΔR_{ll}, $m_T(ll,E_T)$, $\not{E}_T$
OS dileptons, 2+ Jets	Mixture	t-tbar	H_T, ΔR_{ll}, M_{ll}
OS dileptons, low M_{ll}, 0 or 1 Jet	gg→H	W+γ	$p_T(l2)$, $p_T(l1)$, $E(l1)$
SS dileptons, 1+ Jet	WH→WWW	W+Jets	$\not{E}_T$, $\sum E_T^{jets}$, M_{ll}
Tri-leptons, no Z candidate	WH→WWW	WZ	$\not{E}_T$, ΔR_{ll}^{close}, Type(lll)
Tri-leptons, Z candidate, 1 Jet	ZH→ZWW	WZ	Jet E_T, ΔR_{lj}, $\not{E}_T$
Tri-leptons, Z candidate, 2+ Jets	ZH→ZWW	Z+Jets	M_{jj}, M_T^H, ΔR_{WW}
OS dilepton, electron + hadronic tau	gg→H	W+Jets	$\Delta R_{l\tau}$, τ id variables
OS dilepton, muon + hadronic tau	gg→H	W+Jets	$\Delta R_{l\tau}$, τ id variables

Validation of Search Techniques

- Diboson cross section measurements based on the same tools and data samples used for the $H \rightarrow WW \rightarrow l\nu l\nu$ search provide an important cross check on our background modeling and analysis techniques

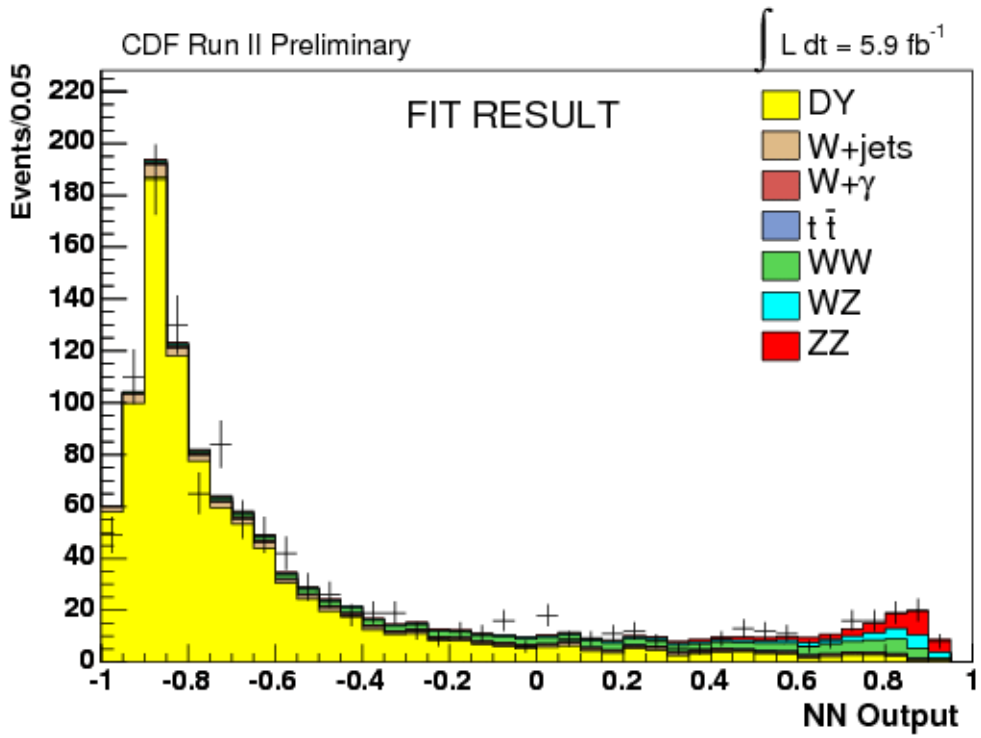
$WW \rightarrow l\nu l\nu$: $\sigma(WW) = 12.1 \,^{+1.8}_{-1.7}$ pb



Validation of Search Techniques

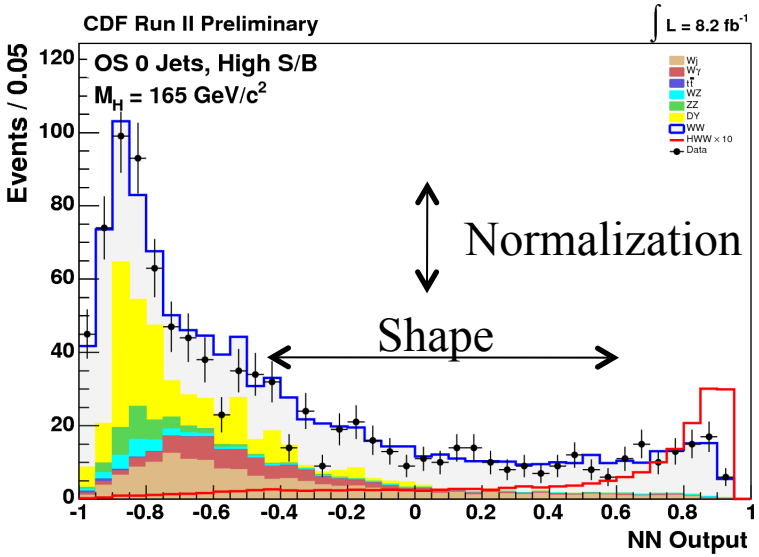
- Diboson cross section measurements based on the same tools and data samples used for the $H \rightarrow WW \rightarrow l\nu l\nu$ search provide an important cross check on our background modeling and analysis techniques

$ZZ \rightarrow ll\nu\nu$: $\sigma(ZZ) = 1.45 \,^{+0.60}_{-0.51}$ pb



Systematic Uncertainties

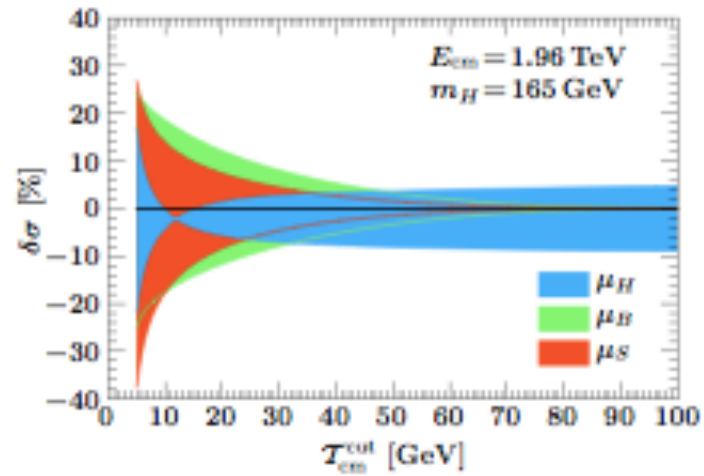
- We consider uncertainties both on the overall normalization of each signal/background process and on the shapes of the final discriminant templates for each signal/background process
- In the limit-setting procedure systematics are included as nuisance parameters, taking into account the correlations between different channels



Using this approach we are able to further constrain our background uncertainties directly from the data

Theoretical Uncertainties

- Since we combine searches focusing on different Higgs production and decay modes, cross section limits are given with respect to nominal SM predictions
- This forces us to incorporate theoretical predictions and uncertainties for signal cross sections and branching ratios
- Changed in each iteration to reflect recent theoretical developments

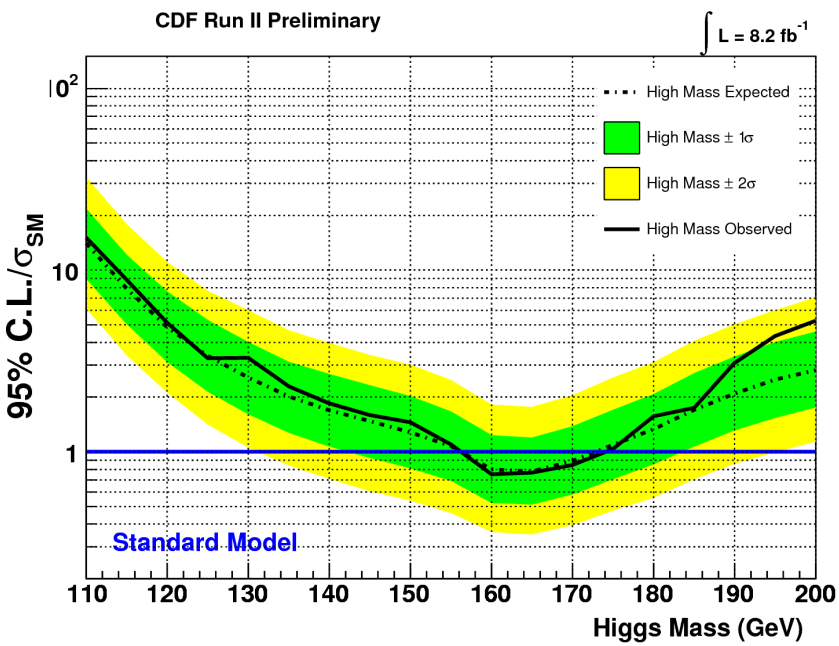


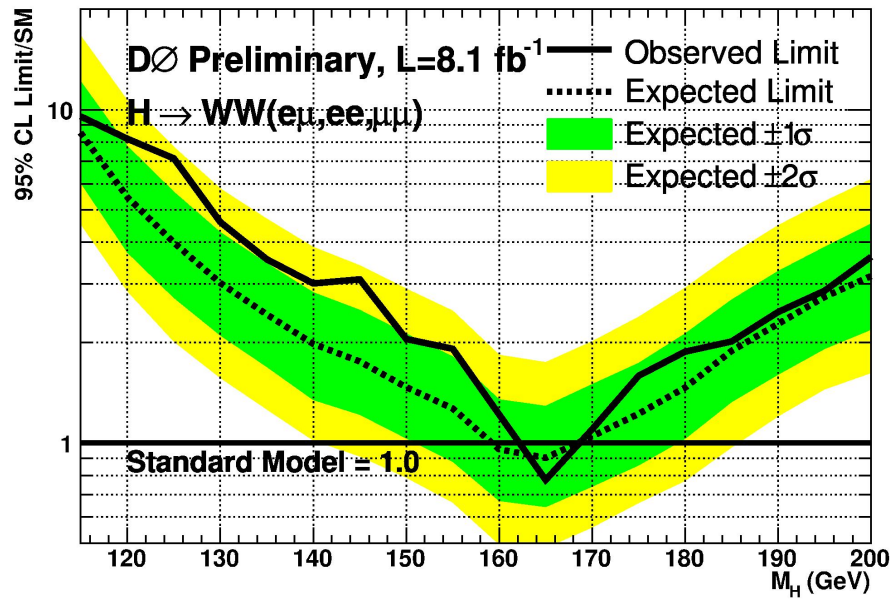
Berger et al., arXiv:1012.4480v2

channel	scale 0	scale 1	scale 2
0 jet	13.4%	-23.0%	-
1 jet	-	35.0%	-12.7%
2+ jets	-	-	33.0%

Stewart and Tackmann, arXiv:1107.2117v1

CDF/D0 H→WW→lνlν Limits

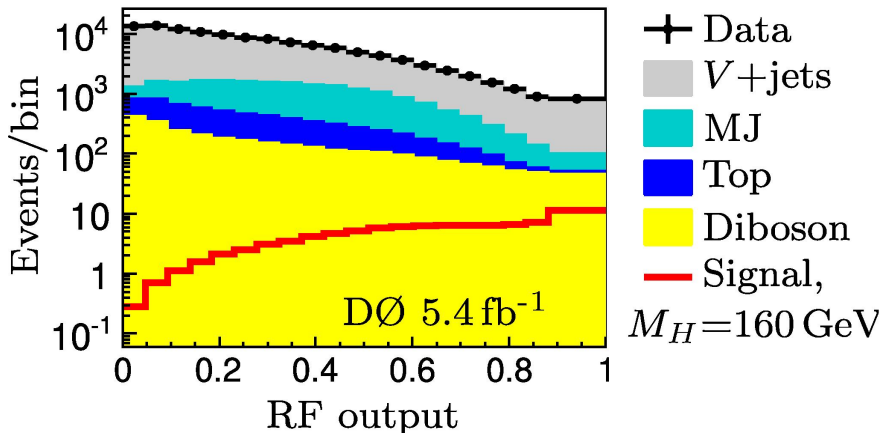


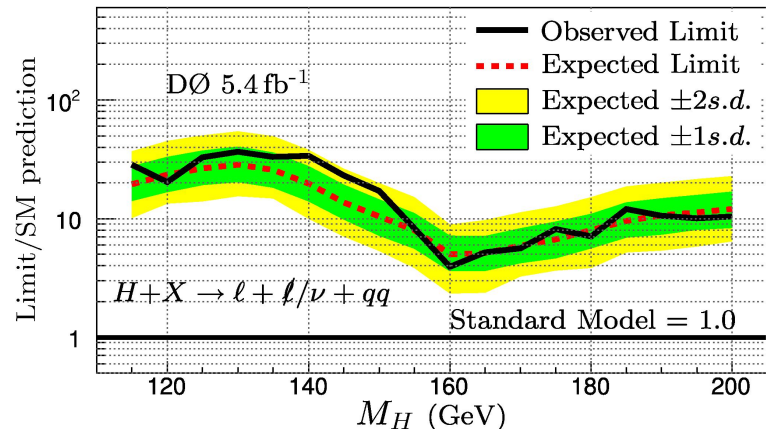


CDF

D0

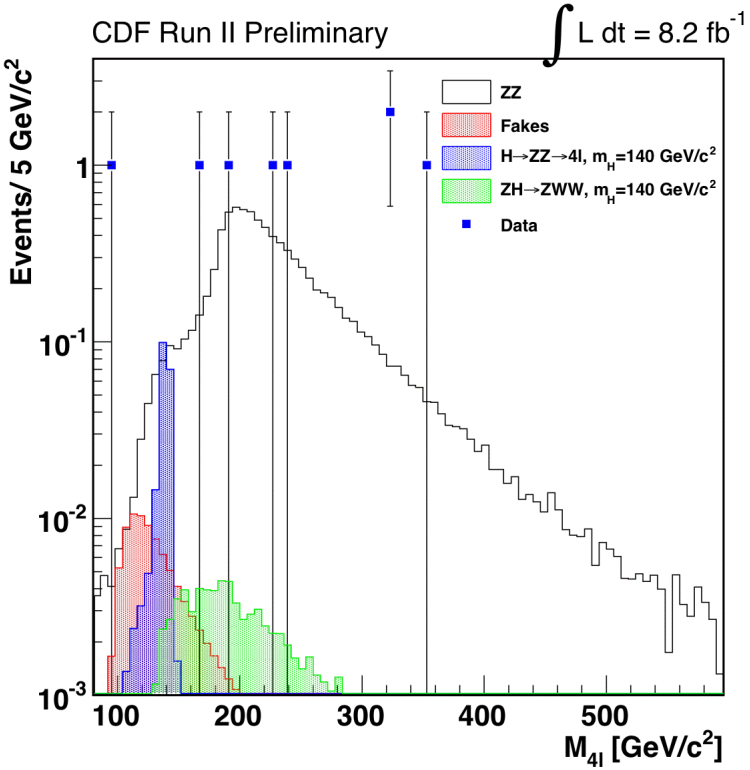
Additional High-mass Channels

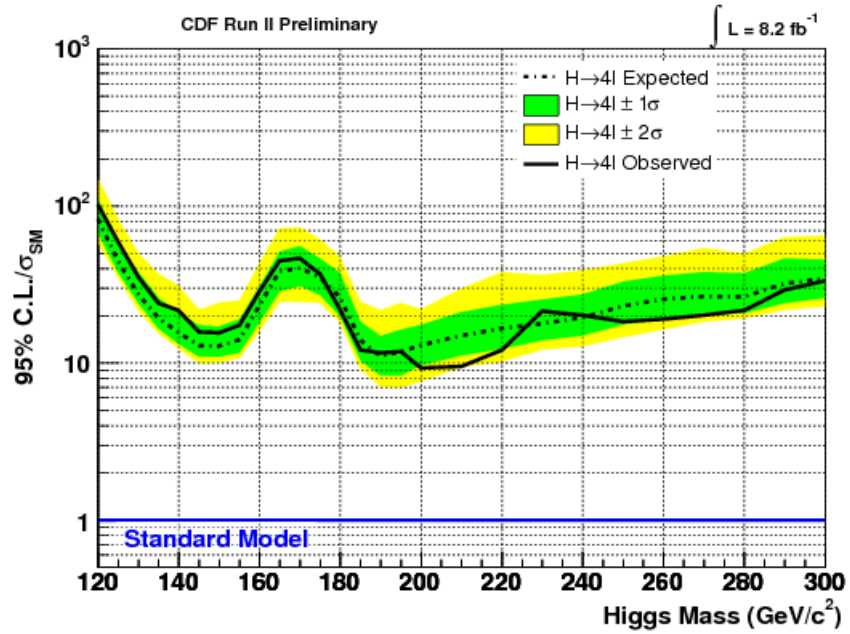




D0 H→WW→lνjj Analysis

Additional High-mass Channels





CDF H→4l Analysis

Conclusions/Outlook

- We continue to obtain large improvements in search sensitivity beyond that expected from simply adding more data
- We are on track to deliver high-mass Higgs search results next spring based on the full 10fb^{-1} datasets that achieve our expected sensitivity goals