Search for SM Higgs in WW^* channel at CDF

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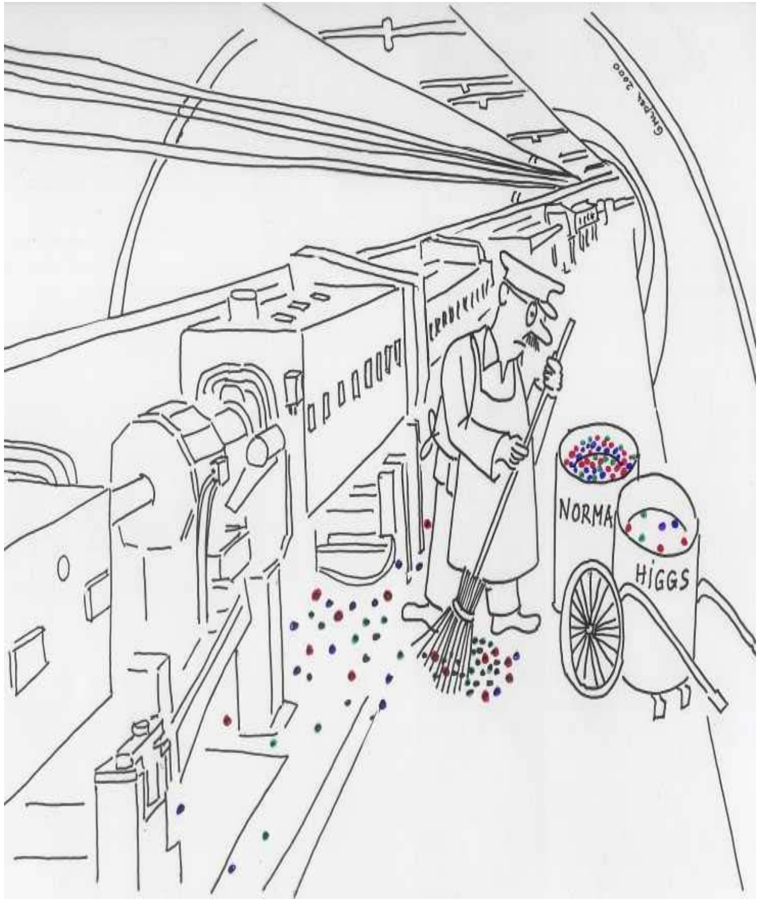
On behalf of the CDF Collaboration

TEV4LHC Workshop
Fermilab October 20-22, 2005

Overview

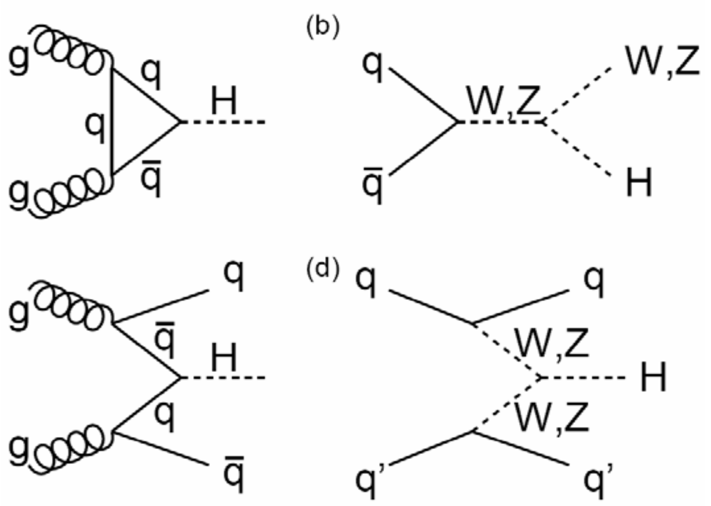
- SM Higgs Production and Decay
- Sensitivity to Non-SM Physics
  - 4^{th} Generation Fermion Families
- Di-boson Cross-Section Measurement at CDF
- Signal and Background for H→WW
- 95% CL. on σxBR(H→WW*)
- Prospects for 1/fb
- Looking forward

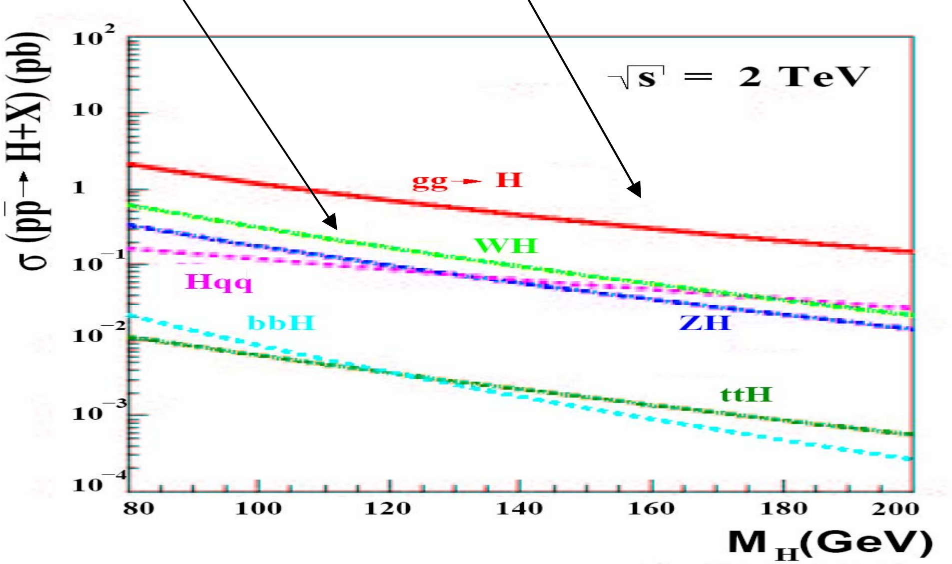
"Panning for Higgs"



Standard Model (SM) Higgs Production …

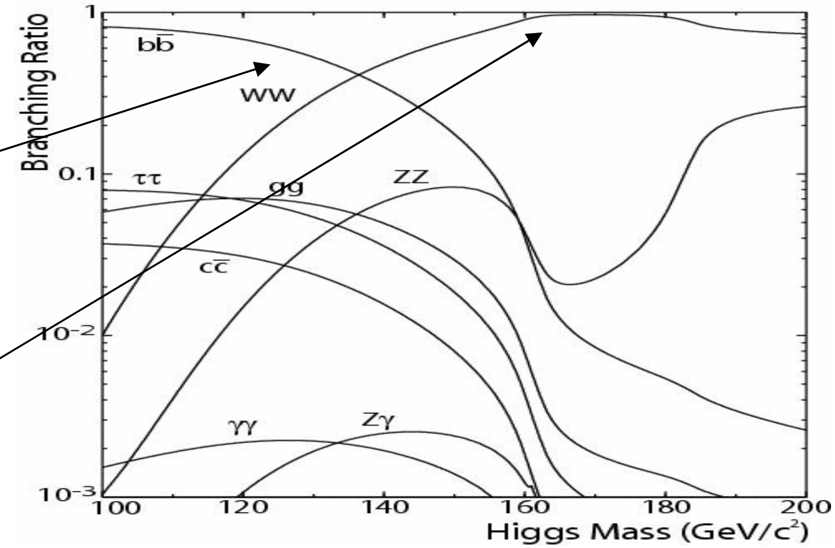
- Higgs Production in SM
  - Four main production mechanisms
  - Gluon fusion dominant
  - Higgs-strahlung also relevant at the Tevatron (x8 smaller cross-section)

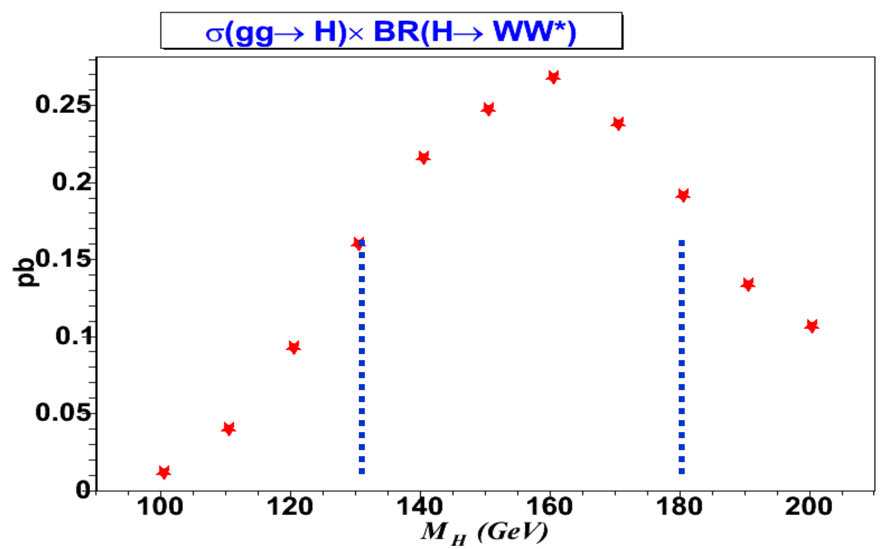




… And Higgs Decay

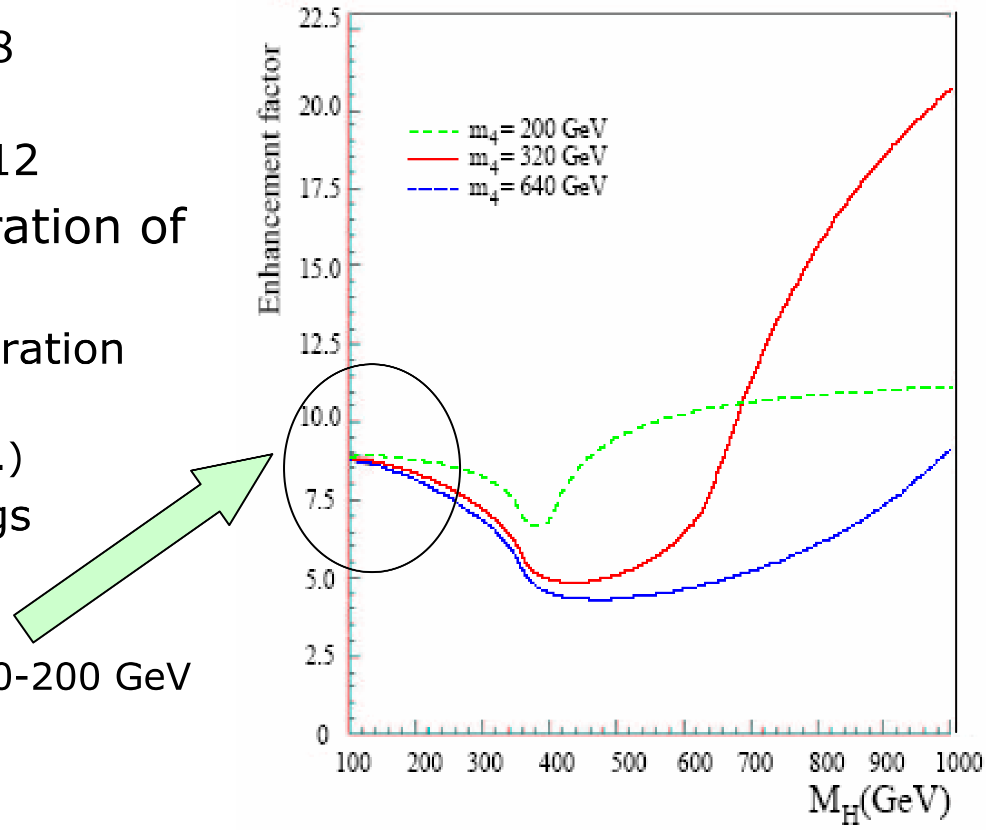
- Higgs Decay in SM
  - M_H< 135 GeV
    - Higgs decays predominantly into bb
  - M_H>135 GeV
    - Higgs decays mainly into WW
  - gg→H→WW*
    - Only search channel using single Higgs production through gluon fusion
    - Maximum sensitivity for M_H=160 GeV





Non-SM Production: 4th Generation Models

- Number of fermion generations N_g not fixed by the SM
  - Asymptotic freedom: N_g<8
  - LEP data: number of light neutrinos N=2.994+/-0.012
- An additional fourth generation of quarks
  - Mass limit for the 4th generation quarks
    - $m_{b'}$>199 GeV/c² (95% CL.)
  - Increase gluon fusion Higgs production cross-section
    - Higgs couples to mass
    - X8 larger $\sigma(gg \rightarrow H)$ for 100-200 GeV Higgs

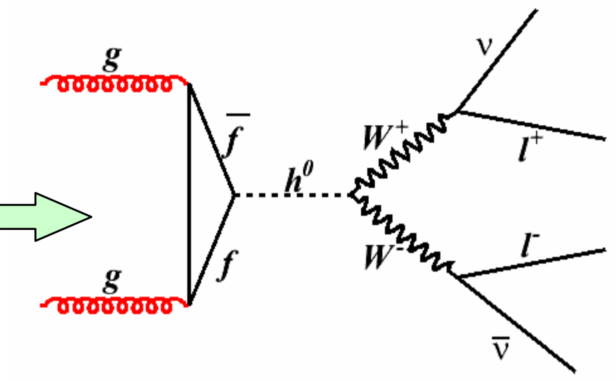


E. Arik-hep-ph/0502050

Higgs WW final states

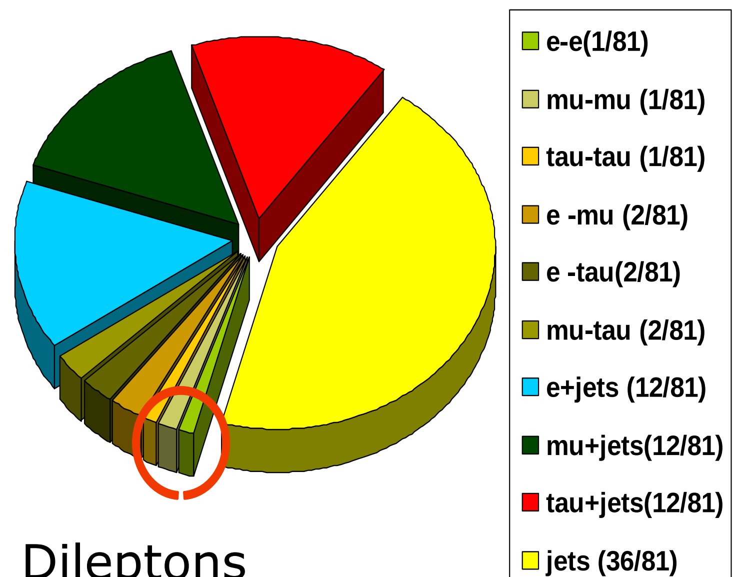
- **W boson decay channels:**
  - leptonically ~ 33 % (ℓ =e,μ,τ)
  - hadronically ~ 67%
- **3 signatures, from WW decay:**
  - Dilepton: BR= 5%
    - Very small BR, but easily triggerable, clean
    - Sensitive to leptonic decays of taus
    - Might be the only signature to identify H→WW at the Tevatron
  - Single lepton+τ_h: BR= 4%
    - Could potentially be used at the Tevatron
  - Single lepton+jets: BR=30%
    - BR larger, large W+multi-jets backgrounds
    - Previous studies concluded that there is not much hope to use this channel
  - All-hadronic: BR=45%
    - BR largest, hard to trigger, enormous QCD backgrounds

Convention: ℓ =e,μ



Final state

- 2 leptons
- missing energy (neutrinos)



Dileptons

Signal and Backgrounds

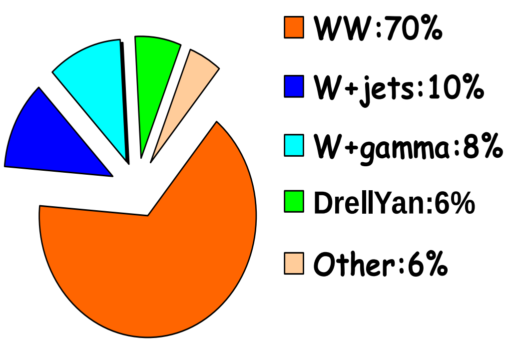
- Signal:
  - Use PYTHIA + GEANT detector simulation
  - 10 Higgs mass points between 110-200 GeV (in 10 GeV steps)

$M_H(\mathrm{GeV}/c^2)$	110	120	130	140	150	160	170	180	190	200
$\sigma \times BR(H \to WW)$(pb)	0.04	0.09	0.15	0.21	0.24	0.26	0.23	0.18	0.13	0.10
$H \to WW(\ell\nu\ell\nu)$ events in 360 pb^{-1}	0.7	1.6	2.8	3.8	4.3	4.6	4.1	3.3	2.3	1.8

- Backgrounds:
  - Vector boson pair production
    - WW, WZ, ZZ (estimated from PYTHIA)
      - WW about 70% of the total background (m_H=160GeV)
  - Vector boson production
    - Drell-Yan: $Z/\gamma^* \to ee/\mu\mu/\tau\tau$ (estimated from PYTHIA)
    - W+jets(jet→e/μ) (estimated completely from data)
    - W+γ (γ→e) (estimated from MC)
  - Smaller backgrounds
    - $t\bar{t}$, multijets

Relative backgrounds

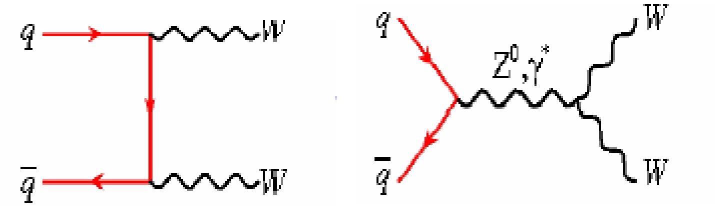
M_H=160GeV



- Luminosity:
  - We analyzed 360pb^{-1} of Run II data.
    - (weighted value–different subsystem requirements).

Diboson Production

- WW production is the dominant background
  - Compulsory to first measure the WW production cross-section
  - Select a large WW sample to check
    - Simulation modelling of the data (PYTHIA, ALPGEN), ex: $\Delta\phi(l,l)$
    - Trigger, lepton identification efficiencies, everything comes into the mix
- Still statistically limited



$200\ pb^{-1}$	ℓ: ee, $e\mu$, $\mu\mu$
DY	$1.06^{+2.03}_{-0.44}$
WZ	0.76 ± 0.06
ZZ	0.70 ± 0.07
$W+\gamma$	1.06 ± 0.19
W+jets	1.34 ± 0.66
$t\bar{t}$	0.08 ± 0.02
WW	10.20 ± 1.19
Bkg	$5.0^{+2.2}_{-0.8}$
Data	17

$$\sigma(p\bar{p} \to WW) = 14.6^{+5.8}_{-5.1}(stat)^{+1.8}_{-3.0}(syst) \pm 0.9(lum)pb$$

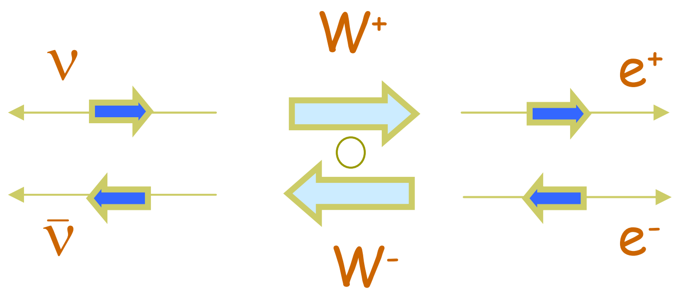
[PRL 94, 211801 (2005)] (CDF)

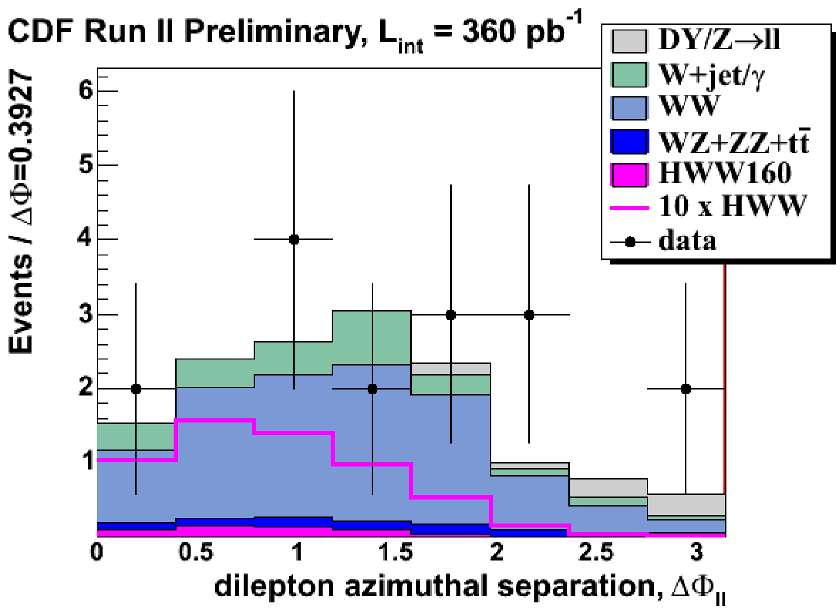
$$\sigma_{WW}(\text{NLO}) = 12.4 \pm 0.8\text{pb}$$

S/B = 2

Handles to separate WW from HWW

- It is the main challenge of this analysis
- Exploit spin correlations
  - Higgs is a spin 0 particle
  - V-A structure in W decay
    - Leptons tend to be parallel
      - Small $\Delta\phi(\ell, \ell)$
    - Neutrinos go parallel
      - Typically larger missing energy than WW
    - Small di-lepton invariant mass
- It is important to have Higgs mass-dependent selection requirements
  - Heavier the Higgs, better the separation of the signal from WW





$\Delta\phi(\ell, \ell)$ after event selection

Event Selection

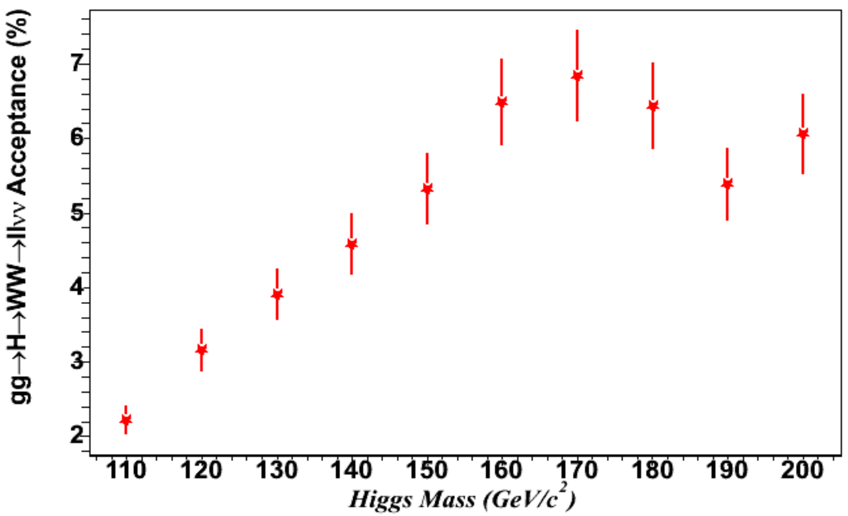
- Optimized for the best a-priori 95% C.L. on σxBR(H→WW)

Backgrounds rejected

- Two leptons:
  - p_T trigger, non-trigger>(20,10) GeV ⇨ WZ, ZZ
  - Muons: $|\eta|<1.0$; electrons: ($|\eta|<1.0$, $|\eta|<2.0$) ⇨ Υ, $b\bar{b}$
- $M_{\ell\ell}$ > 16 GeV
- Jet veto (signal can only have soft ISR jets)
  - 0jet \|\| 15<E_{T1jet}<55 GeV \|\| 15<E_{T2jet}<40 GeV ⇨ $t\bar{t}$
    - jets: $|\eta|<2.5$
- $\not{E}_T > \frac{1}{4} M_H$ ⇨ Drell-Yan, QCD
- $\not{E}_T$ >50 GeV \|\| $\Delta\Phi$(met, closest lep/jet)>20º ⇨ Drell-Yan
- Opposite sign ⇨ $W+\gamma$, $W+jets$
- $M_{\ell\ell} < (\frac{1}{2} {*} M_H - 5)$ GeV ⇨ Drell-Yan, WW
- $p_{T1}^{lep1}+p_{T2}^{lep2}+\not{E}_T < M_H$ ⇨ $t\bar{t}$

Signal Acceptance

H→WW acceptance; does not include BR(H→WW)



Cut (M_H=160GeV)	Efficiency (%)
2 well-identified leptons	9.14 ± 0.04
M_{ll} > 16 GeV	96.1 ± 0.06
jet veto	88.2 ± 0.11
MET > $M_H/4$	80.5 ± 0.14
MET>50GeV || $\Delta\Phi_{met,l/j} > 20^o$	96.4 ± 0.07
opposite signs	98.7 ± 0.04
$M_{ll} < M_H/2 - 5$ GeV	98.9 ± 0.04
$p_t^{lep1} + p_t^{lep2} + met < M_H$	97.2 ± 0.07

Systematic errors

- ISR (initial state radiation) 3.3%
- Parton distribution functions 3.0%
- α_s 3.0%
- Lepton ID, Track Isolation 2.0%
- Jet energy scale, Trigger Effic 1.0%

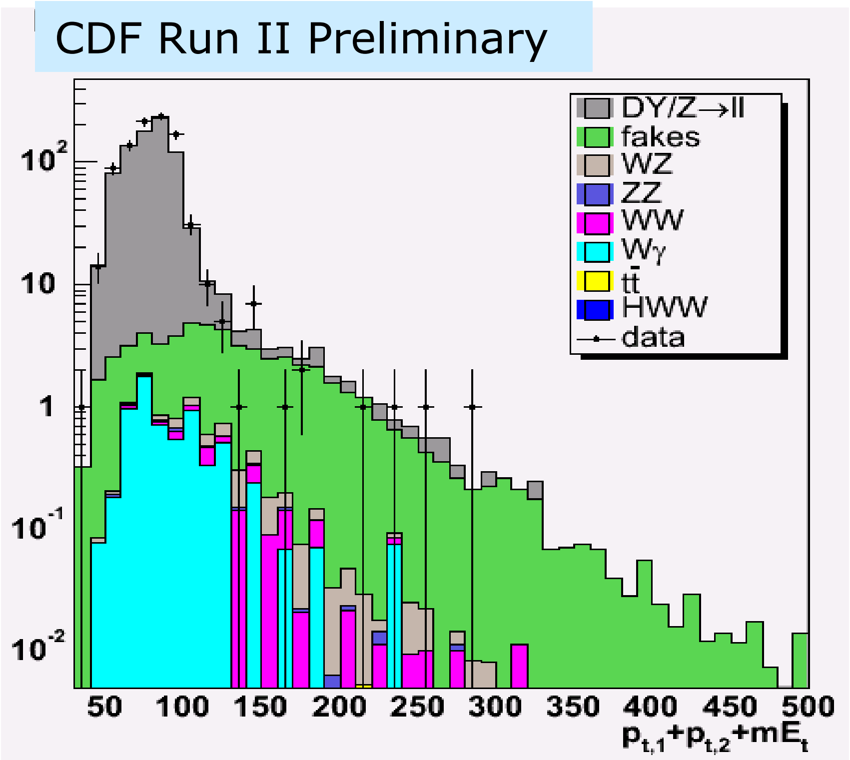
- Acceptance loss due to:
  - detector coverage
  - lepton identification

Control Regions

- We did not performed a blind analysis this time
- Looked in some control regions/cross checks
  - Measured Z→ee, μμ cross-sections ➔ used data with 2 leptons
  - Compare the number of same-sign charge events with SM predictions
  - Compare the SM expectations with data events with

    25< missing energy<$M_H/4$
    - Signal selection requires missing energy>$M_H/4$
- We found good agreement between SM and data

Same-sign events, 2 leptons, jet veto



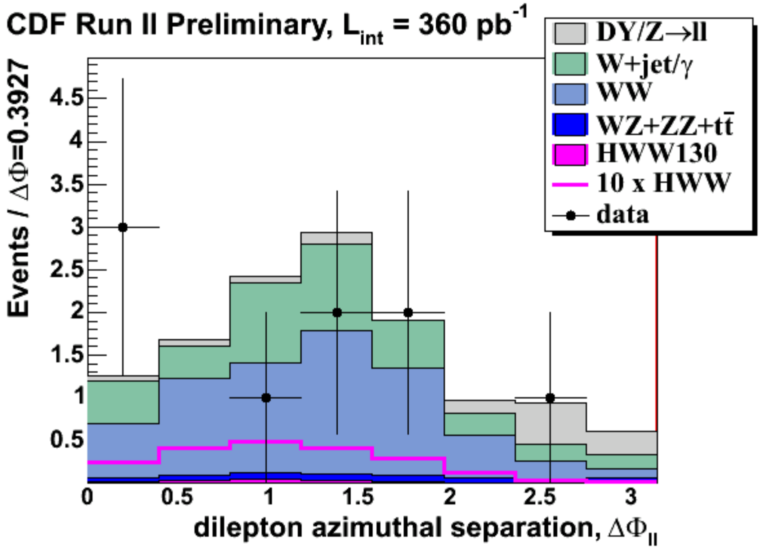
SM Expectation and Data

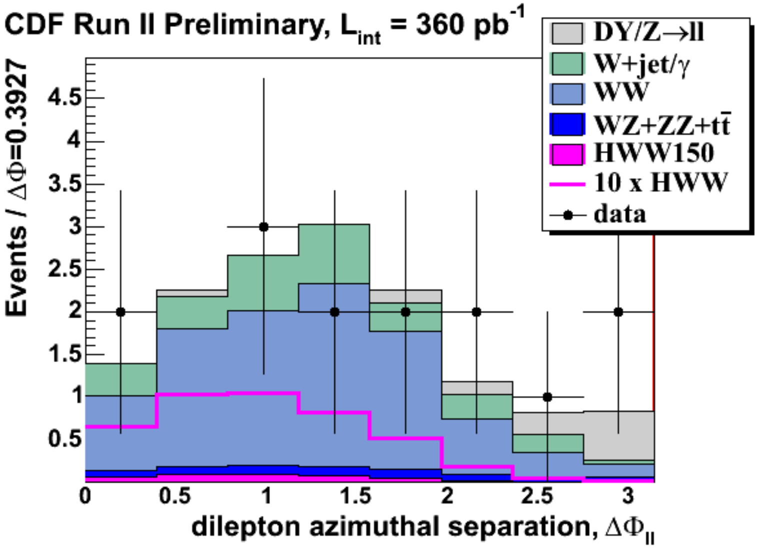
$M_H(\mathrm{GeV}/c^2)$	120	140	160	180	200
			e^+e^-		
Back	4.7 ± 0.5	4.2 ± 0.5	4.4 ± 0.5	4.1 ± 0.5	4.1 ± 0.4
Signal	0.03 ± 0.002	0.08 ± 0.007	0.14 ± 0.012	0.10 ± 0.008	0.05 ± 0.004
Data	2	4	5	5	5
			$e^\pm\mu^\mp$		
Back	5.2 ± 0.5	6.2 ± 0.6	6.5 ± 0.7	6.3 ± 0.6	5.7 ± 0.6
Signal	0.05 ± 0.004	0.17 ± 0.01	0.3 ± 0.03	0.21 ± 0.02	0.11 ± 0.01
Data	1	4	5	6	6
			$\mu^+\mu^-$		
Back	2.1 ± 0.3	2.7 ± 0.3	2.9 ± 0.3	3.0 ± 0.3	3.0 ± 0.3
Signal	0.022 ± 0.002	0.078 ± 0.007	0.141 ± 0.012	0.098 ± 0.008	0.051 ± 0.004
Data	1	4	5	6	6

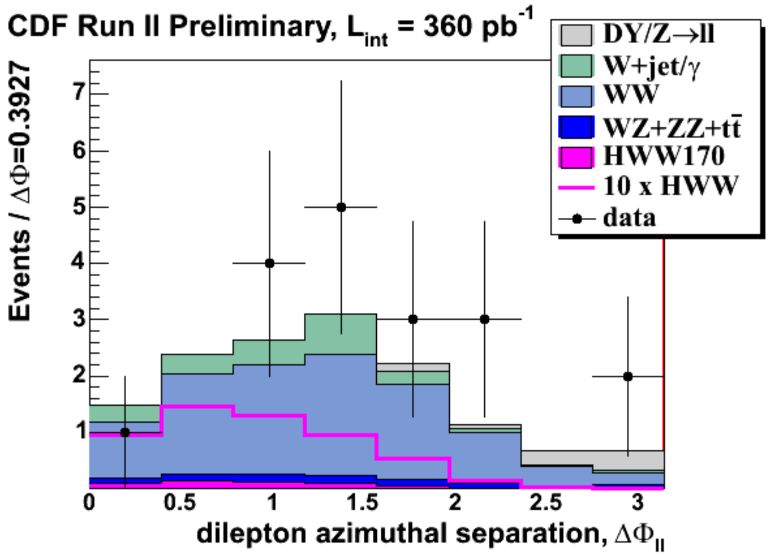
Data does not show any excess.

Azimuthal angle between di-leptons

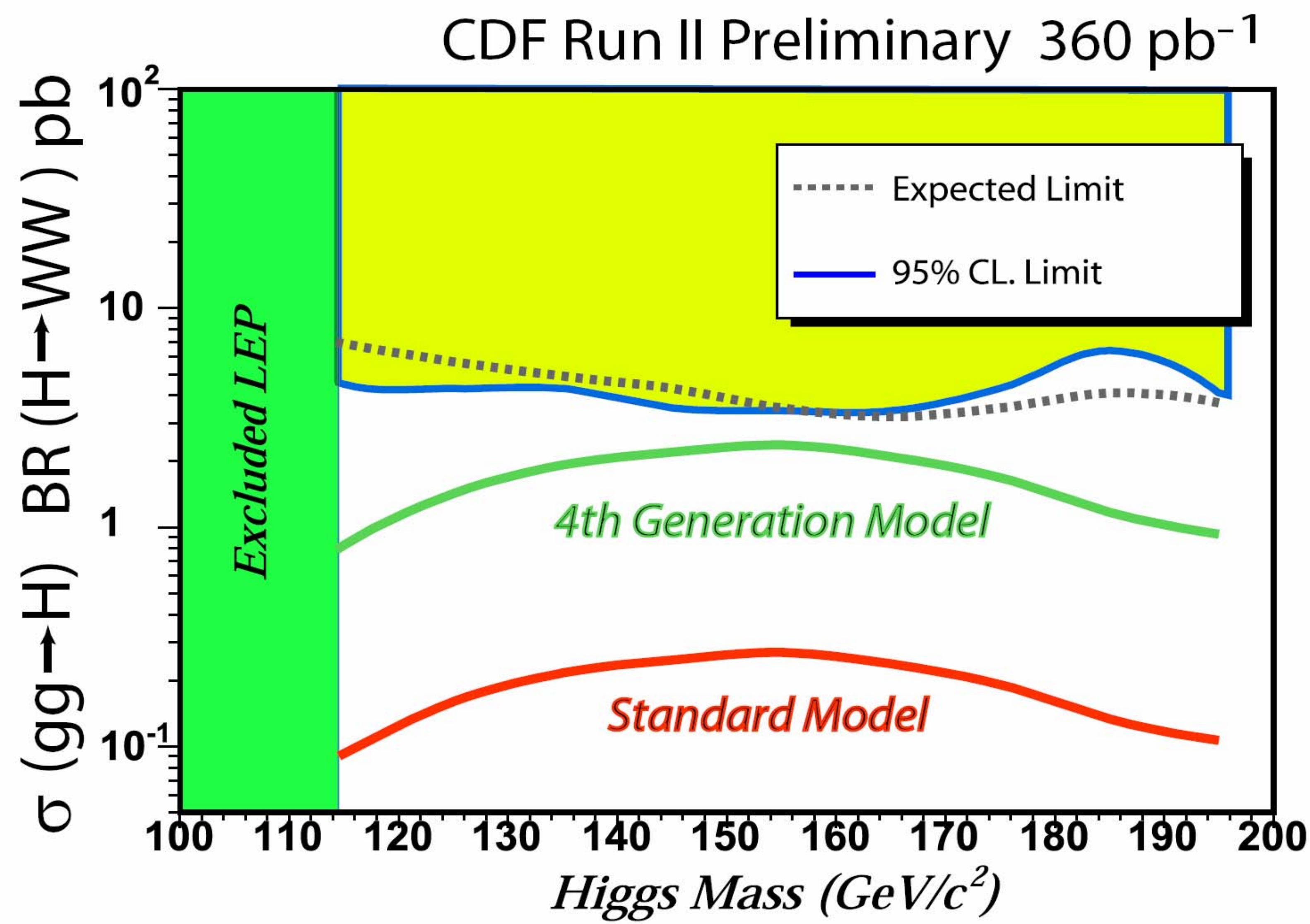
- Take advantage of the difference in the H→WW and WW Δϕ(l,l) distributions
  - Use a binned likelihood in Δϕ, which we maximize as a function of σxBR(H→WW) to set 95% C.L. limits



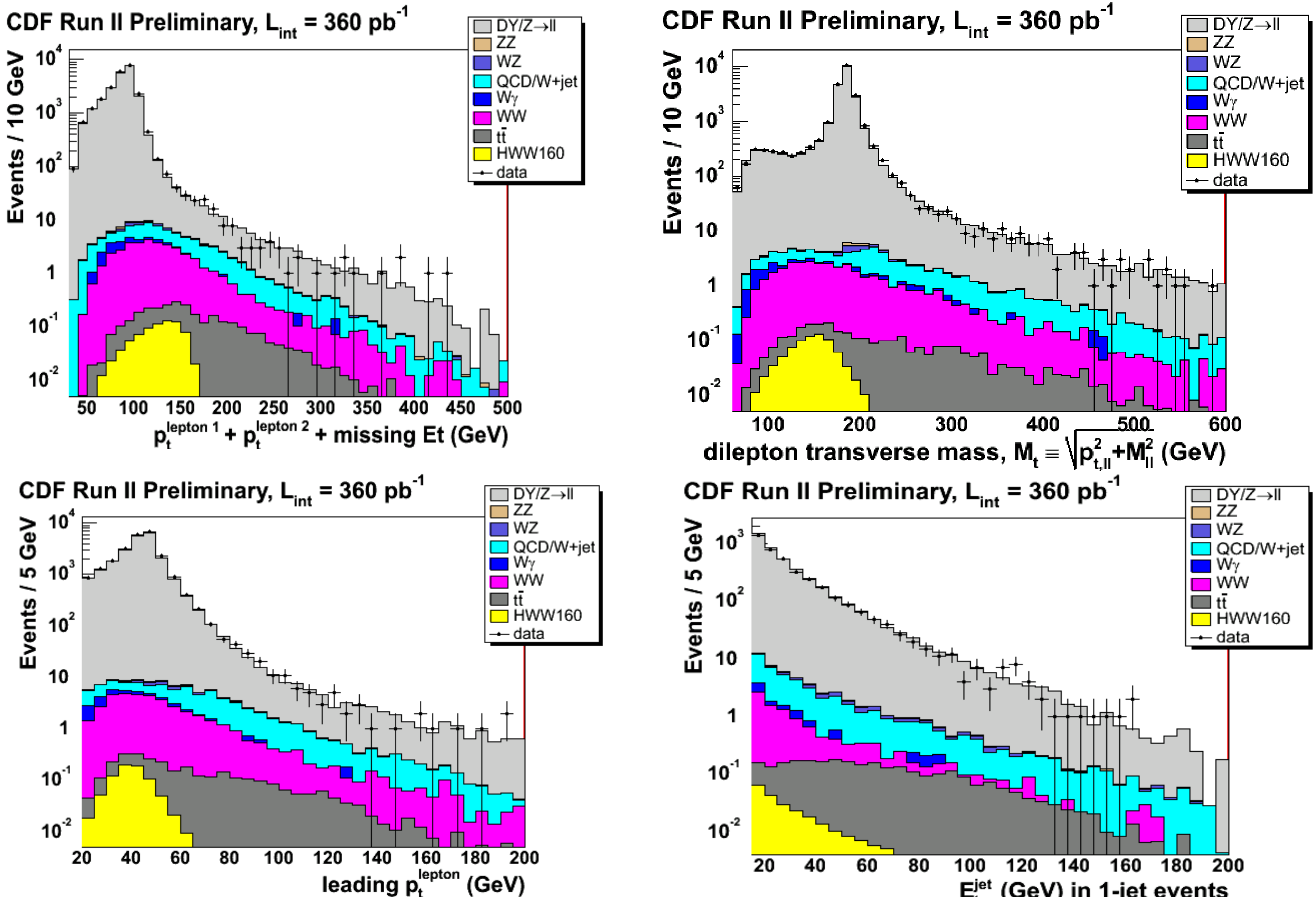




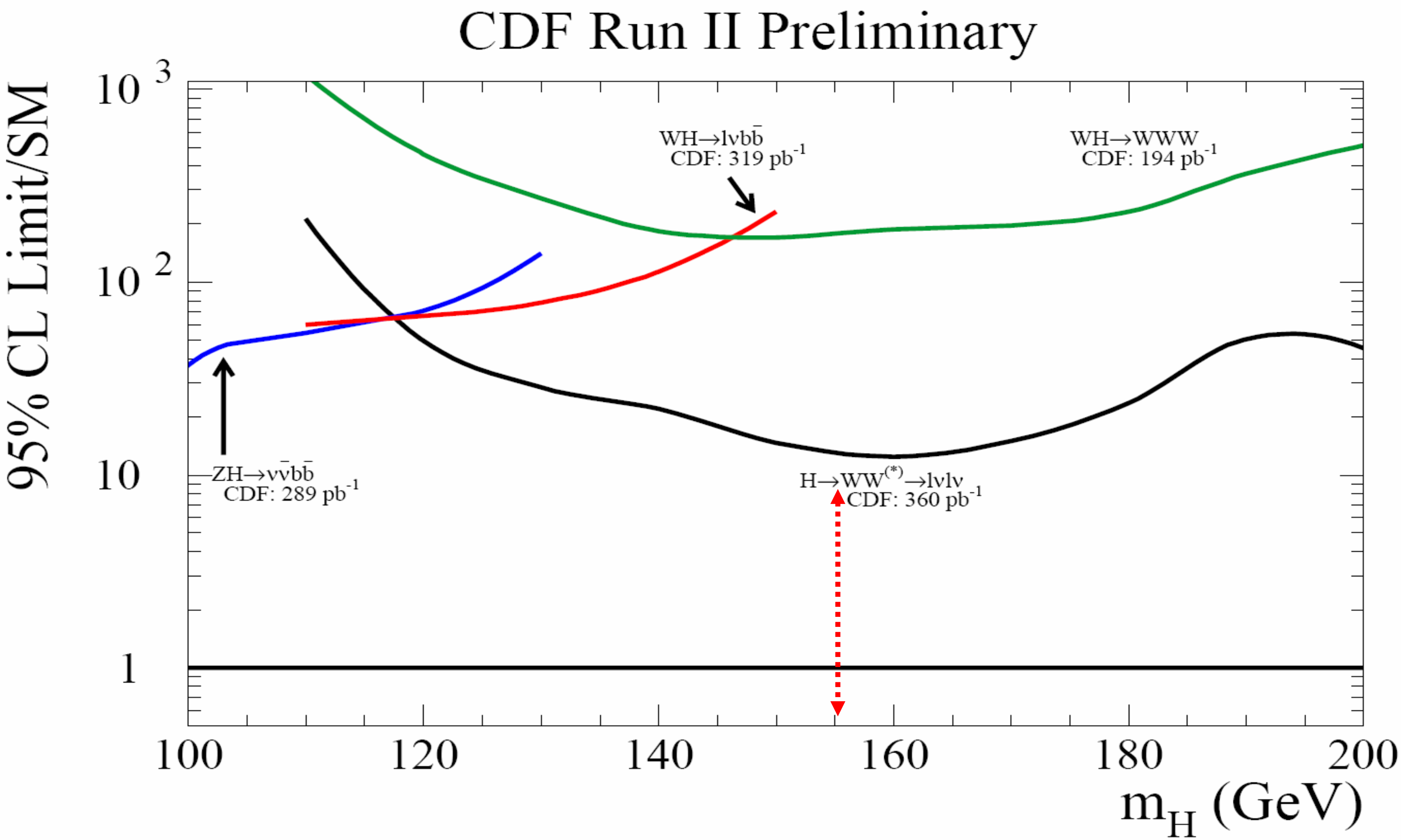
95% CL on σ x BR(H→WW)



Few kinematic distributions



H→WW contribution to the Tevatron Higgs search



HWW channel is important for a M_H>130 GeV SM Higgs discovery.
Tune on Tom Junk's talk for more.

Potential improvements

- Two main areas to focus on:
  - Reducing WW background
    - Find better discriminating variables
    - Exploit any correlations between them
      - Advanced techniques:
        - ANN, likelihood, SVM, etc
  - Increase the signal acceptance
    - Loosen the lepton identification criteria
    - Loosen the trigger lepton P_T
      - Help mainly at lower Higgs masses
      - Involve using a different trigger
    - Include the lepton+hadronic tau channel
    - Include acceptance from associated VH and VV fusion

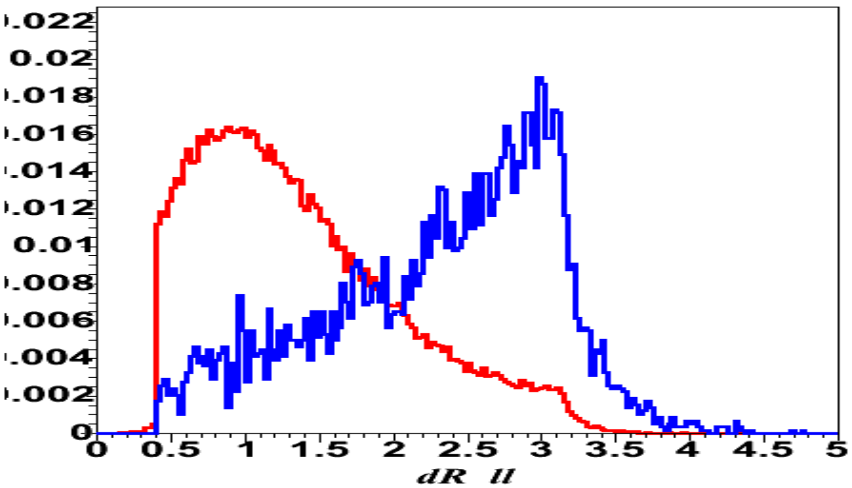
$H \rightarrow WW \rightarrow l\nu l\nu$: L=360 pb^{-1}, M_H=160 GeV		
S	0.58	
B	13.78	WW: 9.8
		W+γ/W+j:2.5
S/$\sqrt{B}$	0.12	

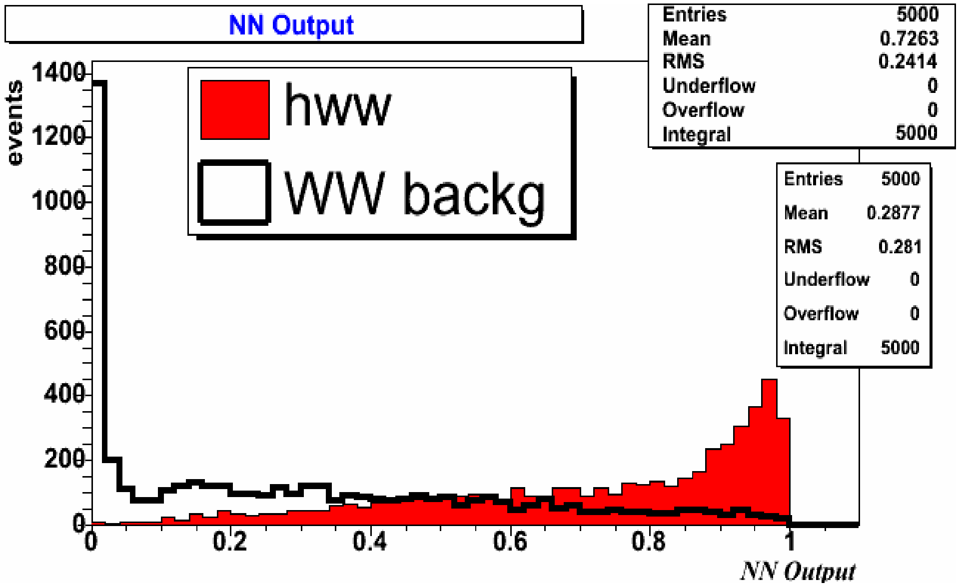
Exploit known/find new discriminating variables

Neural Networks (Work in progress)

- Considered variables showing separation between WW and HWW:
  - Exploit Higgs' spin 0
  - Production of a heavy particle, m_H
  - Exploit different production mechanisms
    - $qq \rightarrow WW$ vs $gg \rightarrow H$
- Optimize on S/sqrt(B) for easy comparison with the current analysis (M_H=160GeV)
- Find 9 discriminating variables
  - 1.42x better S/sqrt(B)

$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$





1/fb projections summary

- Assume the current analysis as starting point
- Below are just few ways we think we can use to improve our sensitivity

Potential Improvement	S/sqrt(B)
Using a NN	1.42*
Including hadronic taus	1.15
Include associated VH and VV fusion	1.15
▪ Estimate performed in hep-ph/0010338	
Loose leptons	1.10
Overall	**2.07**

Equivalent to ~4x more luminosity

- **There is still potential to do better**
- **Not all these improvements might be ready for Winter conferences**

Looking forward

- CDF performed a benchmark search for H→WW* in leptonic decays
- We are a factor of 12 away from the SM predictions (M_H~160 GeV)
- Soon to become sensitive to extra fermion families
- Further optimizations are being worked on
- A lot more to learn about this channel in the next few years
  - Could play a bigger role at the low Higgs masses than previously thought ?

- See Tom Junk's plenary talk for a CDF big picture