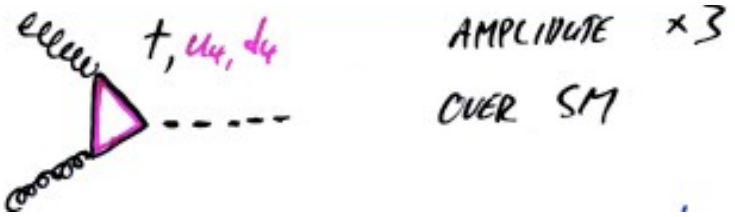
DØ Higgs Searches and a 4th Family



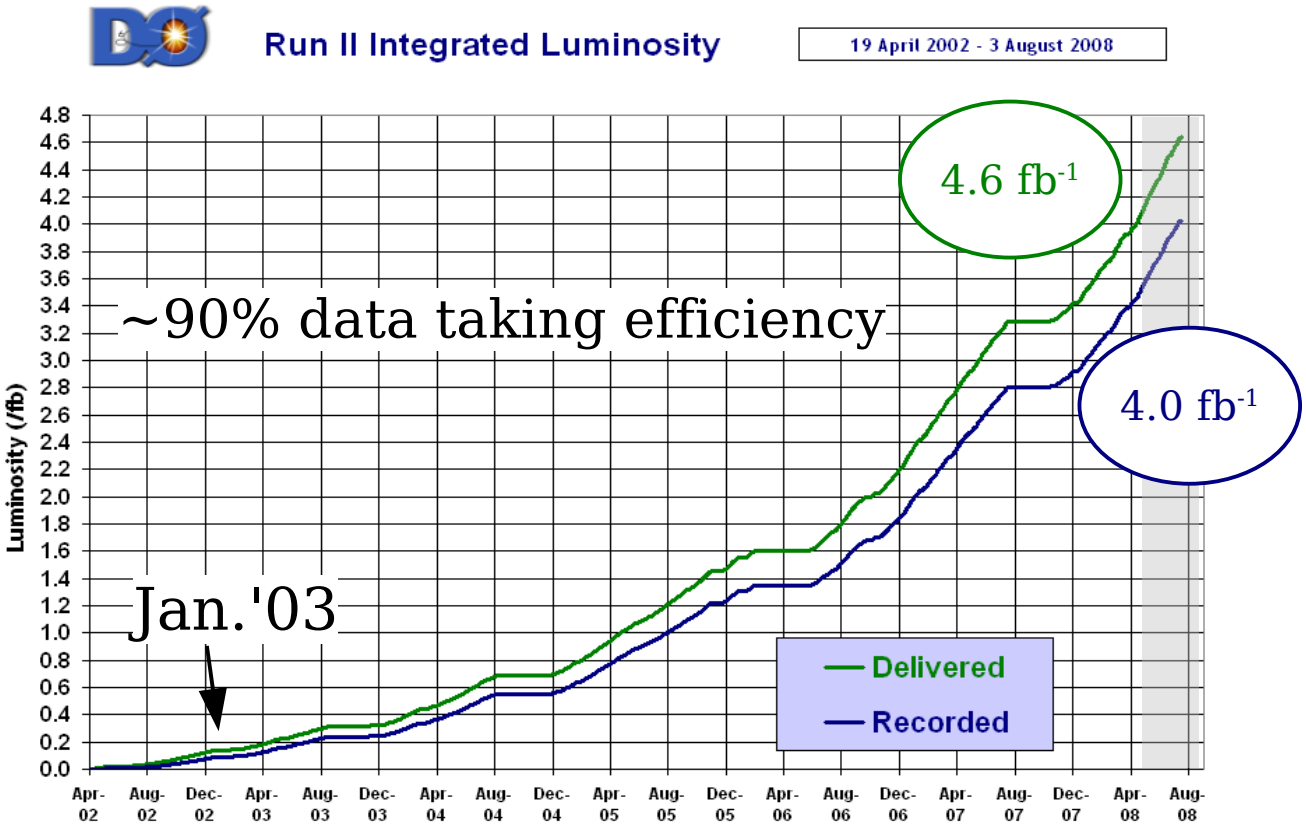
Andy Haas
Columbia University
on behalf of the DØ experiment

"Beyond 3 SM Families at the LHC"
CERN
Sept. 4-5, 2008

DØ and the Tevatron

Running (again) since ~2003
p-p*bar*, sqrt(s)=1.96 TeV

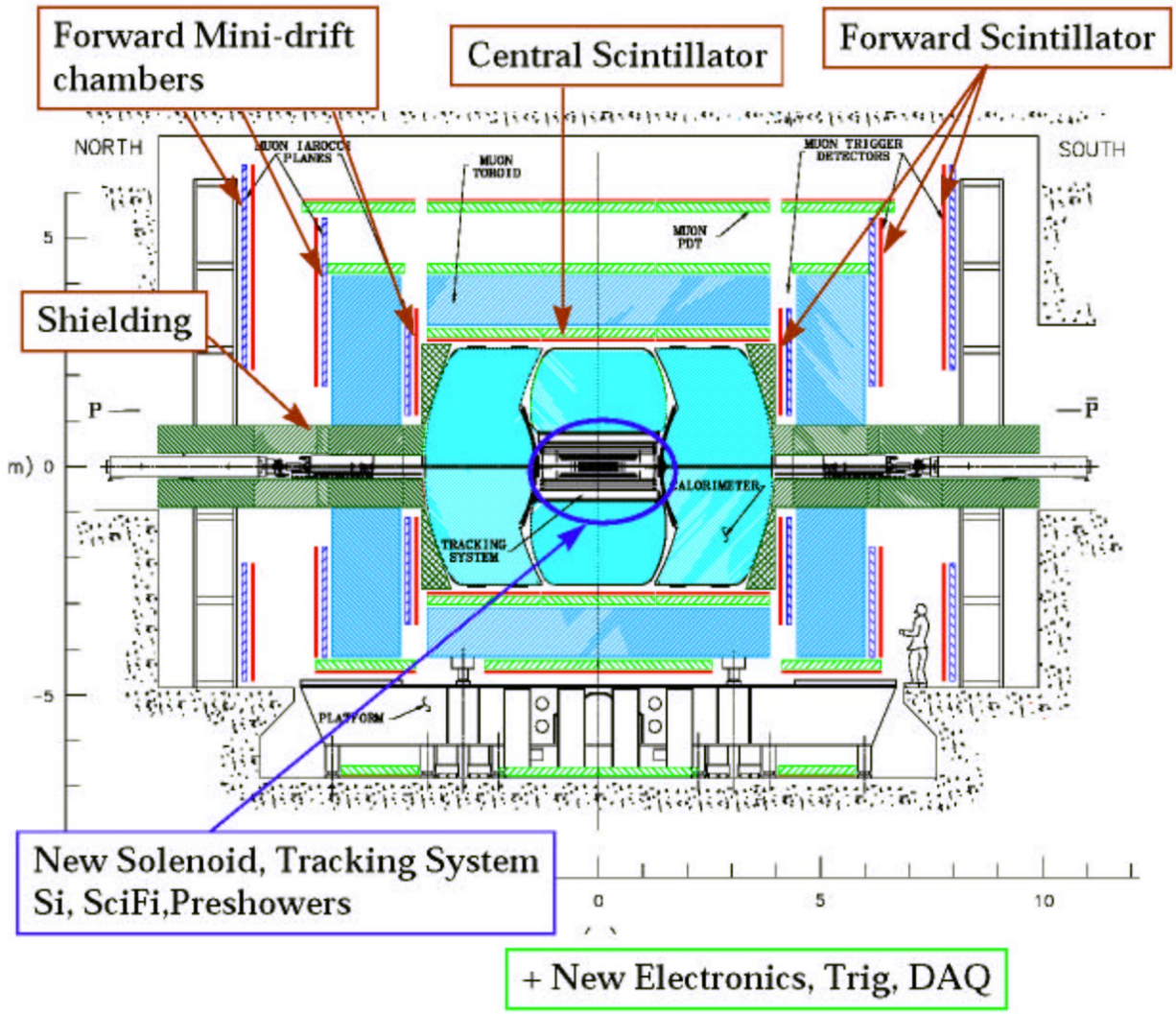
Data recorded May 31 shown at ICHEP July 31!
Up to 3.0/fb of good data analyzed
~14% data quality loss, ~75% overall efficiency



Tevatron and DØ both performing very well!

>3e32 $cm^{-2}s^{-1}$

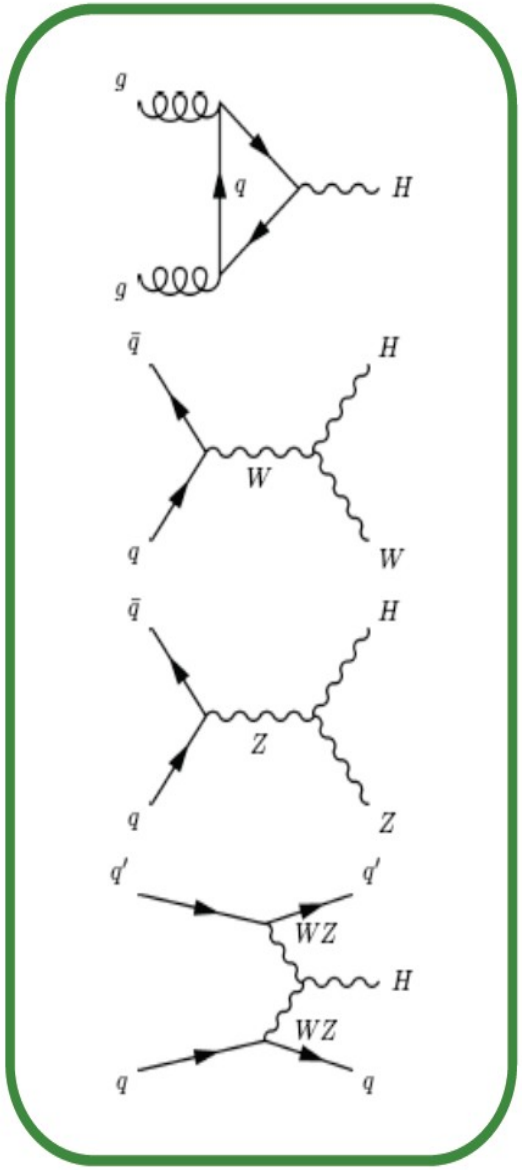
DØ

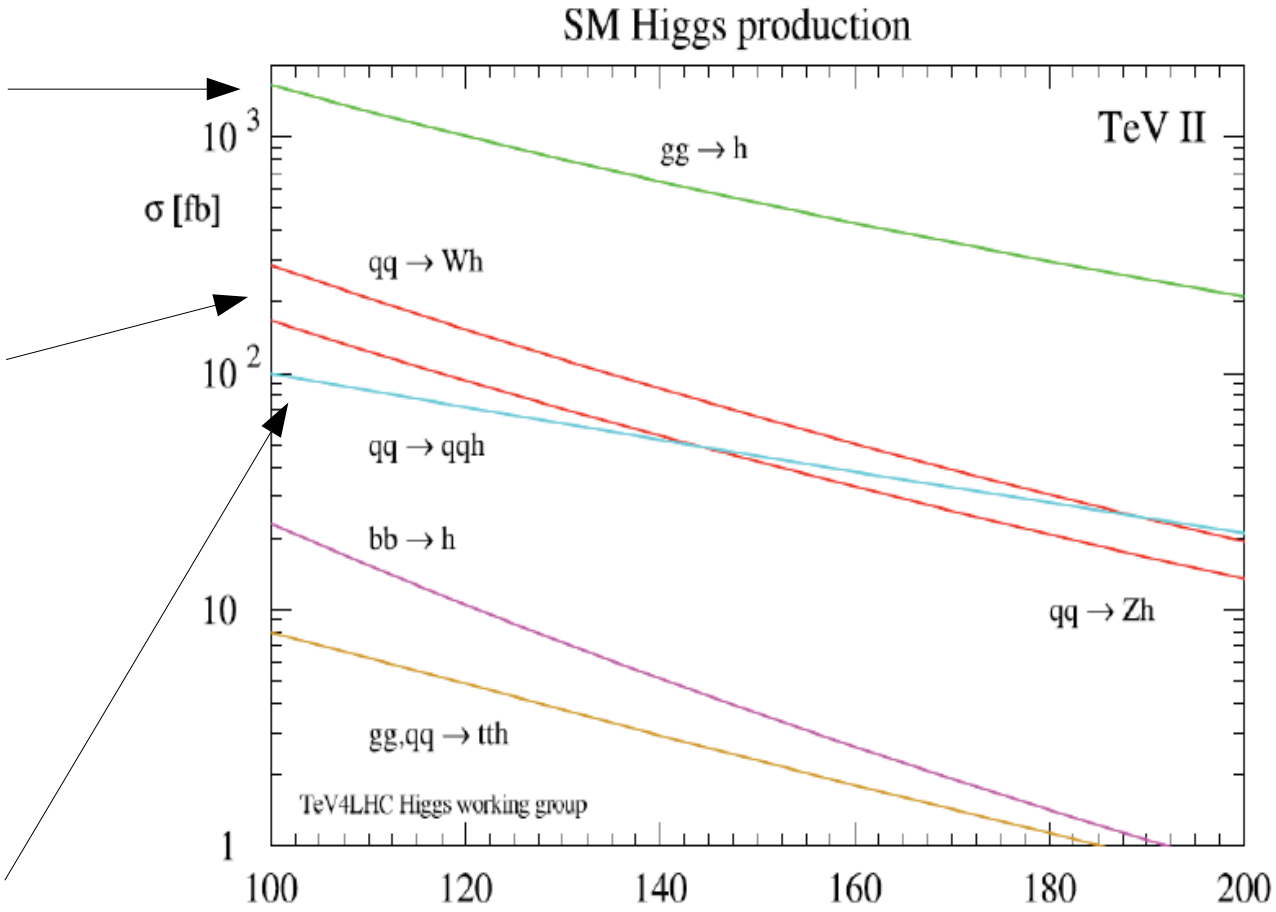


Electrons / photons
Muons
Jets / b-jets / taus
ME_T

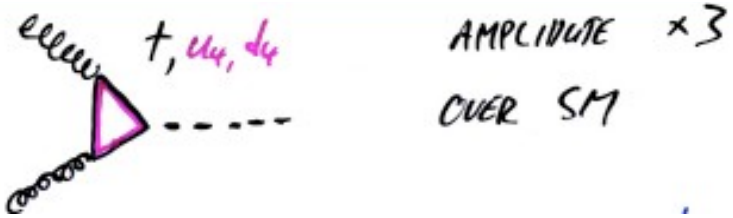
Collaboration is ~300 FTE's

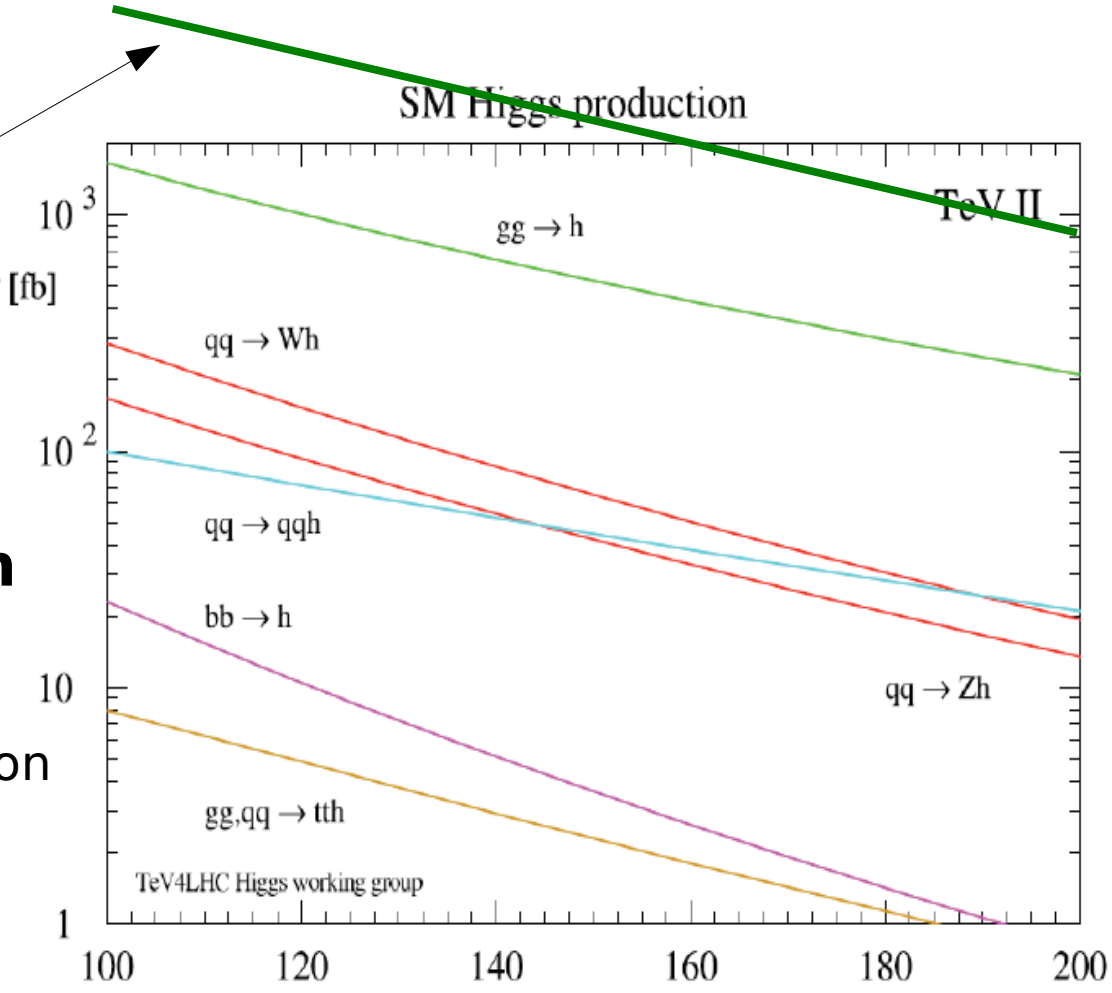
SM Higgs Production at the Tevatron





SM Higgs Production at the 4th Gen. Tevatron





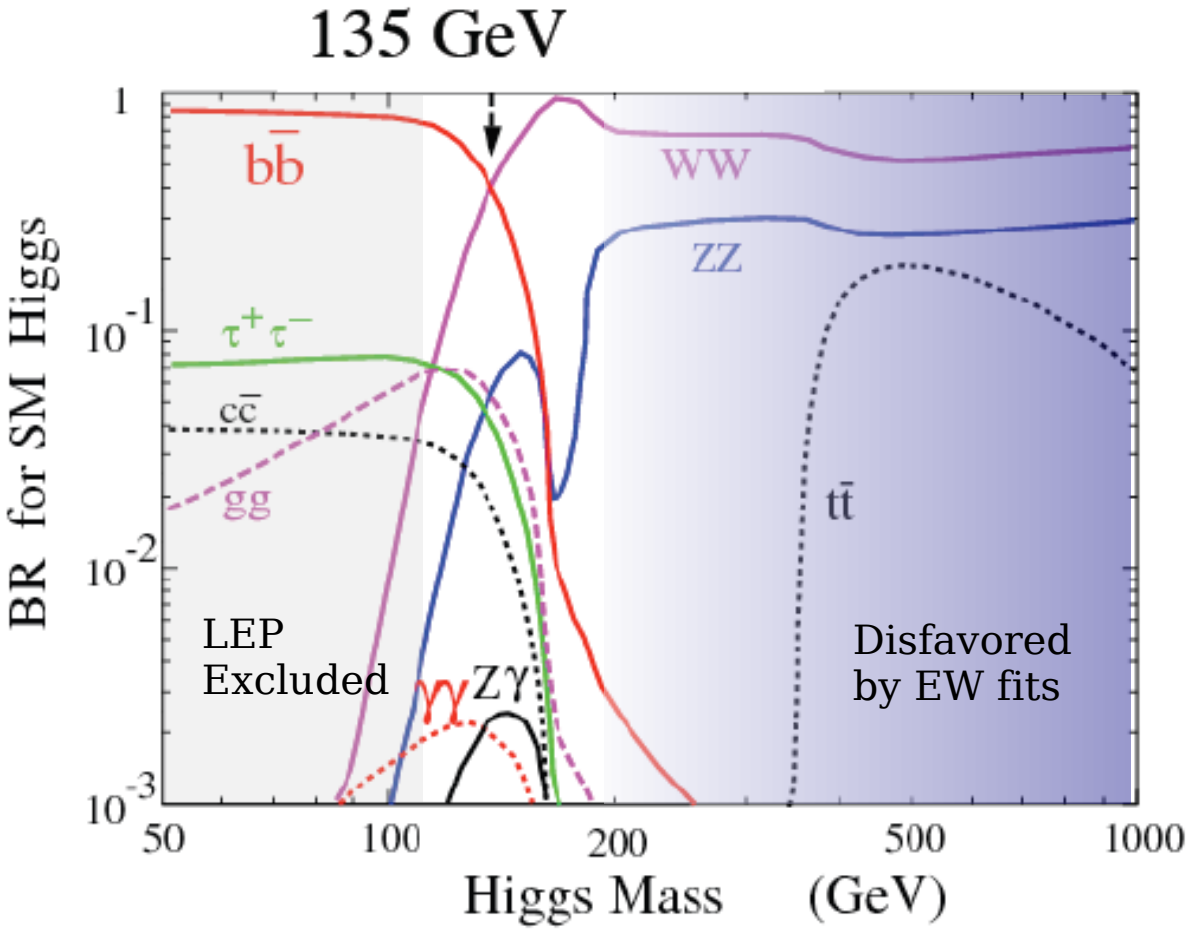
~9x larger cross-section for gg->h !

Need to understand this prediction in detail as a function of m_h

SM Higgs Decay

Low mass: **h->bb**

High mass: **h->WW**



4th Gen. SM Higgs Decay

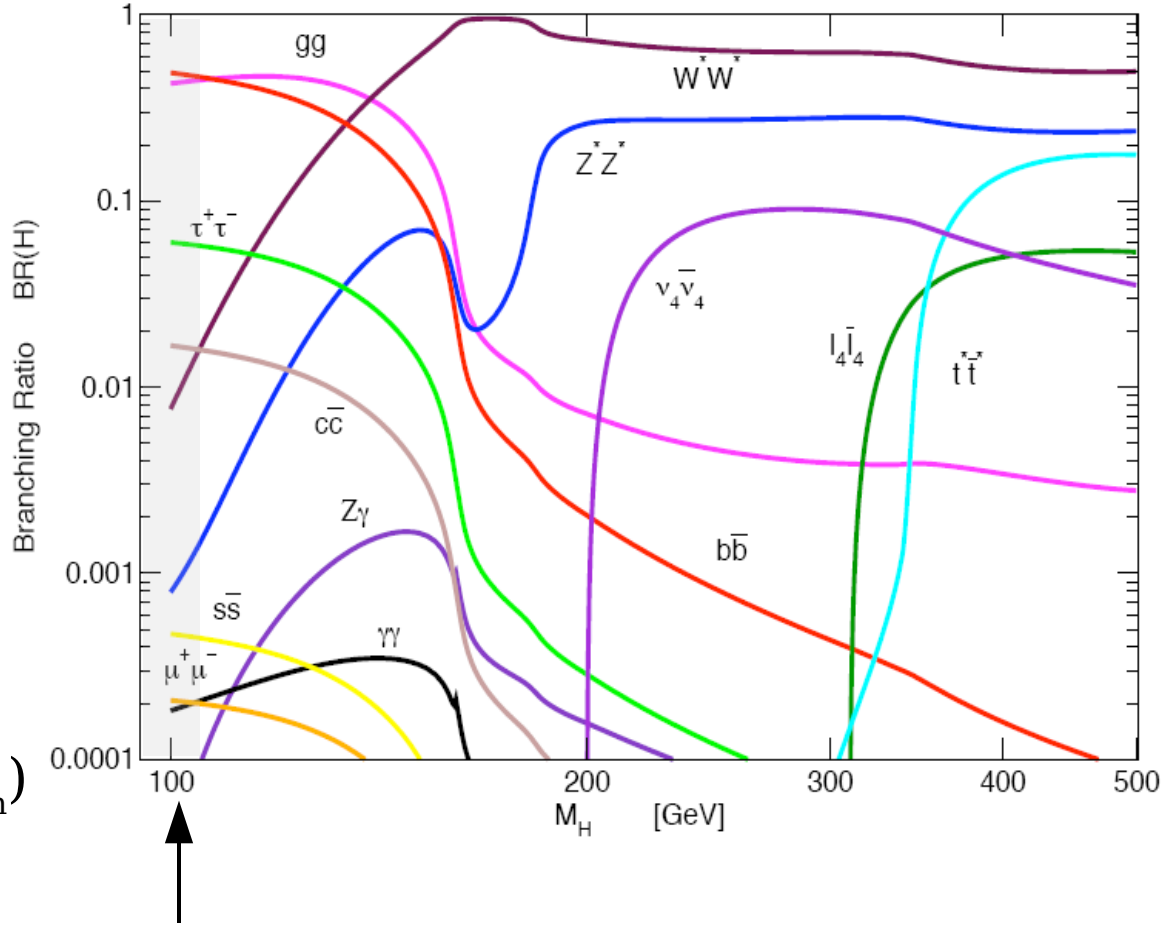
h->bb, h->gg infeasible

Need W/Z+h, h->bb - *suppressed!*

γγ *suppressed* by 4th gen., but may still be powerful at very low mass

ττ, μμ might be useful, but drown by Z background?

h->WW (and ZZ)
Shining stars!
(but BR drops off fast at low m_h)



Where exactly is the LEP limit?
Should be <114.4 GeV... ~110 GeV?

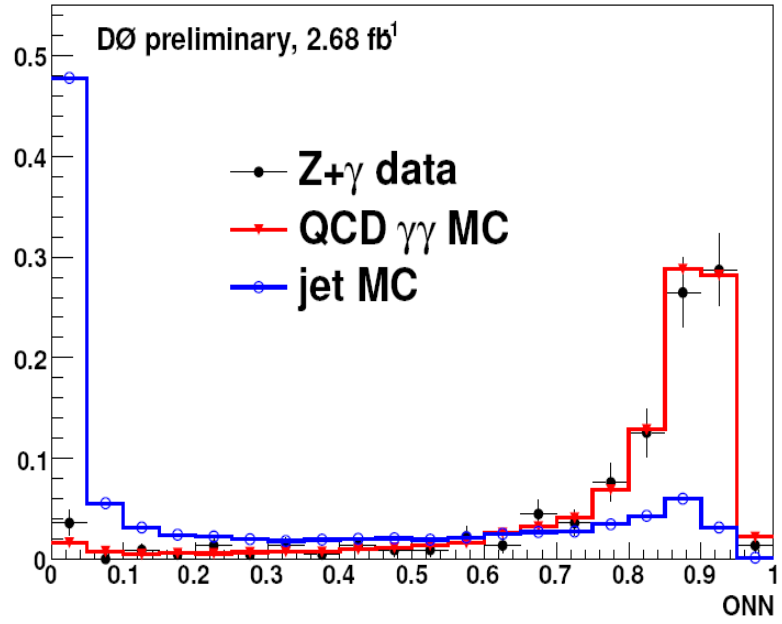
h-> γγ

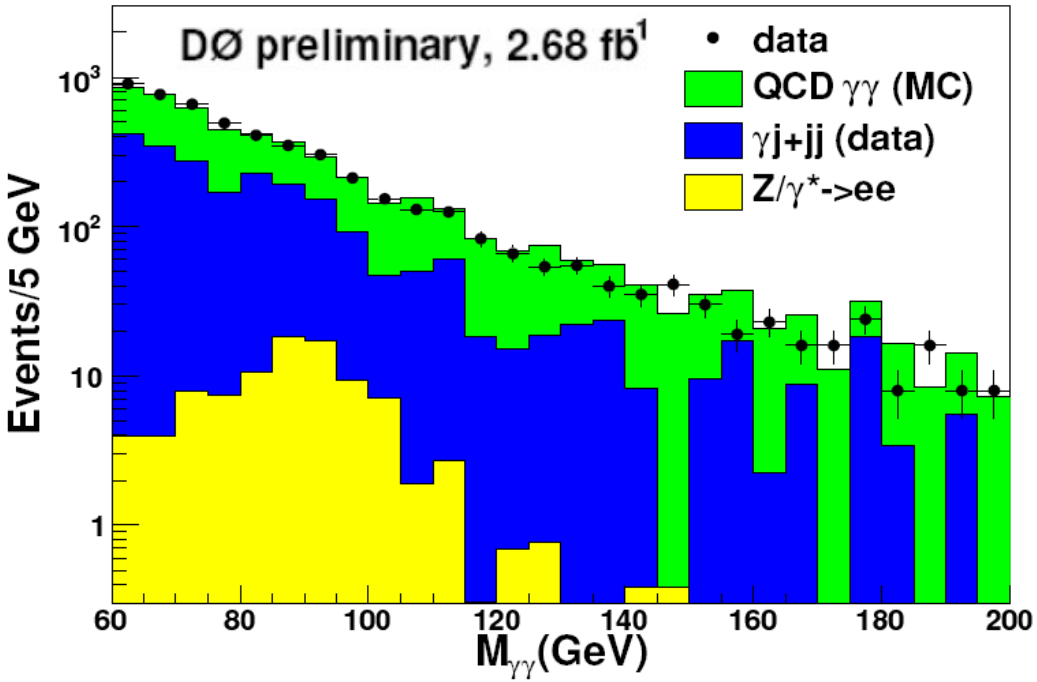
Tiny cross-section, but relatively clean

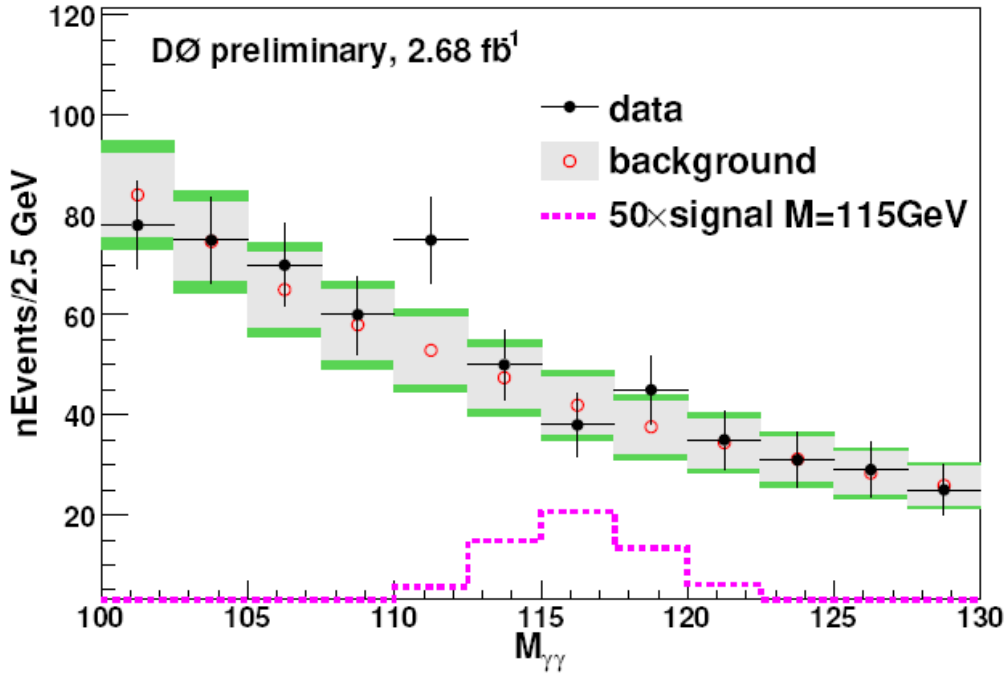
Advanced photon-ID Neural Network

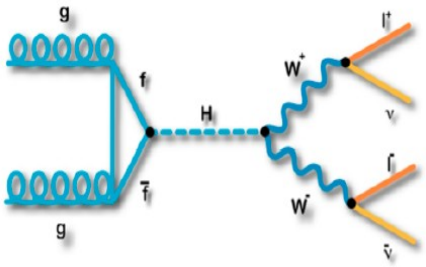
Di-jet and γ+jet measured in data
Data agrees with Pythia re-weighted to DIPHOX

Limit ~ 23x SM @115 GeV, *but may work at LHC*







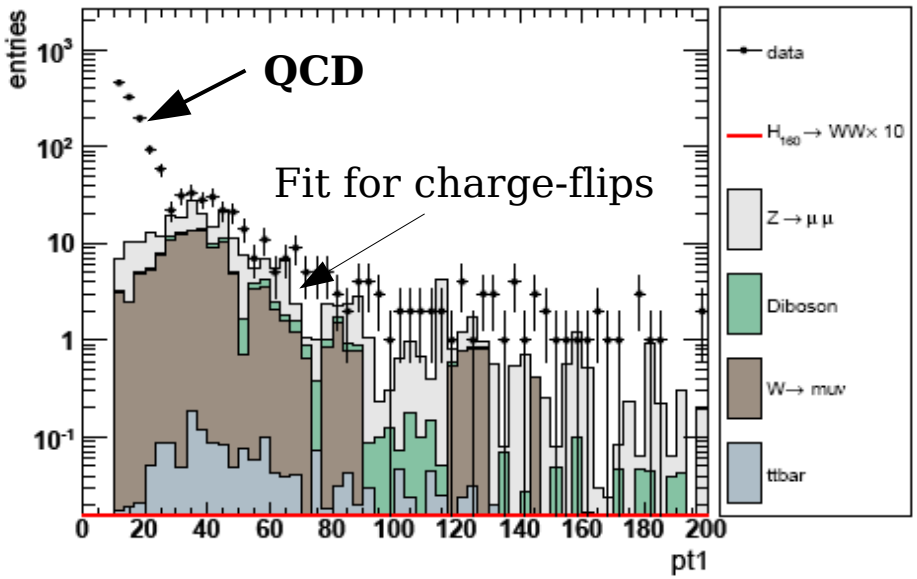


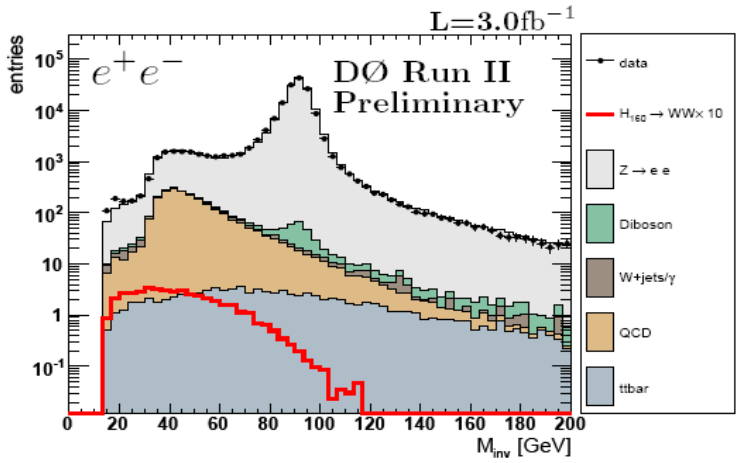
H->WW-> lν lν

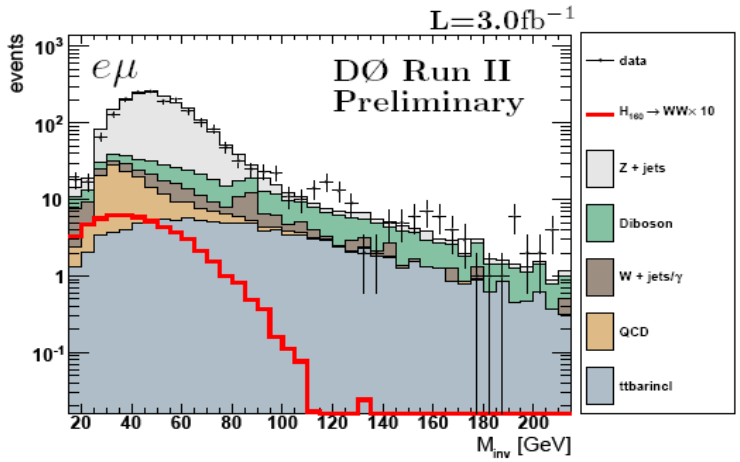
3.0/fb

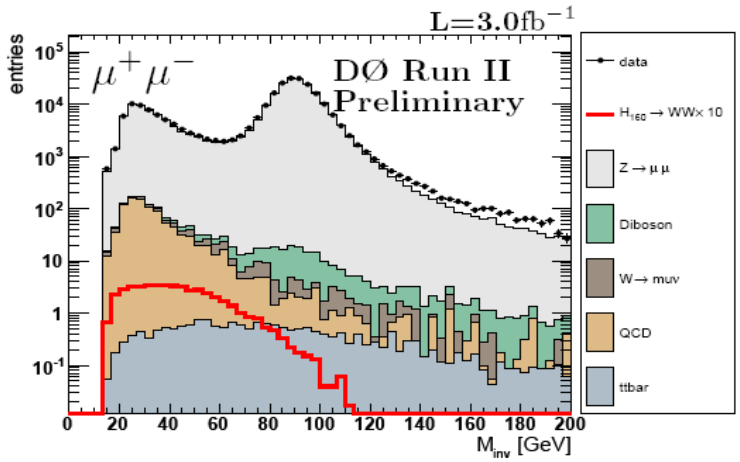
Select di-lepton events (~100% trigger eff.)
Study and compare to Z→ee, μμ, ττ(→eμ)

QCD determined from like-sign data
(accounting for other backgrounds)





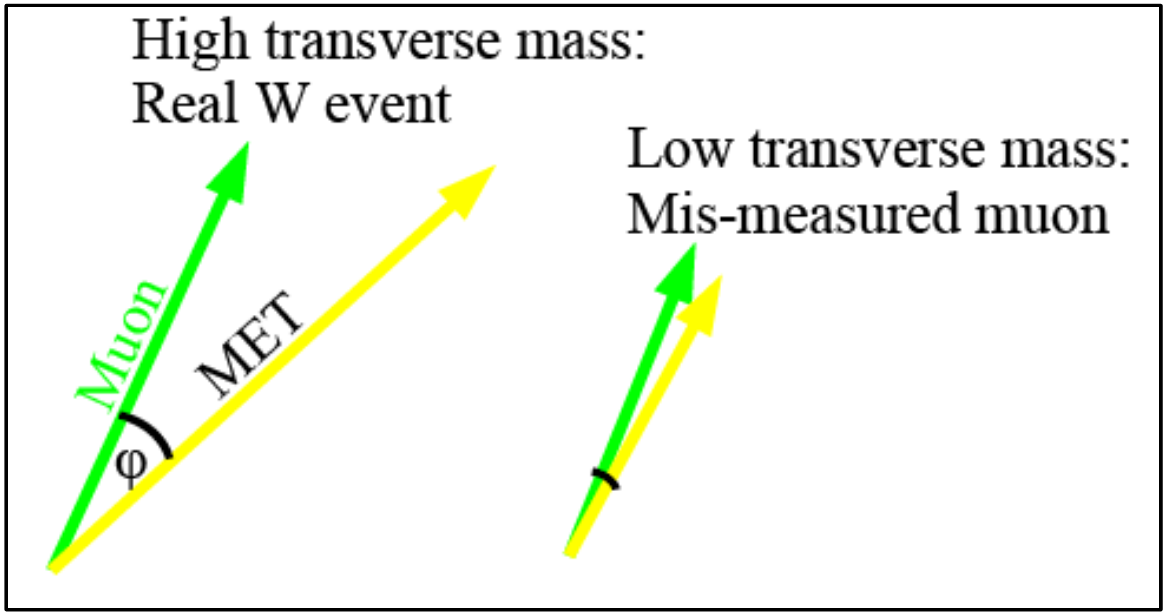


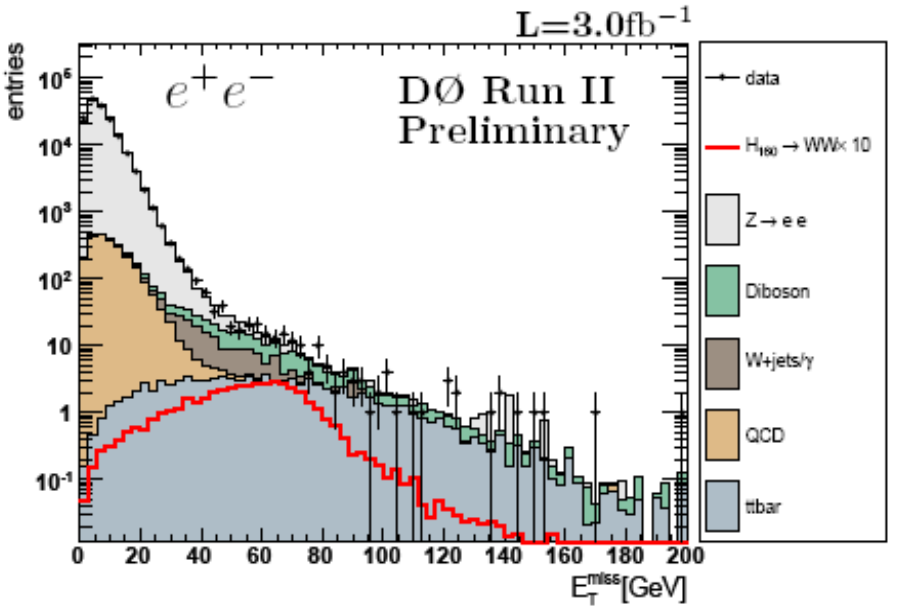


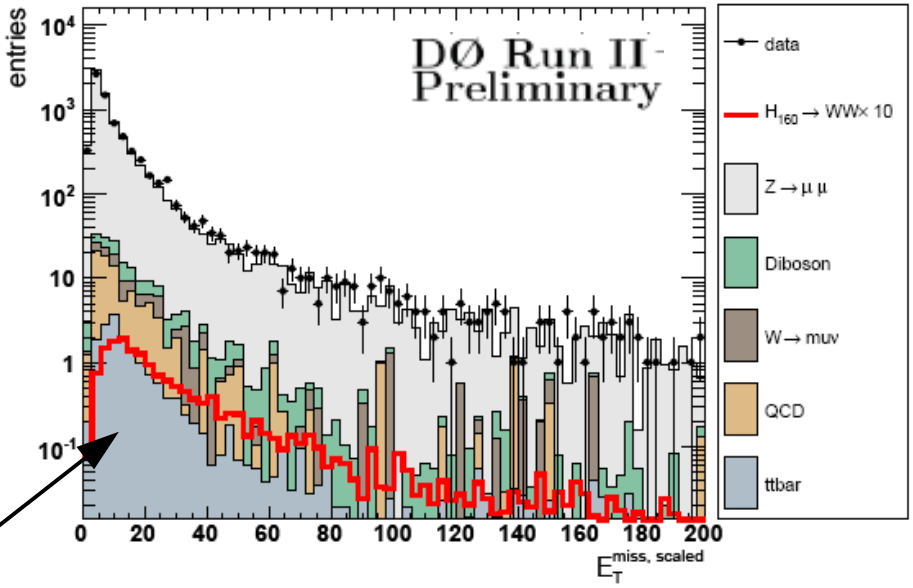
H->WW-> lν lν

Signal has large ME_T and ME_T *significance*

ME_T is not aligned with either lepton







$$\not\!\!E_T^{\text{Scaled}} = \frac{\not\!\!E_T}{\sqrt{\sum_{\text{jets}} \left(\Delta E^{\text{jet}} \cdot \sin\theta^{\text{jet}} \cdot \cos\Delta\phi\left(\text{jet}, \not\!\!E_T\right)\right)^2}}$$

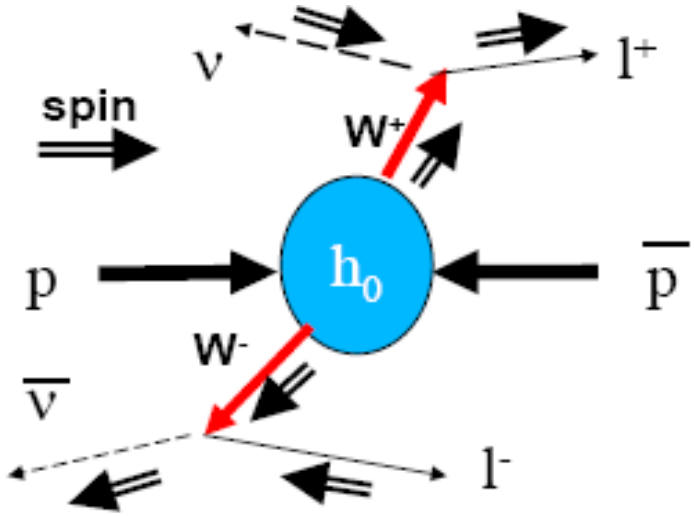
MET projected onto jet direction

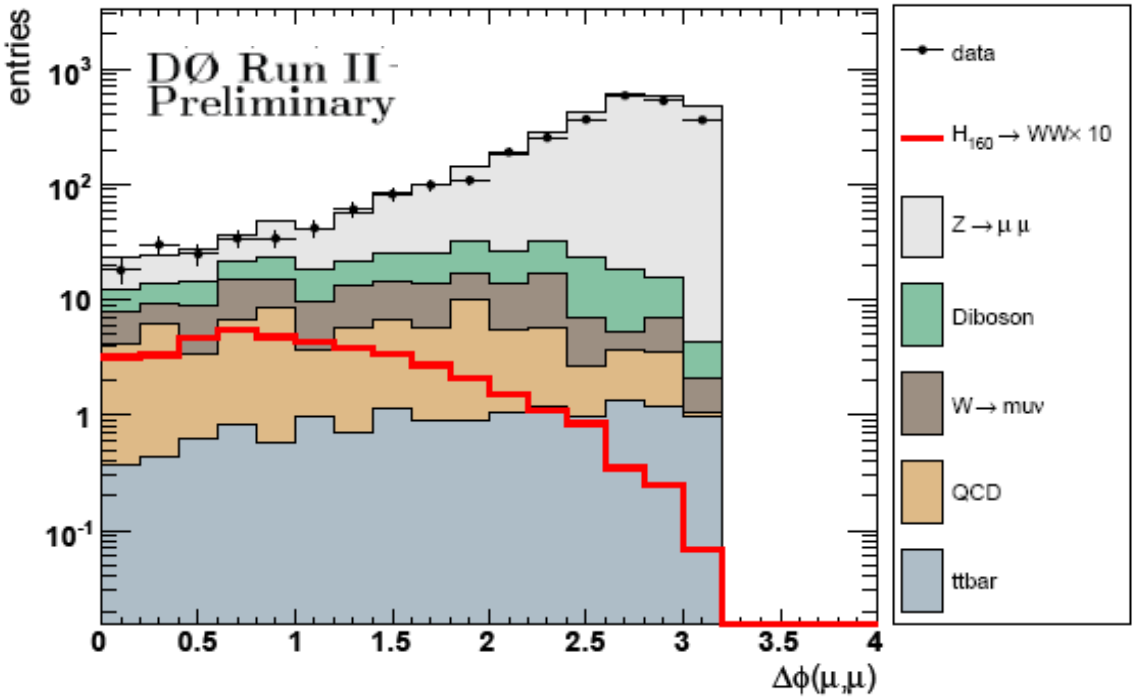
H->WW-> lν lν

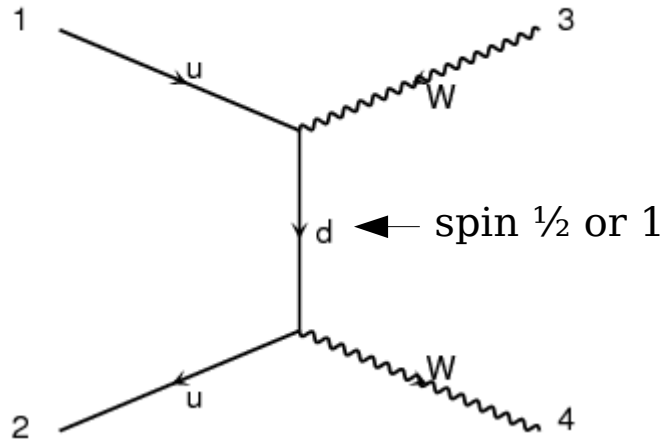
Higgs is a scalar,
leptons are more aligned

qq->WW (spin ½ quark, spin 1 boson),
leptons are less aligned

Z->ll is also back-to-back, not aligned







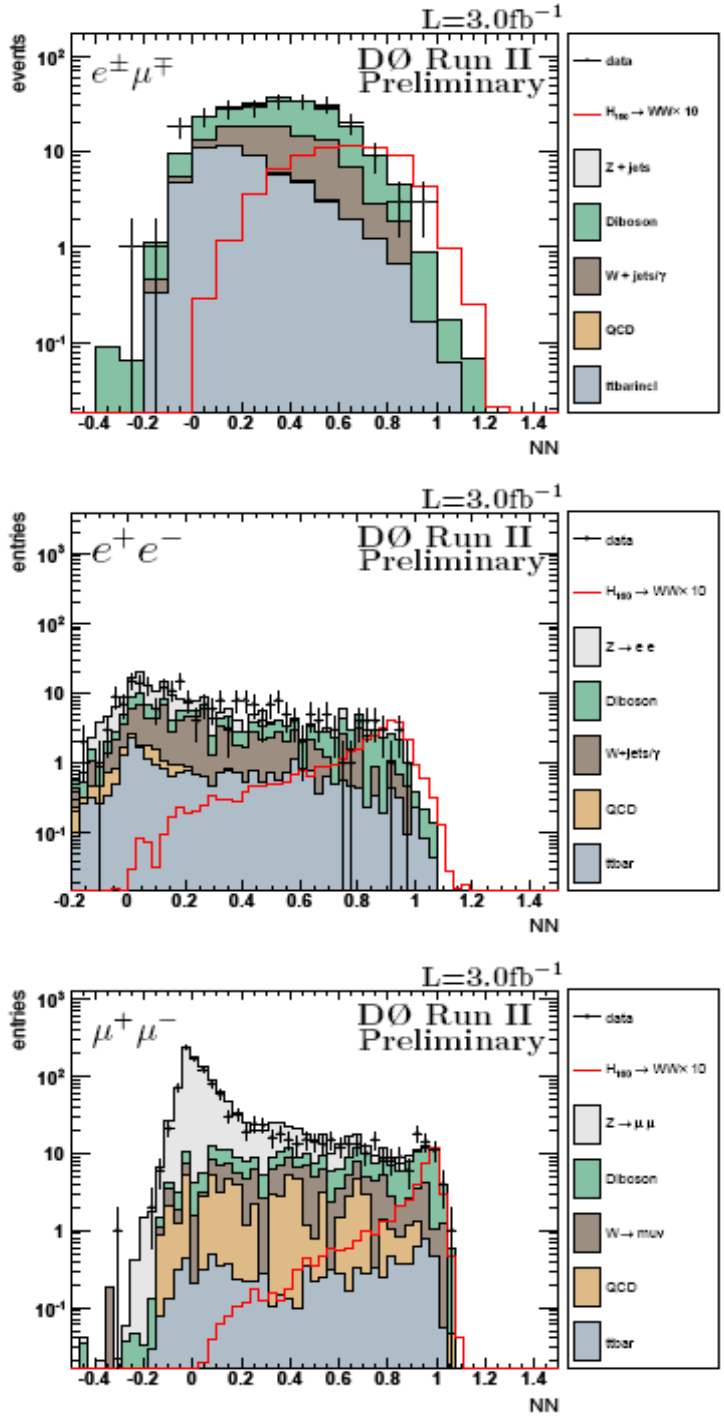
H->WW-> lν lν

Artificial Neural Net used to separate signal

- Trained against weighted sum of all backgrounds
- Each lepton channel independently
- Each mass (every 5 GeV) independently

~30% more sensitive than cut-based analysis

Object Variables	Event Var	Topo Var
P_T^{l1} & P_T^{l2}	$M_{inv}(l,l)$	$\Delta\phi(l,l)$
Σ lepton P_T	$M_t^{min}(l,\not{E}_T)$	$\Delta\phi(\not{E}_T,l_1)$
Σ jet P_T (H_T)	$\not{E}_T$	$\Delta\phi(\not{E}_T,l_2)$
Lepton Quality	$\not{E}_t^{scalar}$	



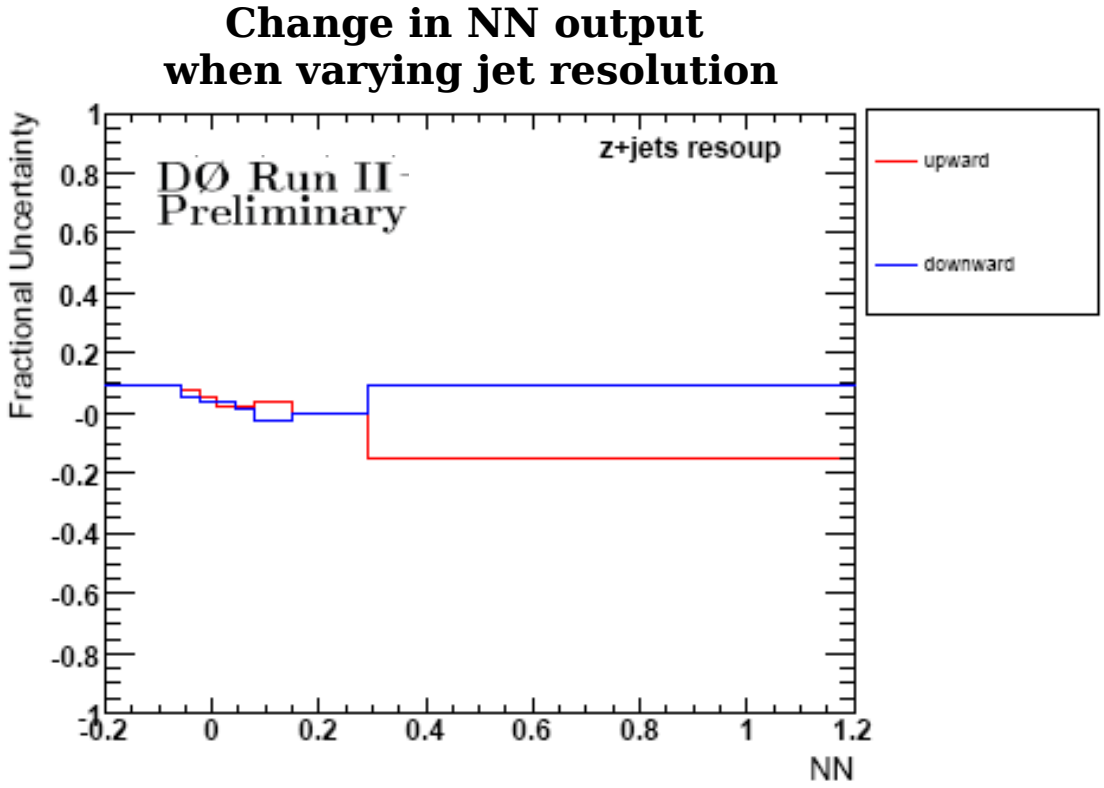
H->WW-> lν lν

Flat systematics:

- Lepton efficiencies (2-8%)
- Lepton momentum scale (2%)
- Theoretical cross-sections (7-10%)
- Jet->lepton fake rate (10%)
- QCD normalization (30%)

Shape systematics (on NN output):

- Jet efficiency (6%)
- Jet energy scale (7%)
- Jet energy resolution (3%)
- Inst. luminosity (0.3%)
- Inst. luminosity (1%)
- Boson p_T (5%)

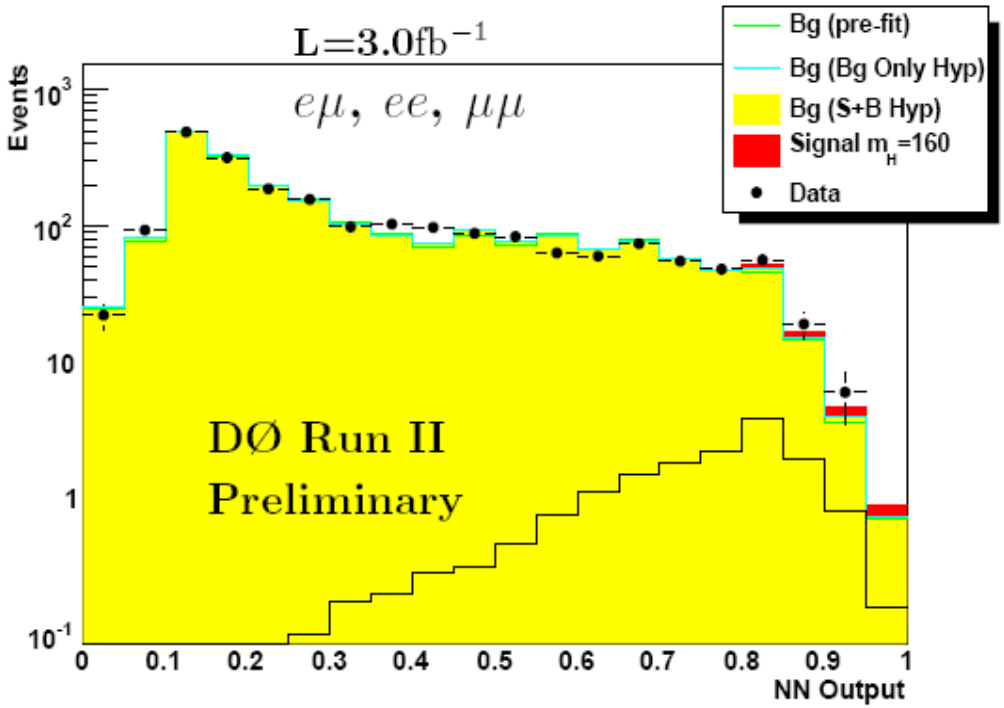


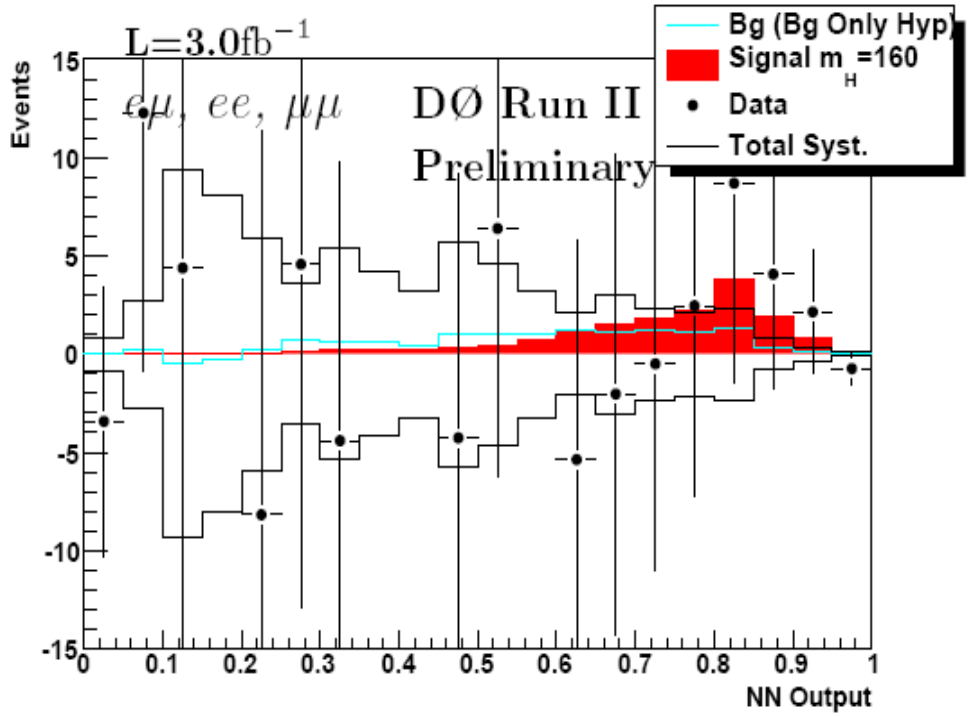
H->WW-> lν lν

Backgrounds are large!

Systematics under control

- but further understanding will improve sensitivity

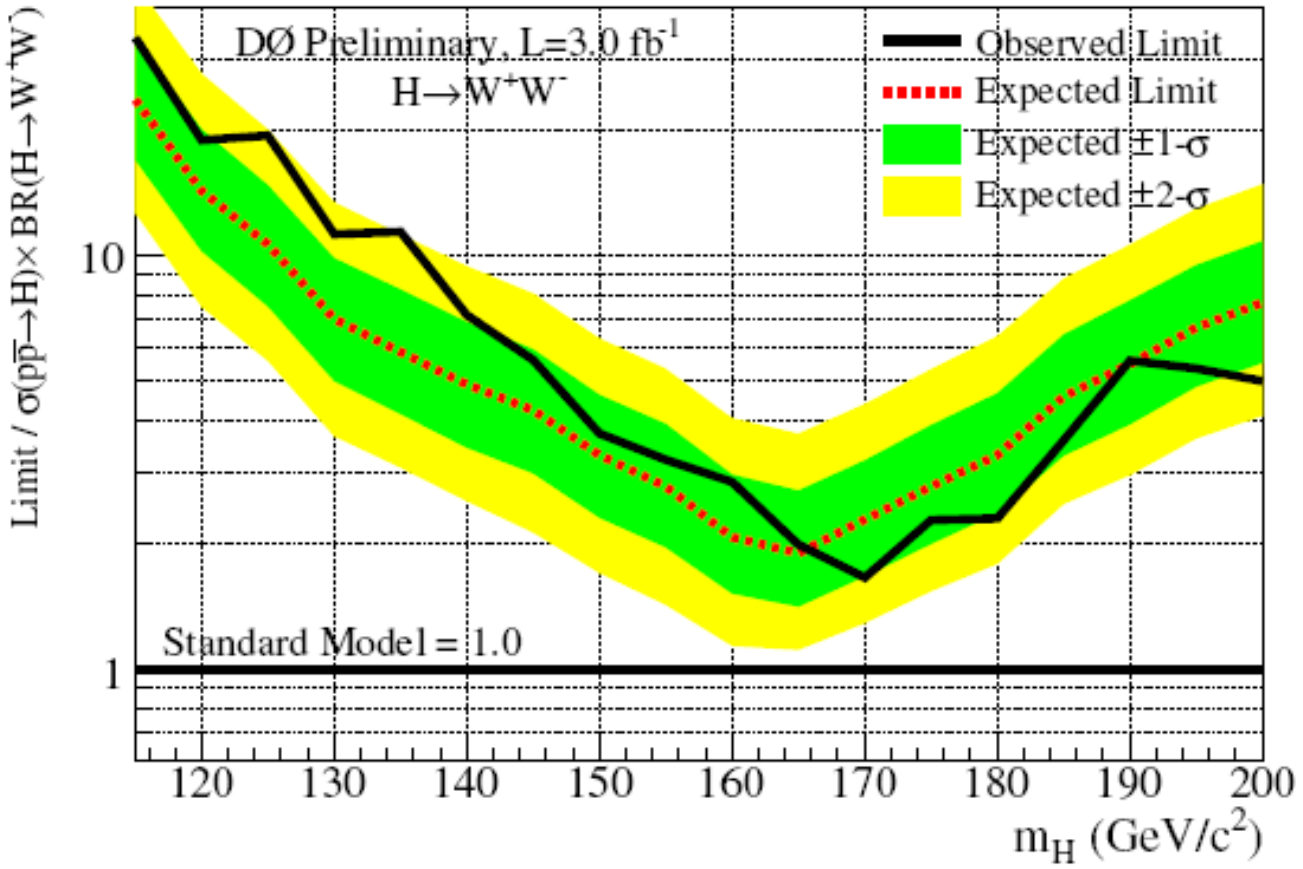




H->WW-> lν lν

Output of NN used to set limits at 95% CL every 5 GeV

CL_s method with log-likelihood ratio test statistic



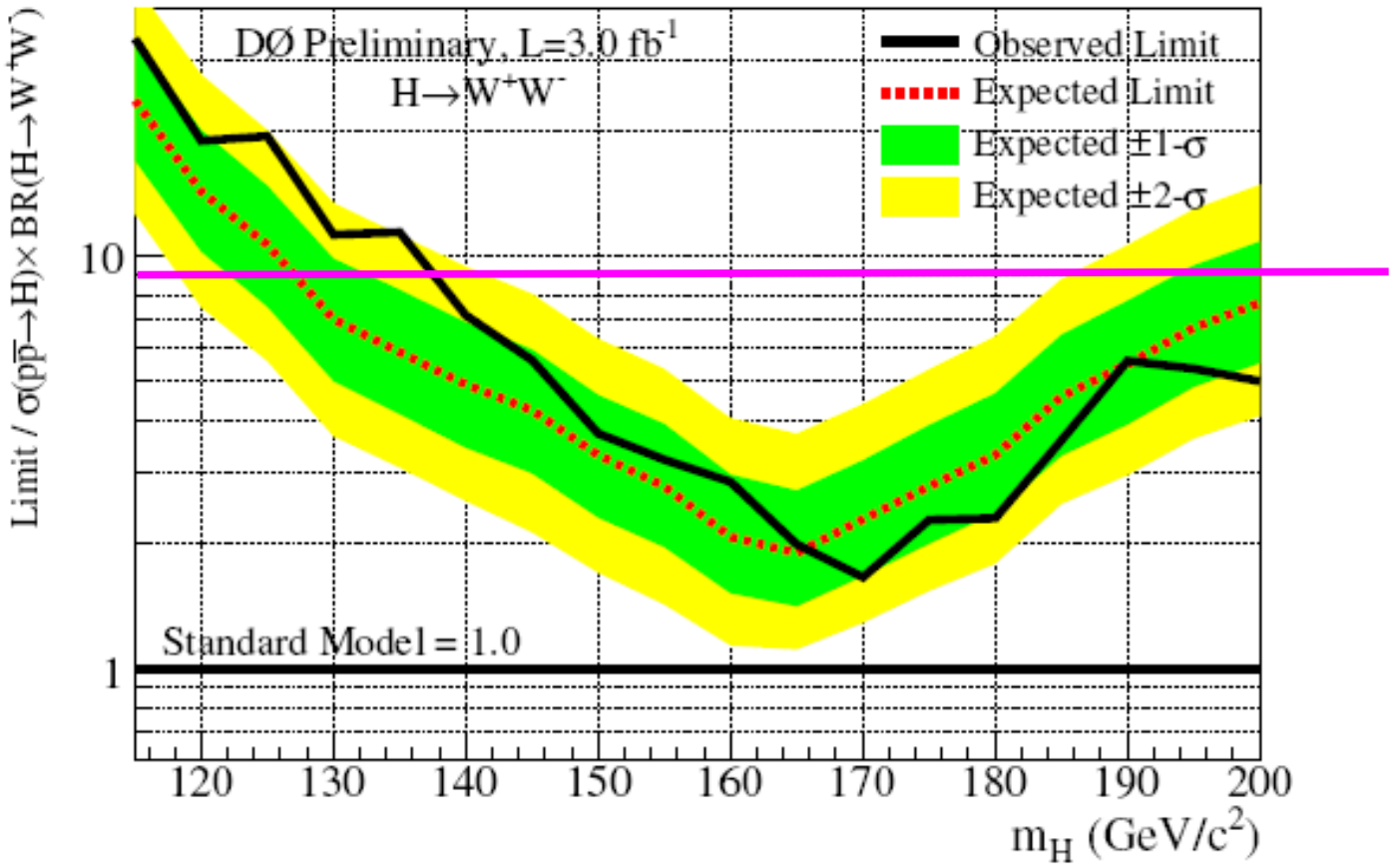
H->WW-> lν lν

Need to learn exactly how to draw the purple line as a function of m_h

- gg->h enhancement
- BR(h->WW)

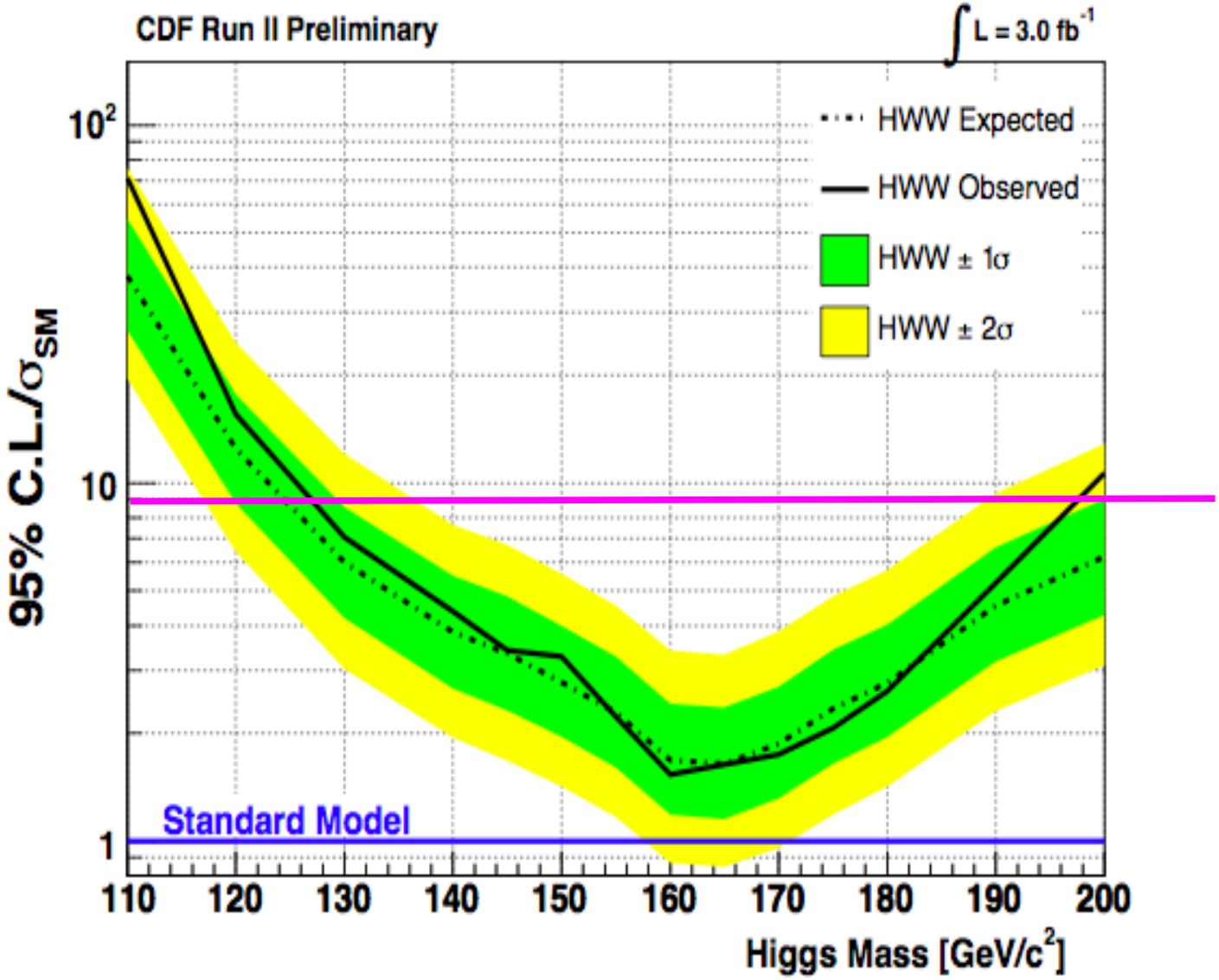
Only include gg->h signal

(This plot has VBF too, ~10% effect)



H->WW-> lν lν

CDF has a similar result



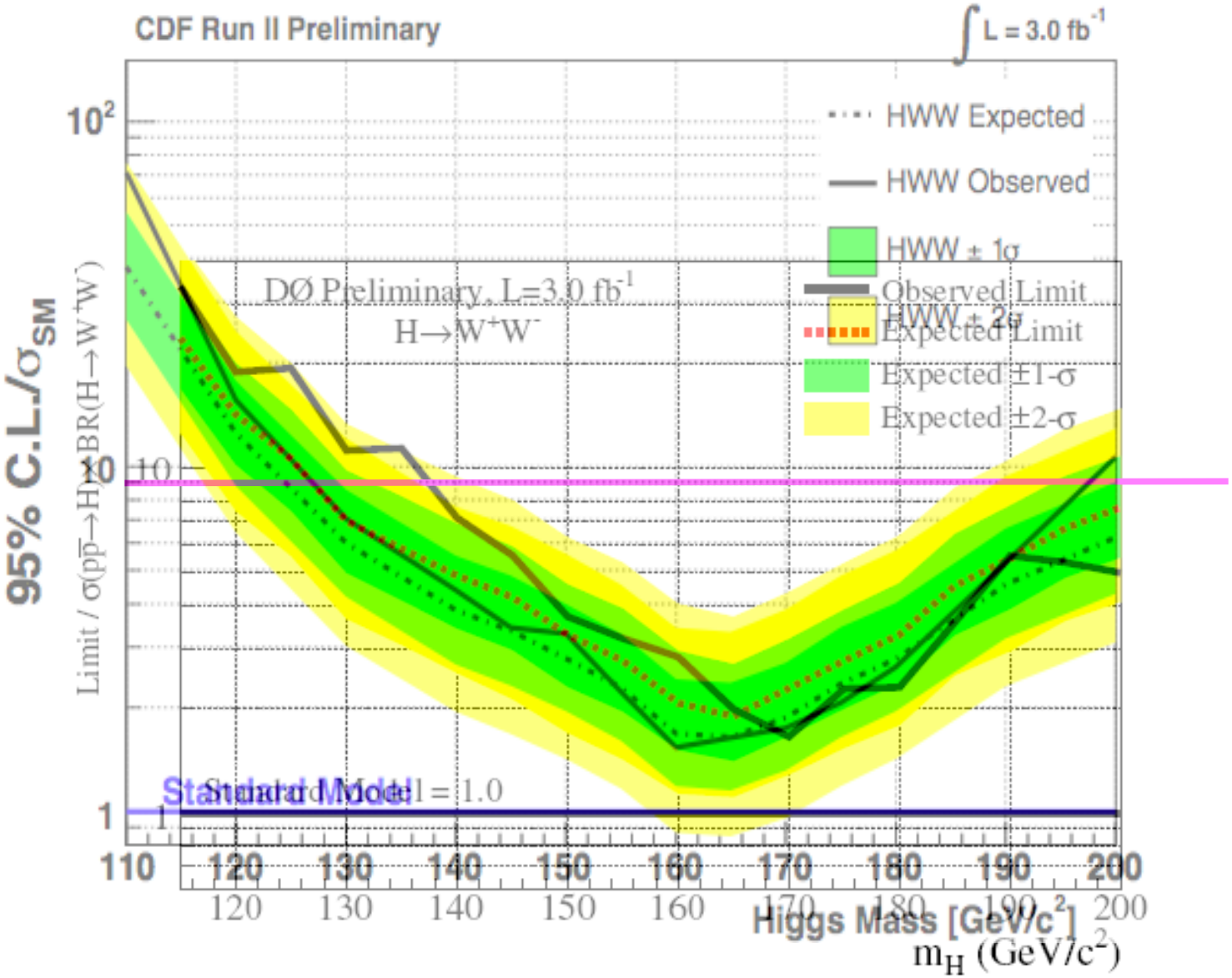
H->WW-> lν lν

Need to combine!

Machinery in place and used extensively for SM combinations

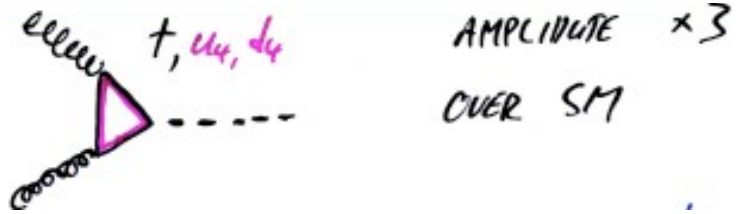
Will give sqrt(2) times more sensitivity

Include h->γγ ?



Conclusions

4th family enhances gg->h cross-section dramatically!



DØ already has sensitivity to a
~130 – 200 GeV Higgs (in 4th family model)
(~120 – 220 GeV if combined with CDF)

Precise interpretation in 4th family model and DØ / CDF combination underway...

With full Tevatron data and analysis improvements, sensitive from LEP lower limit (110 GeV?) to ~240 GeV?

Backup

The Higgs Boson

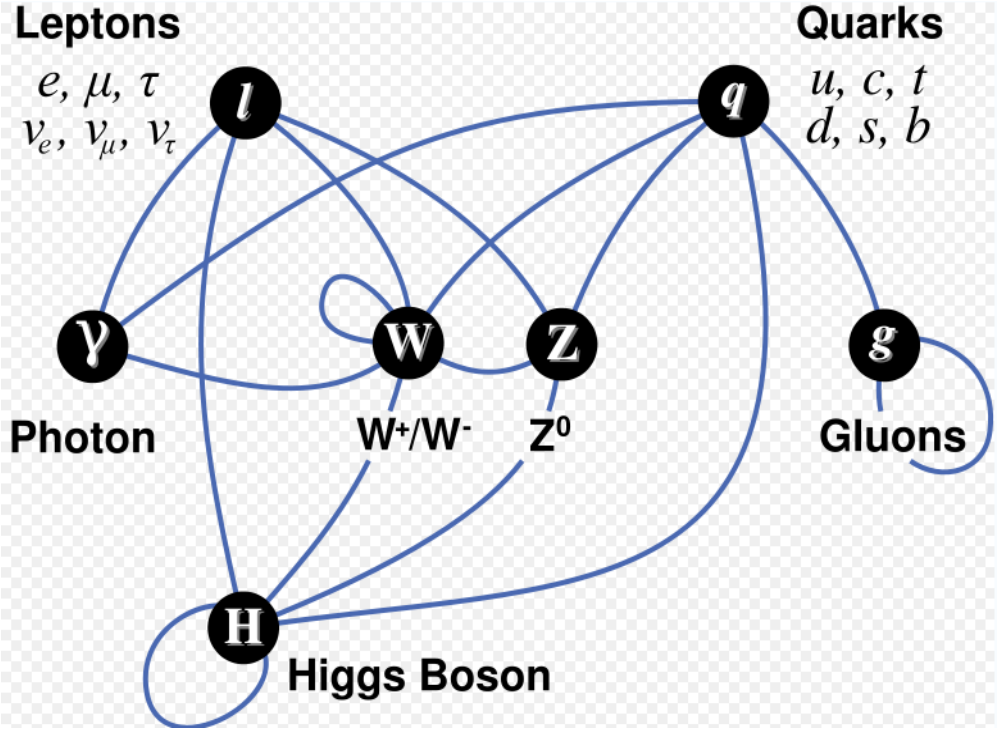
Postulated in the 1960's as a way to give mass to the W/Z bosons

Can also give masses to fermions

Only Standard Model particle not yet observed!

- What is its mass?
- What are its couplings?
- Is it a fundamental particle?
- Is there just one Higgs boson?

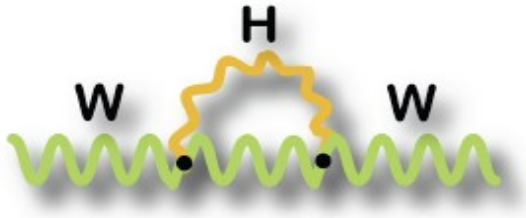
- Why is $m_h << m_p$? (hierarchy problem)



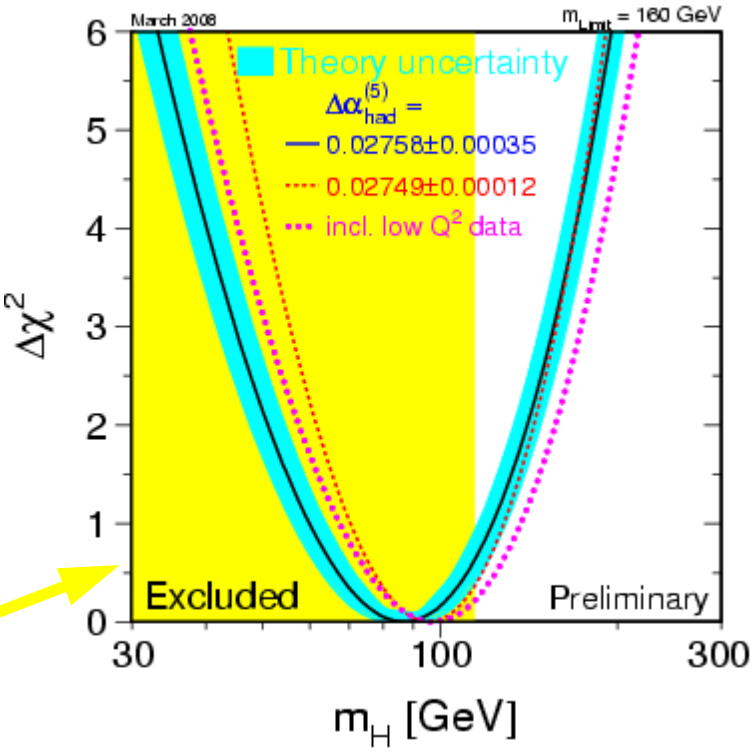
A critical piece of physics we know very little about!

Where's the Higgs?

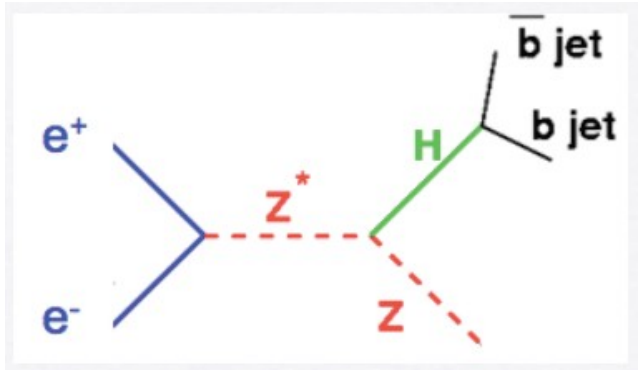
EW variables sensitive to m_H via radiative corrections:

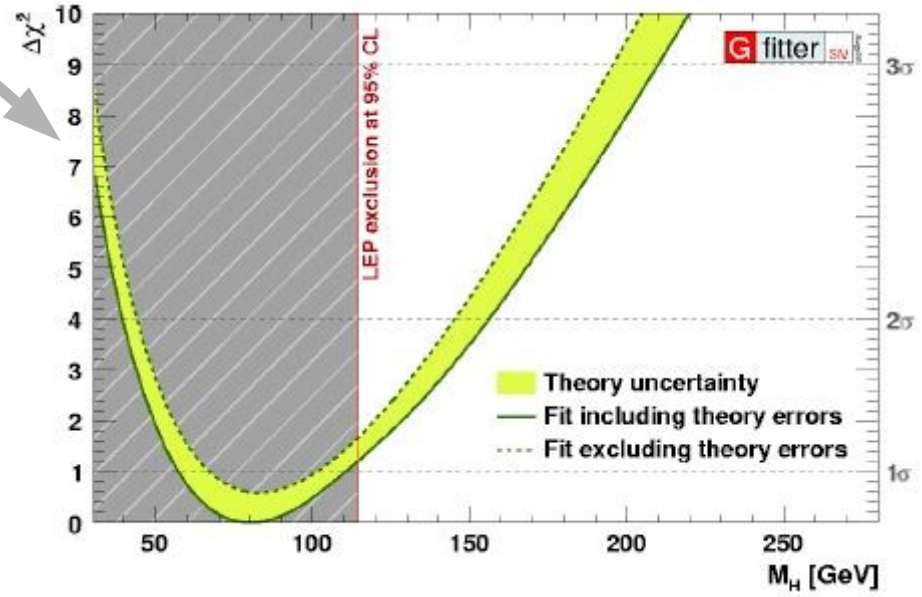


$$\log \frac{m_H}{m_Z}$$



LEP II direct: m_H>114.4 GeV





Main SM Higgs Search Channels

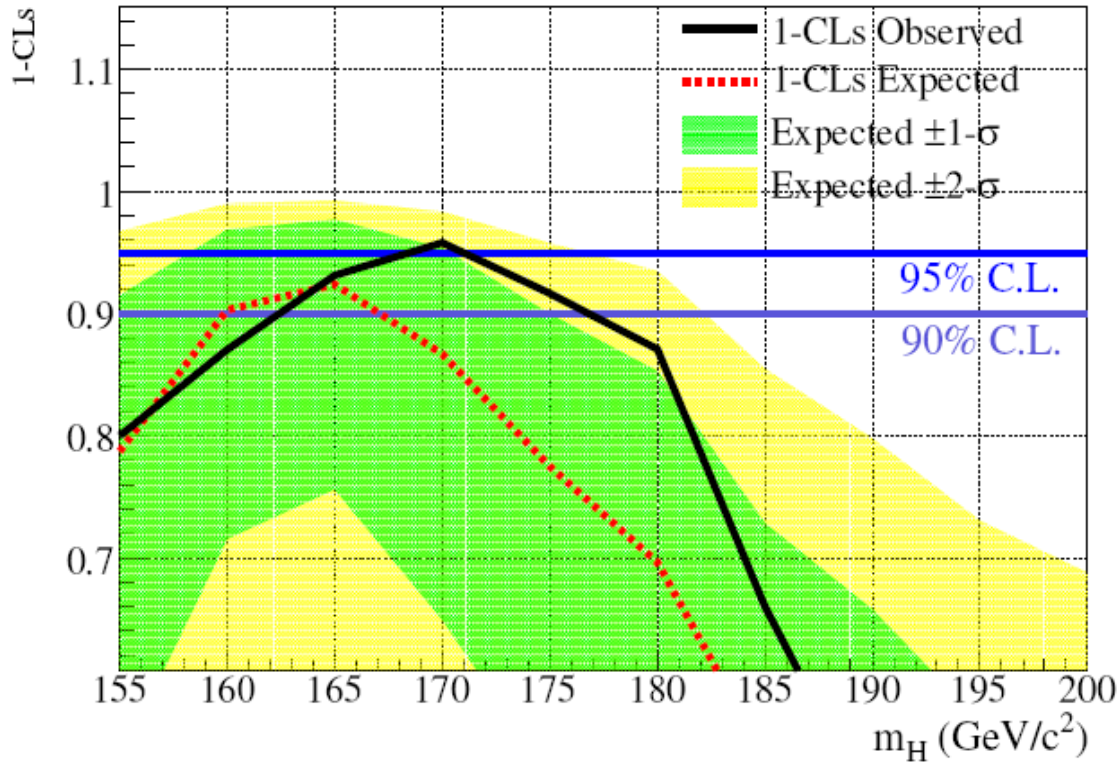
	H→bb (low mass)	H→WW (high mass)
$p\bar{p}\to H$	~~H→bb~~	H→WW→ **lν lν**
$p\bar{p}\to WH$	WH→Wbb→ **lν bb**	
$p\bar{p}\to ZH$	ZH→Zbb→ **ll bb**, **νν bb**	

W/Z+H→W/Z+WW→ $l^+l^-\,l^+$ / l^+l^+jj + ν's

Tevatron Higgs Combination

SM Higgs excluded at 170 GeV !!!

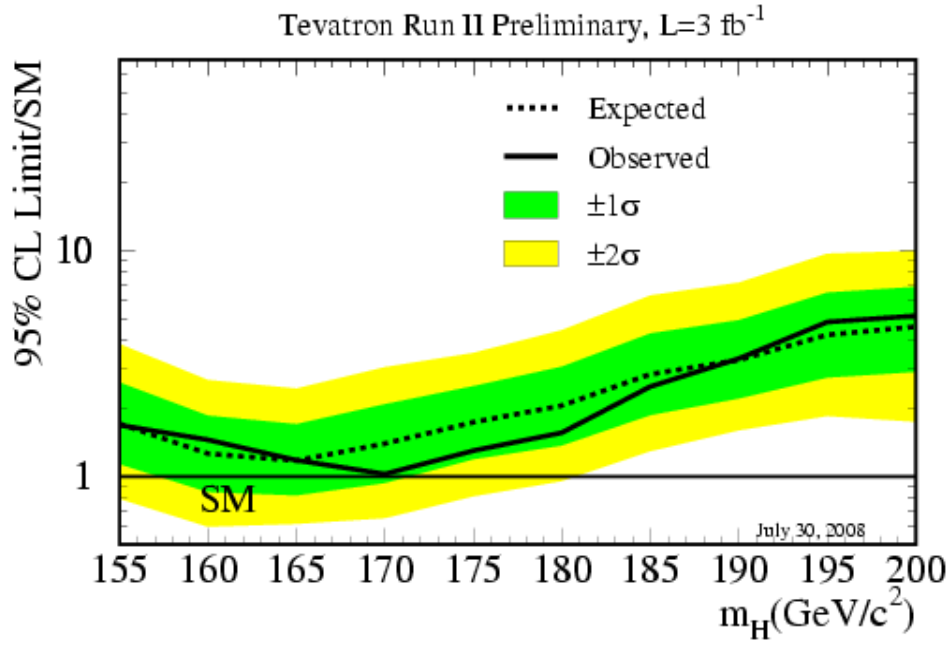
Expect to exclude a large range of Higgs masses by Moriond



Verified using two calculations

95%CL Limits/SM

M_Higgs(GeV)	160	165	**170**	175
Method 1: Exp	1.3	1.2	1.4	1.7
Method 1: Obs	1.4	1.2	**1.0**	1.3
Method 2: Exp	1.2	1.1	1.3	1.7
Method 2: Obs	1.3	1.1	**0.95**	1.2



H->WW-> lν lν

All pre-selections kept as loose as possible

- Cut out regions with almost no signal
- Cut out regions that could not be well modeled

Final state	$e\mu$	ee	$\mu\mu$
Cut 0 Pre-selection	lepton ID, leptons with opposite charge and $p_T^\mu > 10$ GeV and $p_T^e > 15$ GeV invariant mass $M_{\mu\mu} > 15$ GeV $\mu\mu$: $n_{\rm jet} < 2$ for $p_{\rm T}^{\rm jet} > 15$ GeV and $dR(\mu, {\rm jet}) > 0.1$		
Cut 1 Missing Transverse Energy $\not\!\!E_T$ (GeV)	> 20	> 20	> 20
Cut 2 $\not\!\!E_T^{\rm Scaled}$	> 7	> 6	> 5
Cut 3 M_T^{min} $(\ell, \not\!\!E_T)$ (GeV)	> 20	> 30	> 20
Cut 4 $\Delta\phi(\mu, \mu)$	< 2.0	< 2.0	< 2.5

H->WW-> lν lν

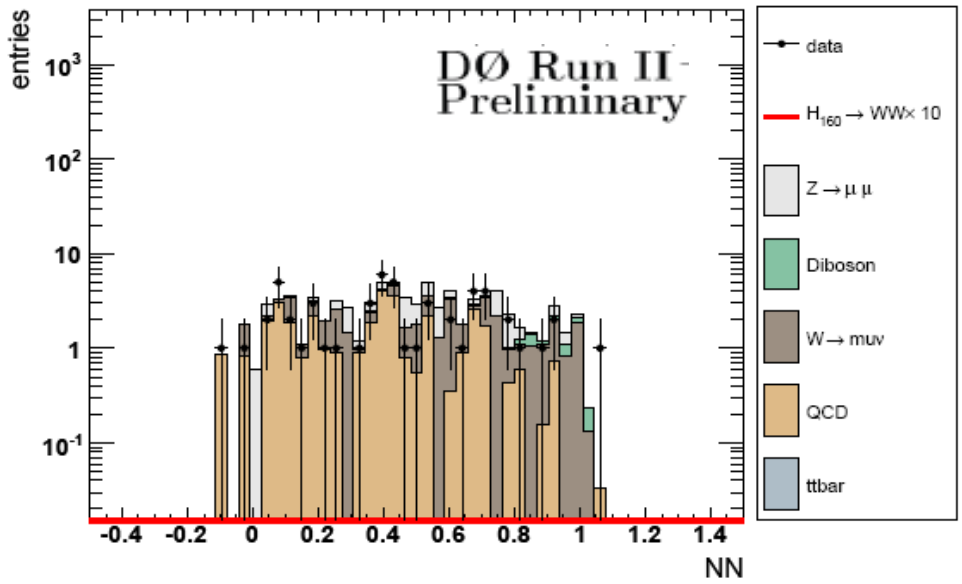
Many cross-checks performed in various other sets of the data/MC

- Like-sign (check W+jets and QCD)
- W+jets selection

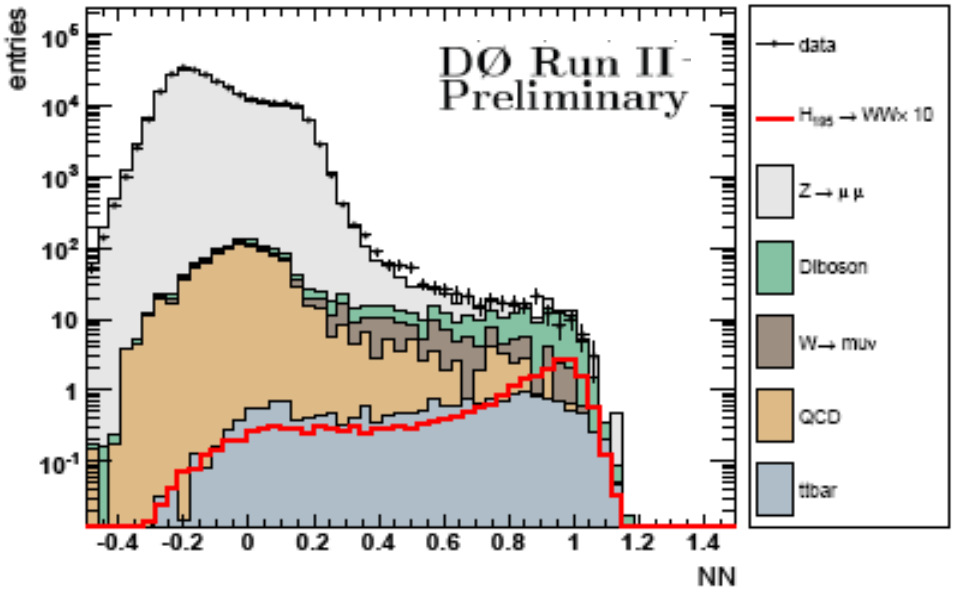
Pre-selection NN output

- Check for correlations not modeled in high-statistics Z samples

W+jet selection, like-sign



Pre-selection, opposite-sign



Pre-selection, like-sign