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Search for the Standard Model Higgs Boson at High Mass at the Tevatron

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on behalf of the

CDF and DØ

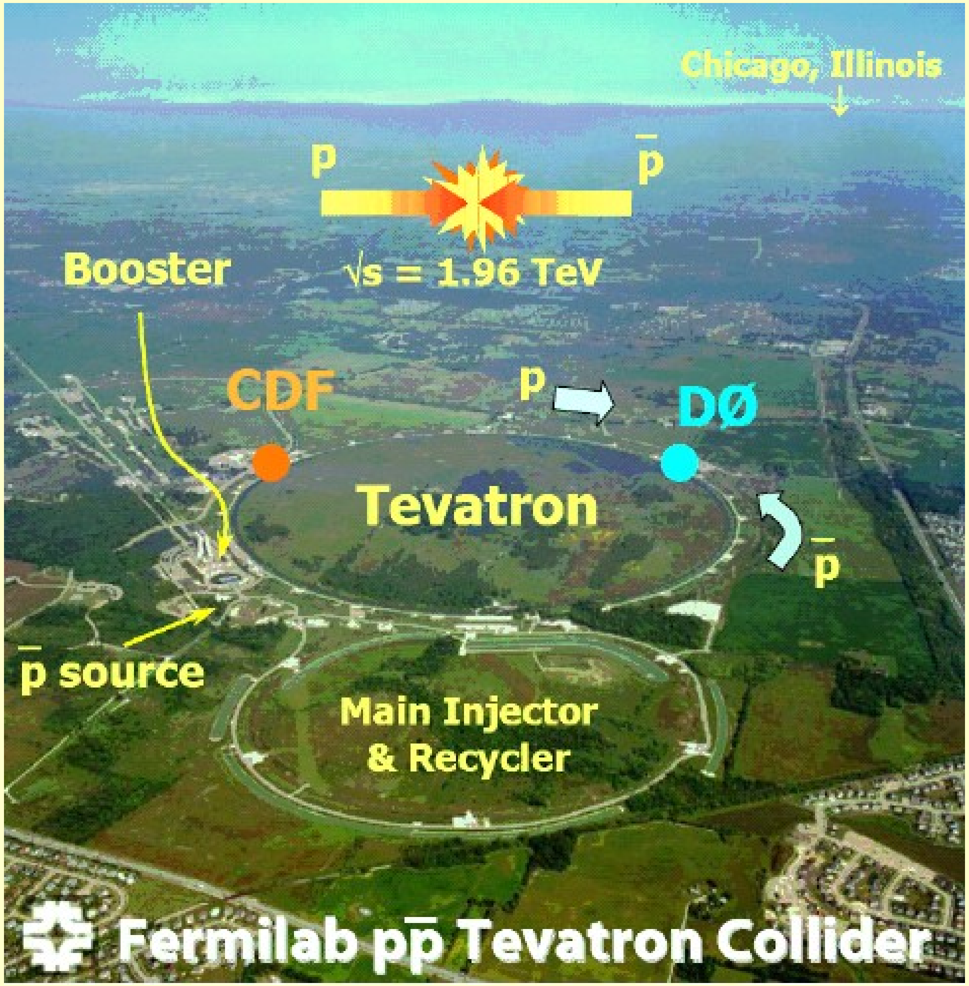
collaborations

XLIIId Rencontres de MORIOND
La Thuile, March 1-8, 2008

Outline

- Motivation
  - Theoretical overview
- Analysis overview
  - CDF
  - DØ

  } up to 2.4 fb^{-1}
- Combined Limits
- Future perspectives



Motivation - The Higgs Mechanism

- Essential ingredient of the Standard Model
  - Complex scalar field with potential
- Used to break the el. weak symmetry……

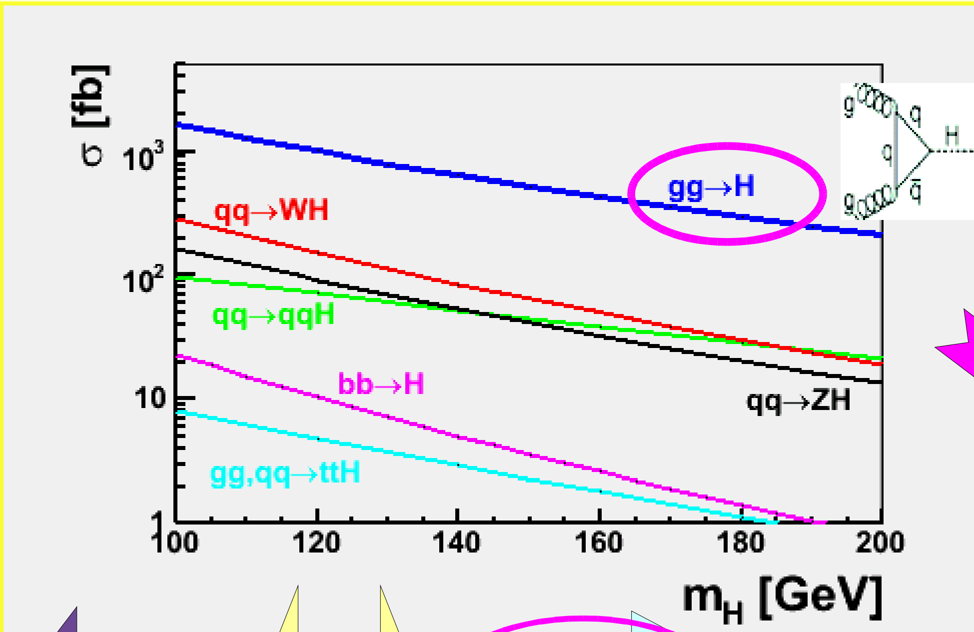
$$M_{W^\pm} = \tfrac{1}{2} vg \qquad M_Z = \tfrac{1}{2} vg / \cos\theta_W = M_W / \cos\theta_W$$

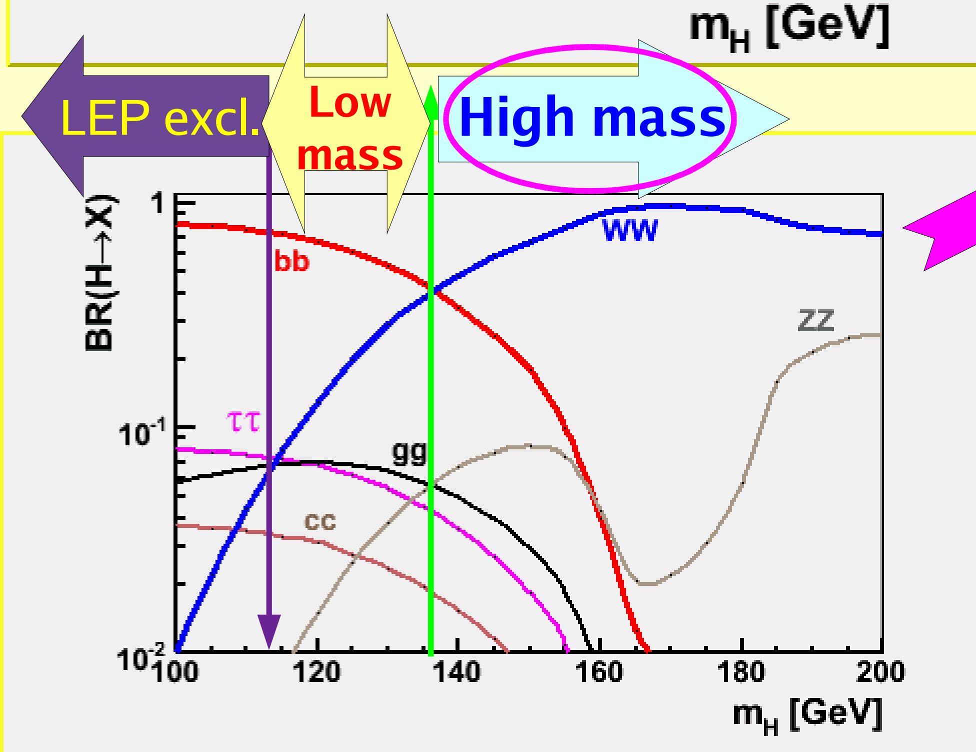
- ….. and to generate fermion masses:

$$\mathbf{m_f = g_f v / \sqrt{2} \qquad \Rightarrow g_f = m_f \sqrt{2} / v}$$

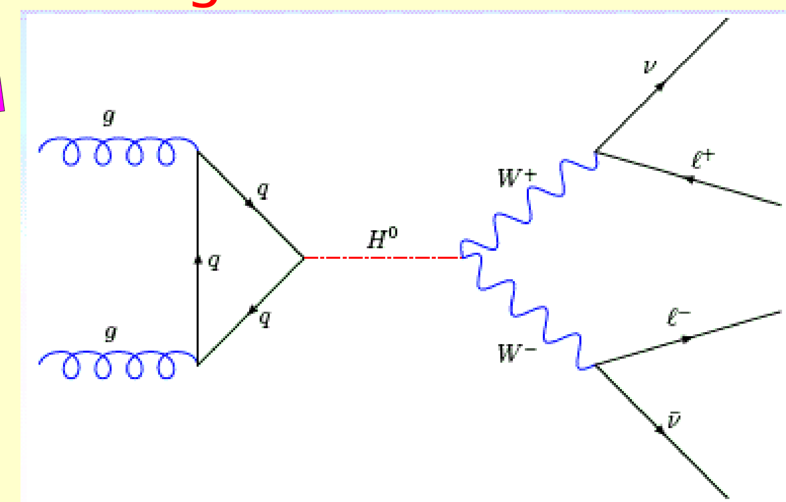
- Search for the Higgs boson is a key issue for experiments at current and future colliders
- Experimental challenges:
  - Higgs boson discovery
    - Measurement of Higgs boson parameters (couplings to bosons and fermions) and the Higgs self coupling
- Mass limits: lower 114.4 GeV/c^2 and upper 182 GeV/c^2 from combined direct and indirect searches

Production and Decay





- Dominant production process is gluon fusion
- Associated with vector boson is also significant

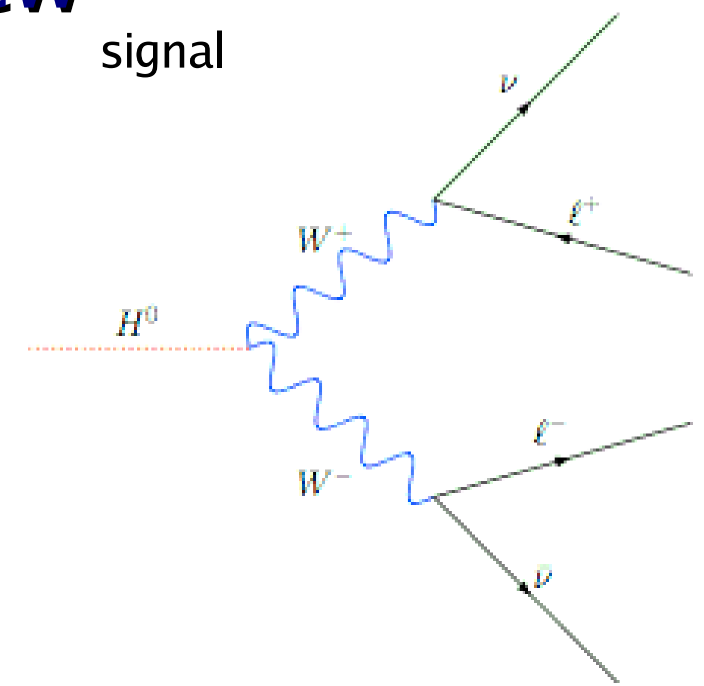


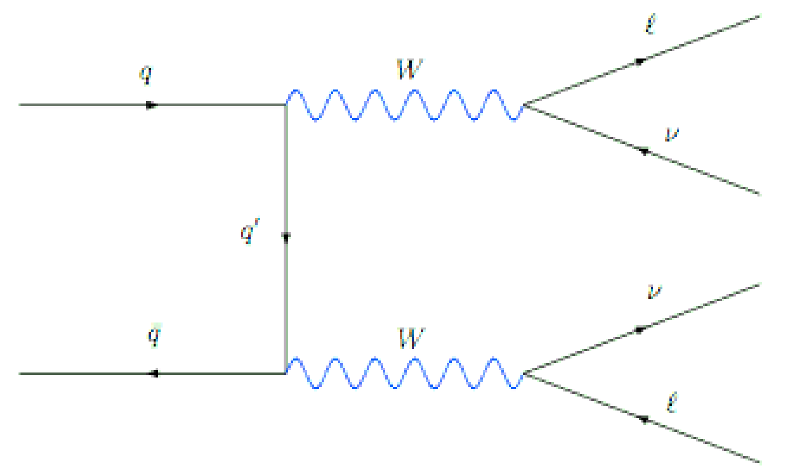
- Dominant decay for high mass Higgs boson is WW
- For m_H = 160 GeV, σ×BR = 390 fb; several hundreds H→WW so far at either DØ or CDF (2 fb^{-1} per exp.) few tens to two leptons and neutrinos

Analysis overview

- To suppress hadron backgrounds we look into final states where both W decay to leptons, i.e. ee, μμ and eμ
- Major backgrounds: Diboson (mainly WW), W+jets, Drell-Yan, tt, Multijets
- Signature:
  - Two energetic isolated leptons with opposite charge
  - Large missing transverse energy

signal

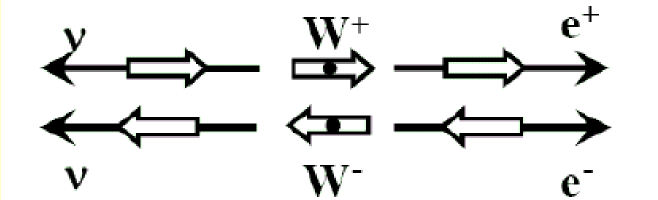




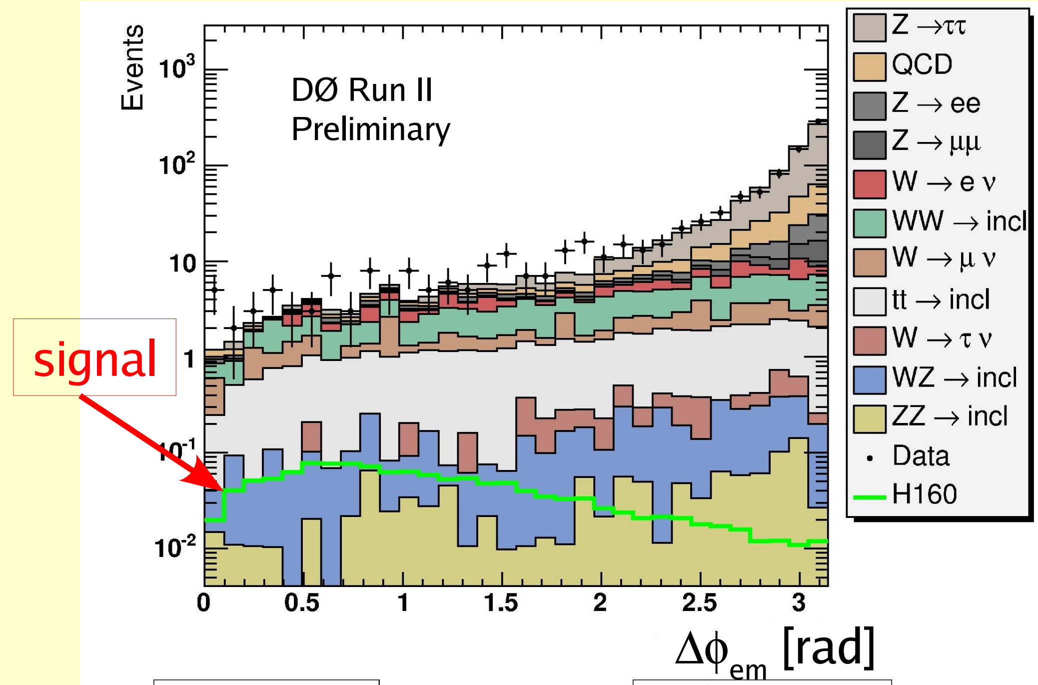
WW background

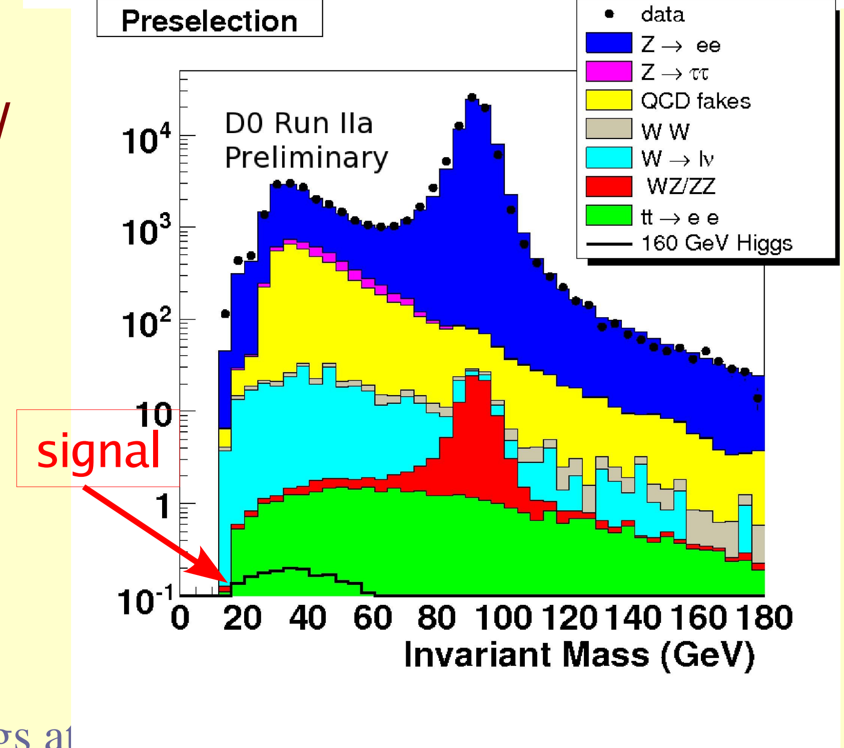
Analysis overview

- Characteristics:
  - In signal WW pair is coming from spin 0 Higgs boson
    - Leptons prefer to point in same direction



    - Di-lepton opening angle $\Delta\phi_{ll}$ discriminates against dominant WW background.
  - Dilepton mass is small and broad
    - Discriminates against Drell-Yan





Multivariate techniques

- In order to better separate signal from backgrounds we use different multivariate techniques: CDF combines Leading Order (LO) Matrix Elements and Neural Networks (NN), DØ uses Neural Networks
- LO Matrix Elements are used to calculate event probabilities

$$P_m(x_{obs}) = \frac{1}{<\sigma_m>} \int \frac{d\sigma_m^{th}(y)}{dy} \epsilon(y) G(x_{obs}, y) dy$$

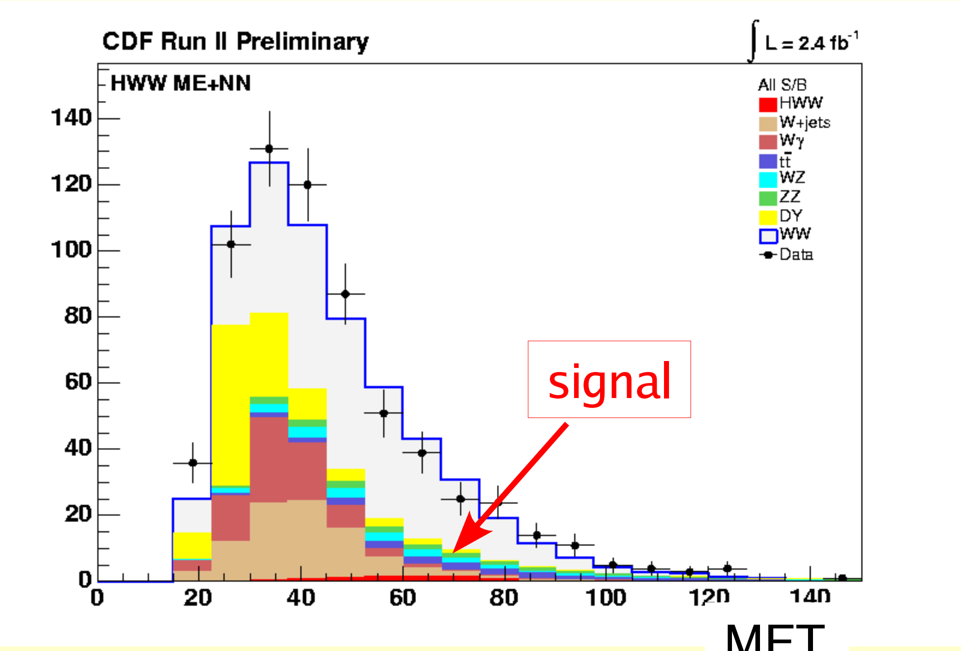
ME efficiency resolution

and calculate likelihood ratio: $LR(x_{obs}) \equiv \frac{P_H(x_{obs})}{P_H(x_{obs}) + \sum_i k_i P_i(x_{obs})}$

- Neural network:
  - CDF uses ME and kinematic variables as inputs
  - DØ uses kinematic variables as inputs
- Single output from NN is used as discriminant variable

CDF - selection

- Basic Selection:
  - Lepton trigger selection
  - Several categories of lepton(track) pairs with opposite charge divided into two groups – high signal to background and low signal to background
  - Lepton and missing E_T cuts applied to reduce backgrounds: $p_T(l_1) > 20$ GeV, $p_T(l_2) > 10$ GeV, $\not{E}_T \cdot \sin(\min(\pi/2, \Delta\phi(\not{E}_T, l \text{ or jet}))) > 25$ GeV, $n_{jets} < 2$ ($p_T(jet) > 15$ GeV, $|\eta| < 2.5$), $m_{ll} > 16$ GeV, trilepton veto
  - Data are well described



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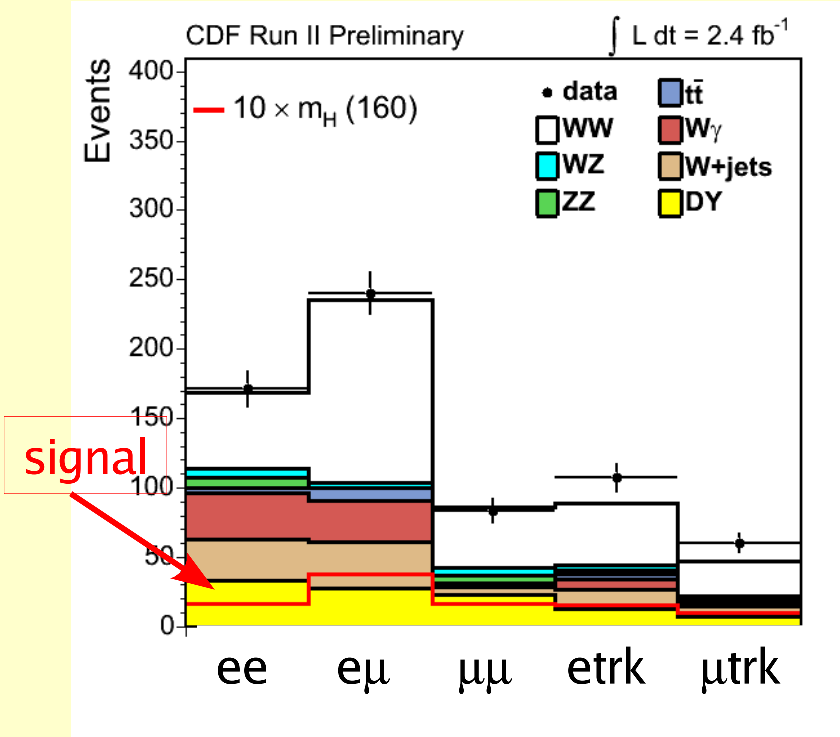
CDF – event yields



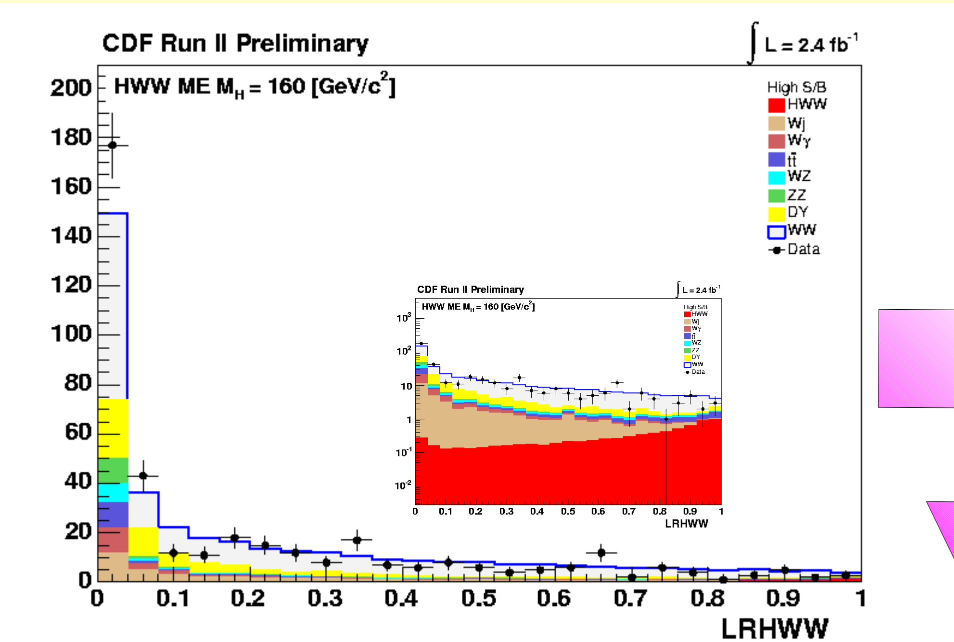
CDF Run II Preliminary	$\int \mathcal{L} = 2.4\,\mathrm{fb}^{-1}$		
$M_H = 160$ GeV$/c^2$			
$H \to WW$	9.5	±	1.1
WW	300.3	±	38.1
WZ	20.5	±	3.1
ZZ	18.2	±	2.7
$t\bar{t}$	20.8	±	3.8
DY	104.0	±	23.0
$W\gamma$	72.4	±	18.7
$W+$jets	89.2	±	22.8
Total BG	**626**	±	**54**
Data		**661**	

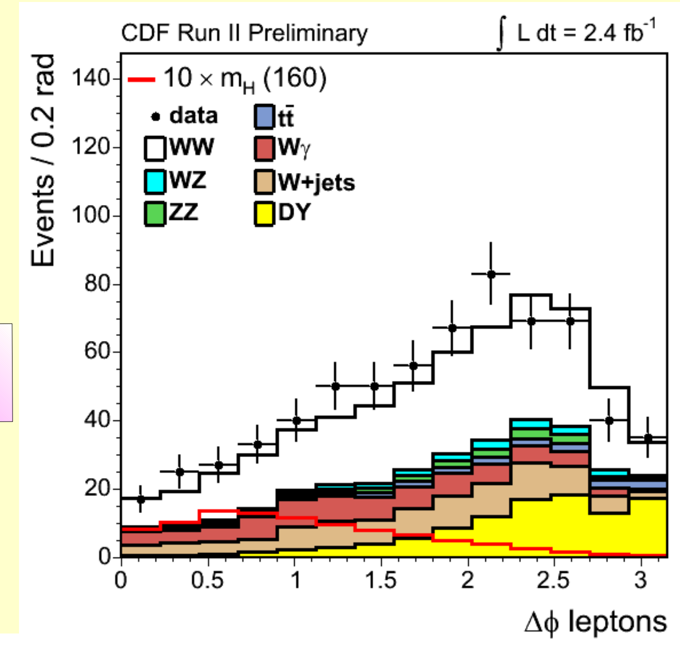
HWW ME+NN

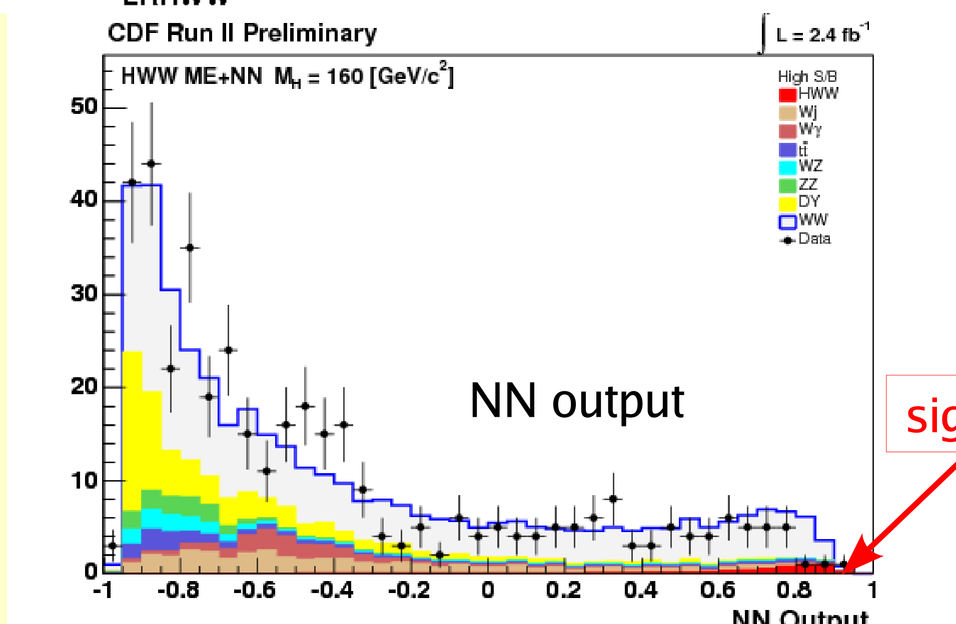
- All five channels are combined leading to 626 expected events from known SM processes and 661 observed events
- 9.5 signal events are expected for Higgs mass of 160 GeV

CDF – final discriminant

- ME calculated from lepton 4-vectors and missing transverse energy is used as an input to NN together with several kinematic distributions







signal

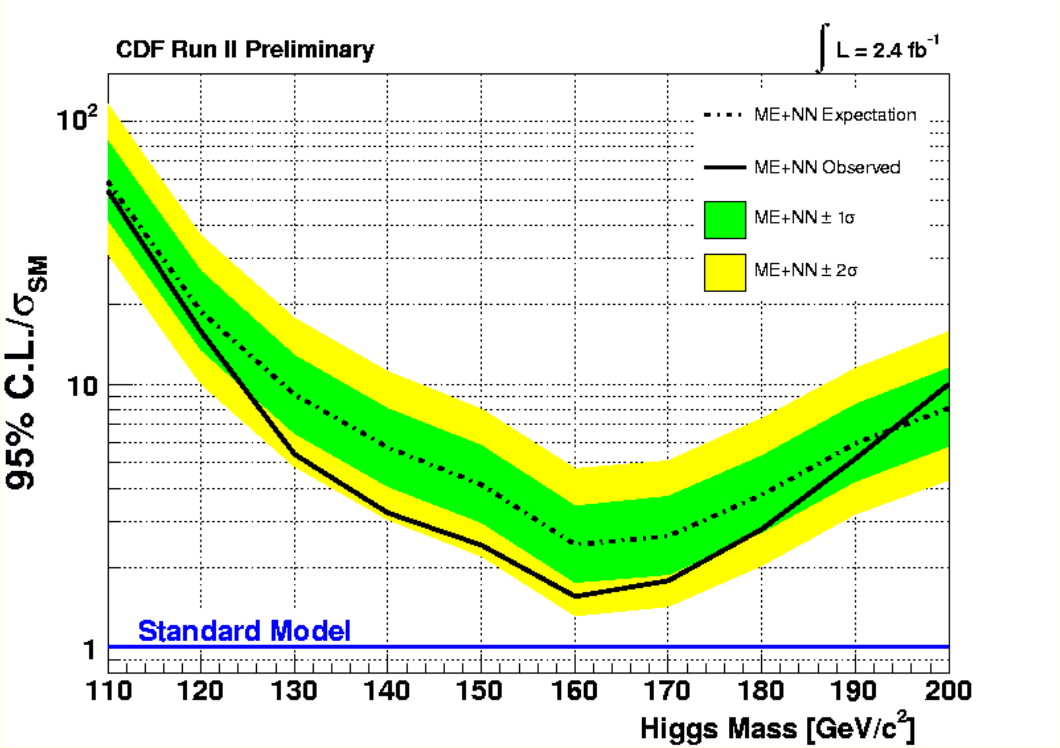
CDF - results

- Various sources of systematic uncertainties affect the background estimation and the signal efficiency:
  - Theoretical uncertainty of background production cross sections (10-15%), lepton id (2%), trigger efficiency (~5%)

Binned maximum likelihood fit of NN discriminant used to determine limit

$\sigma \times BR < 0.8$ pb @ 95% CL
for m_H=160 GeV

Observed Limit/σ_{SM} (NNLL) ~ 1.6
Expected Limit/σ_{SM} (NNLL) ~ 2.4



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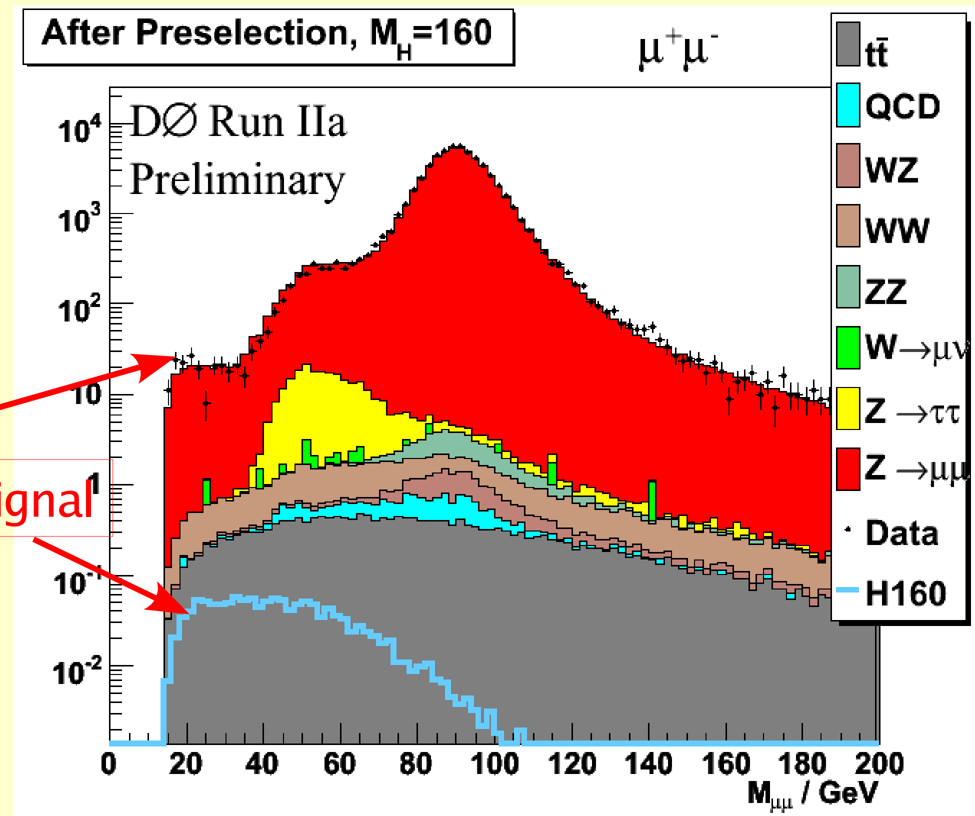
DØ - selection

- Basic Selection:
  - Combination of several lepton triggers ensures trigger efficiency ~95%
  - Two isolated leptons with opposite charge
  - Lepton and missing E_T cuts applied to reduce backgrounds
  - Final selection cuts optimized for each Higgs mass separately
  - Data are well described

	$ee(1.1 fb^{-1})$	$e\mu(1.1 fb^{-1})$	$\mu\mu(1.7 fb^{-1})$
lepton ID	$p_{T,1} > 15, p_{T,2} > 10$		$p_{T,1} > 20, p_{T,2} > 10$
lepton ID	$m_{ll} > 15$, isolation		$m_{ll} > 17$, isolation
$\not{E}_T$	$\not{E}_T > 25 - 35$, scaled$(\not{E}_T) > 7$		
$m_{ll} < x$	$\min(m_H/2, 80)$	$m_H/2$	
$p_{T,1} + p_{T,2} + \not{E}_T$			$m_H/2 + 20 < x < m_H$
$m_{T,\min}(l, \not{E}_T)$	$x > 50 - 65$		$x > 30 - 45$
$H_T = \sum p_T^{jet}$	$H_T < 70$		$H_T < 50 - 60$
$\Delta\phi_{ll}$	$\Delta\phi_{ll} < 1.25 - 1.5$		



signal

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DØ – event yields

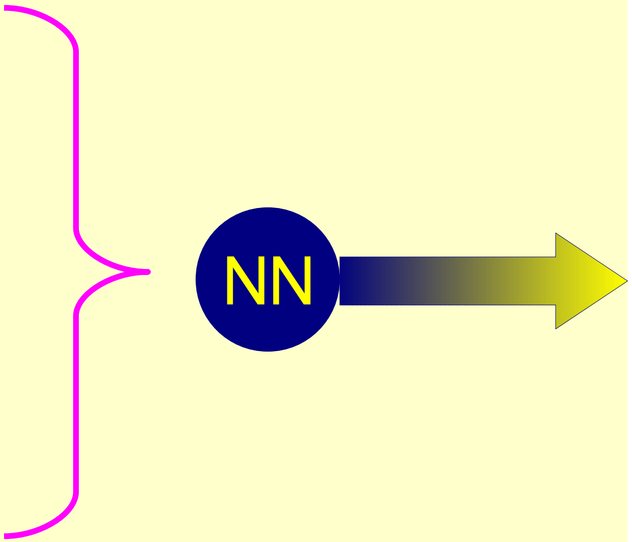
	ee	eμ	μμ
m_H [GeV]	160	160	160
H → WW	0.78±0.02	1.64±0.03	1.29±0.01
Z/γ → ll	0.0±0.0	0.2±0.1	1.3±0.02
WW,WZ	5.5±0.3	13.2±0.1	9.7±0.1
tt	1.4±0.1	1.25±0.1	0.6±0.1
W+jet/γ	6.7±2.0	7.5±1.9	1.1±1.1
Multi-jet	0.1±0.05	2.1±0.2	0.0±0.0
Total Background	13.8±2.0	24.2±2.0	12.6±2.0
Data	15	20	10

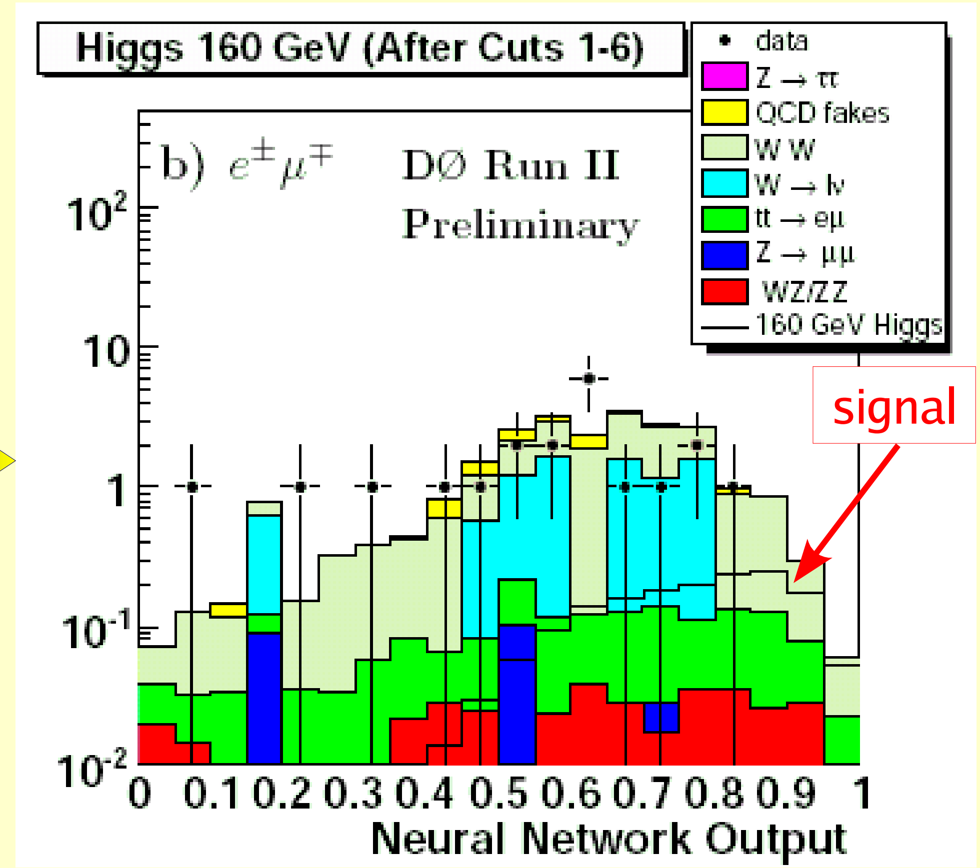
- Combining three analyzed channels there are 50.6 expected events from known SM processes and 45 observed events
- 3.71 signal events expected for Higgs mass of 160 GeV

DØ – final discriminant

- Kinematic distributions are used as inputs for the NN

$p_T(l_1,l_2)$
$m_T(l_1,l_2,MET)$
m_{l1l2}
$\Delta\phi_{l1,l2}$
$\Delta\phi_{l1(2),MET}$
MET
$p_T(l_1)+p_T(l_2)+MET$





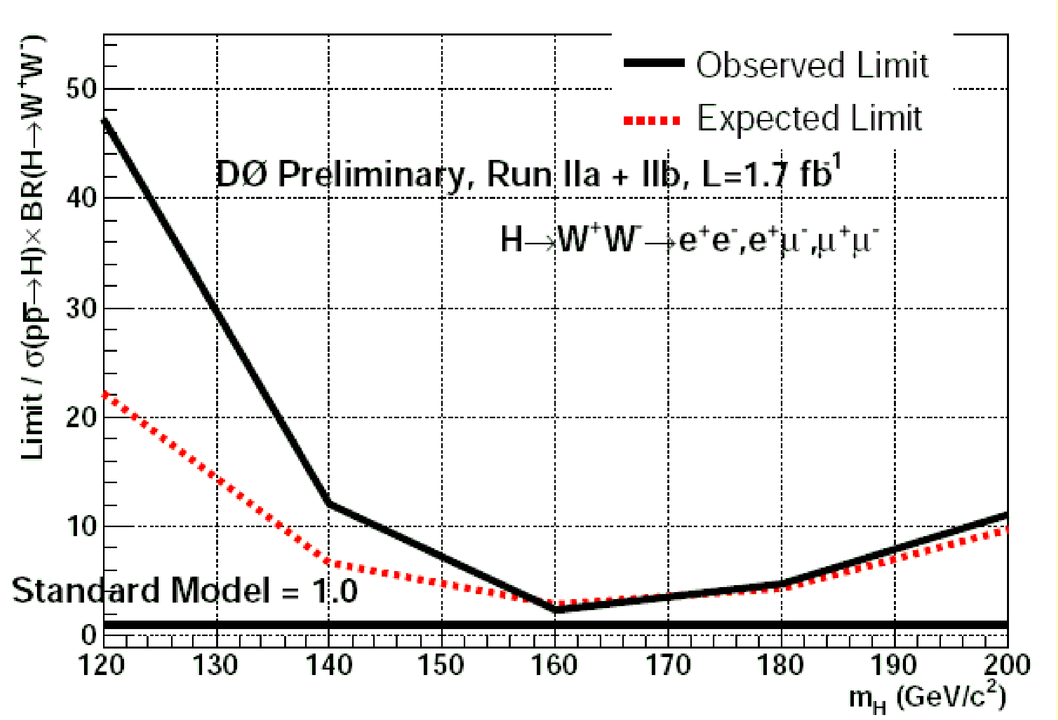
- NN trained on WW background samples, run on all backgrounds; separate optimization for each channel and Higgs mass

- Final result determined from fit to NN output

DØ – result

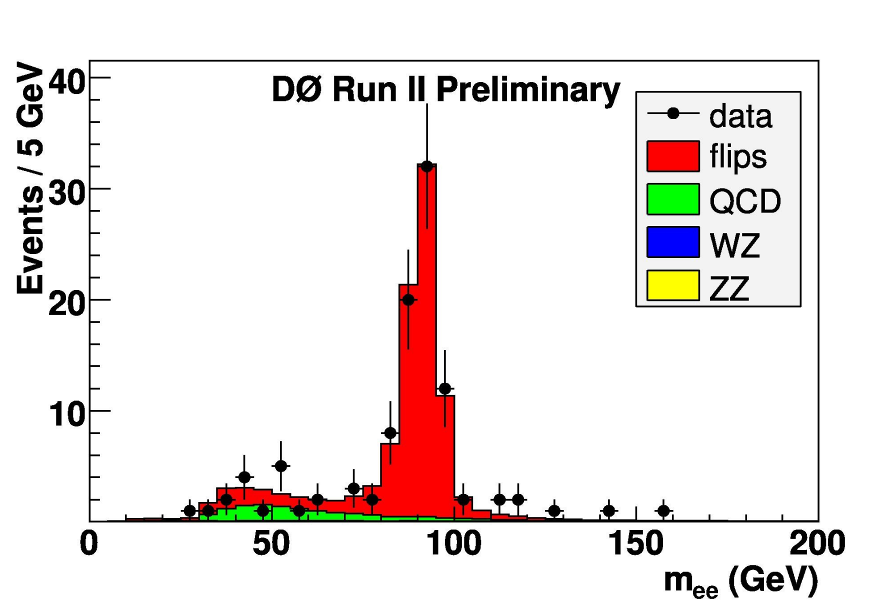
- Various sources of systematic uncertainties affect the background estimation and the signal efficiency:
  - Dominated by background normalization (6-20%), others include theoretical uncertainty of background production cross sections (~4%), Jet Energy Scale – JES (5-10%), electron and muon reconstruction efficiencies and resolutions (2-11%), trigger efficiency (~5%)

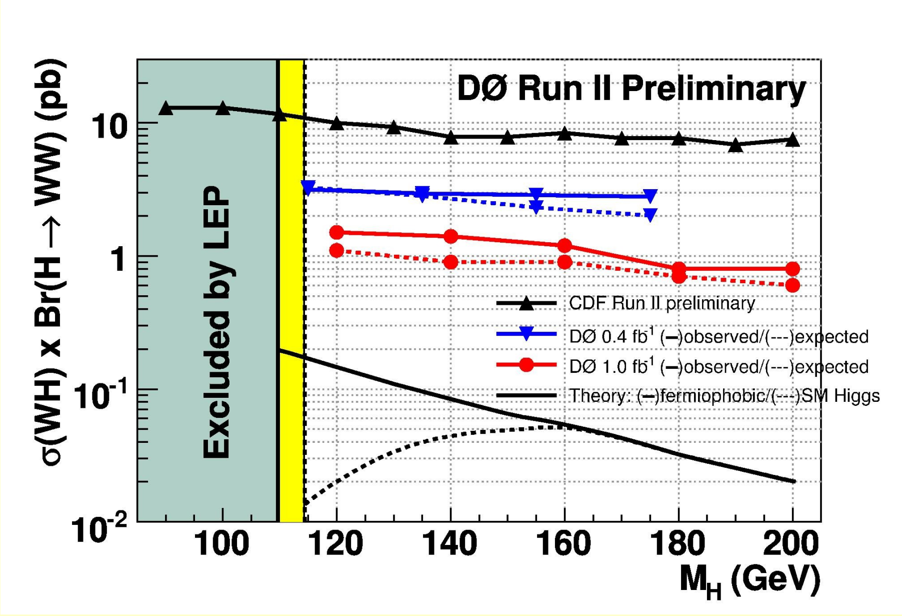
Observed Limit/σ_{SM} (NNLL) ~ 2.4
Expected Limit/σ_{SM} (NNLL) ~ 2.8



WH->WWW(*)->l±νl±ν+X

- Helps to cover intermediate mass region
- Basic selection requires two same charge leptons with p_T > 15 GeV
- Two main types of backgrounds:
  - With two real same charge leptons like WZ→lνll
  - Instrumental – measured from data:
    - "QCD" with misidentified lepton
    - "flip charge" when charge of the lepton is mismeasured
- Main source of systematic uncertainty is coming from instrumental background (~30%)
- Limit: 0.9 pb at 95% CL for m_H=160 GeV

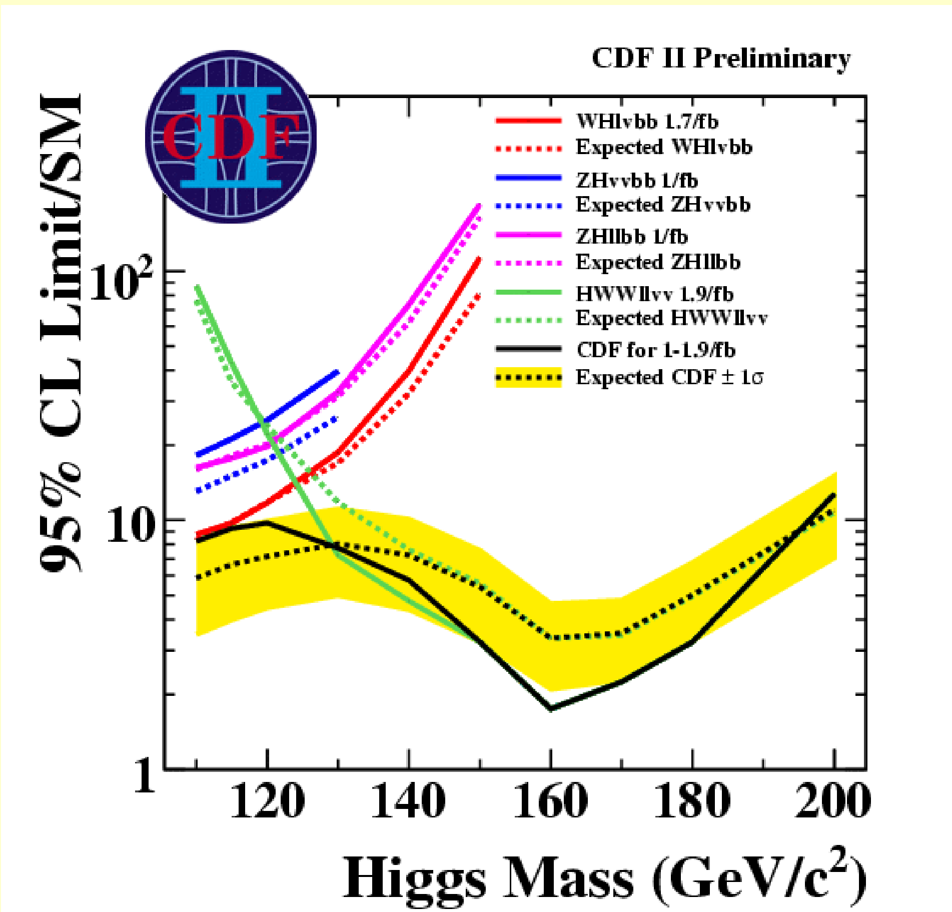


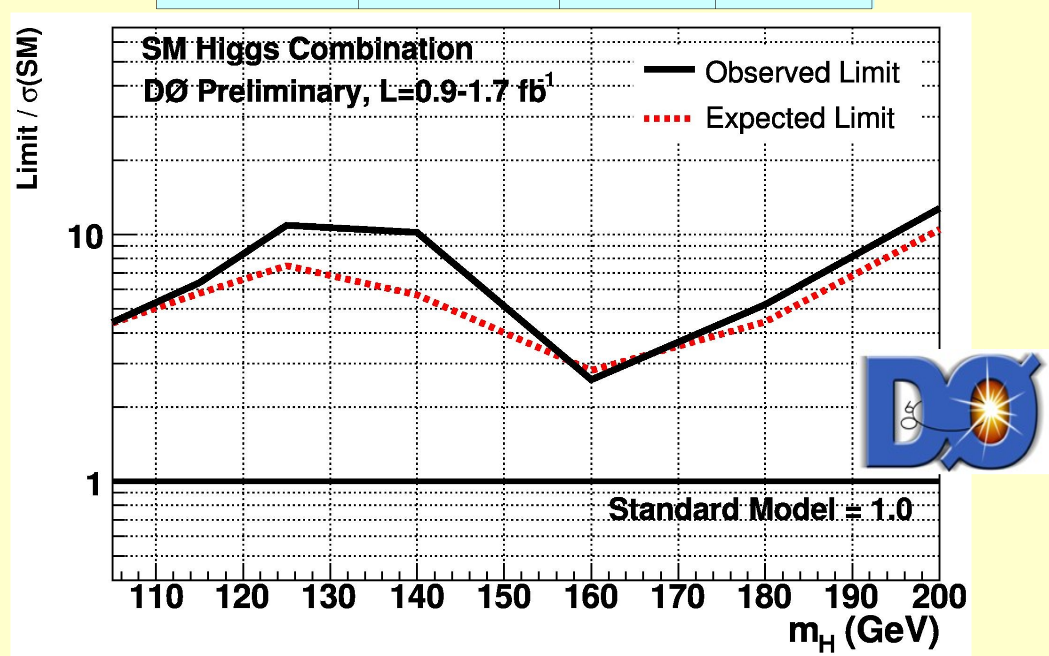


Combined limits – CDF and DØ

- Combined limits from December 2007
  - New results shown today not yet included!
- Expect both experiments to show improved limits next week

	m_H [GeV]	CDF	DØ
expected	115	6	5.7
	160	3.1	2.8
observed	115	9.6	6.4
	160	2	2.5





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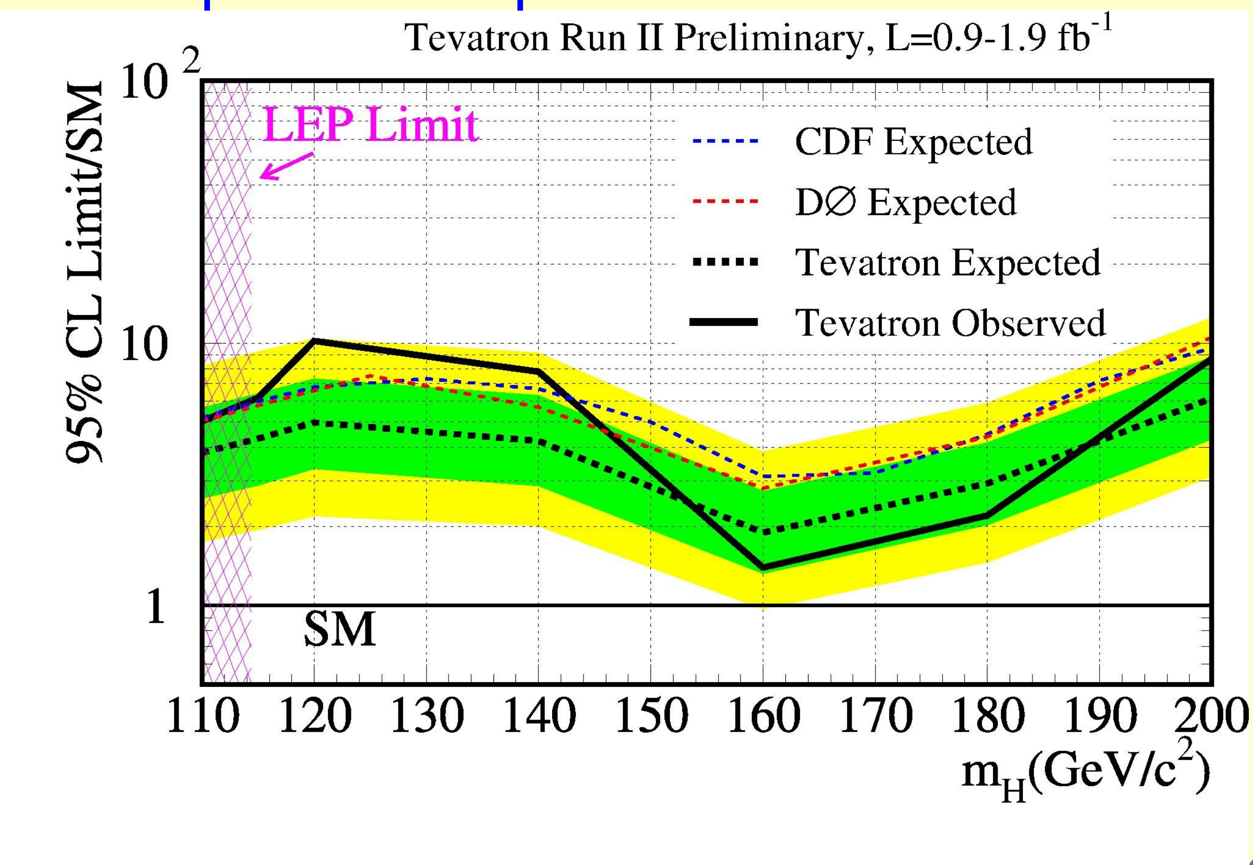
Combined limits – Tevatron

- New results shown today not yet included!
- CDF limits improved more than 20% (10% from improved analysis)
  - m_H = 160 GeV: (exp) 3.1 → 2.4
- We expect significant improvement of DØ limits (next week)
- Expect new improved combination from Tevatron (next week)



	m_H [GeV]	Tevatron
expected	115	4.3
	160	1.9
observed	115	6.2
	160	1.4

http://arxiv.org/abs/0712.2383

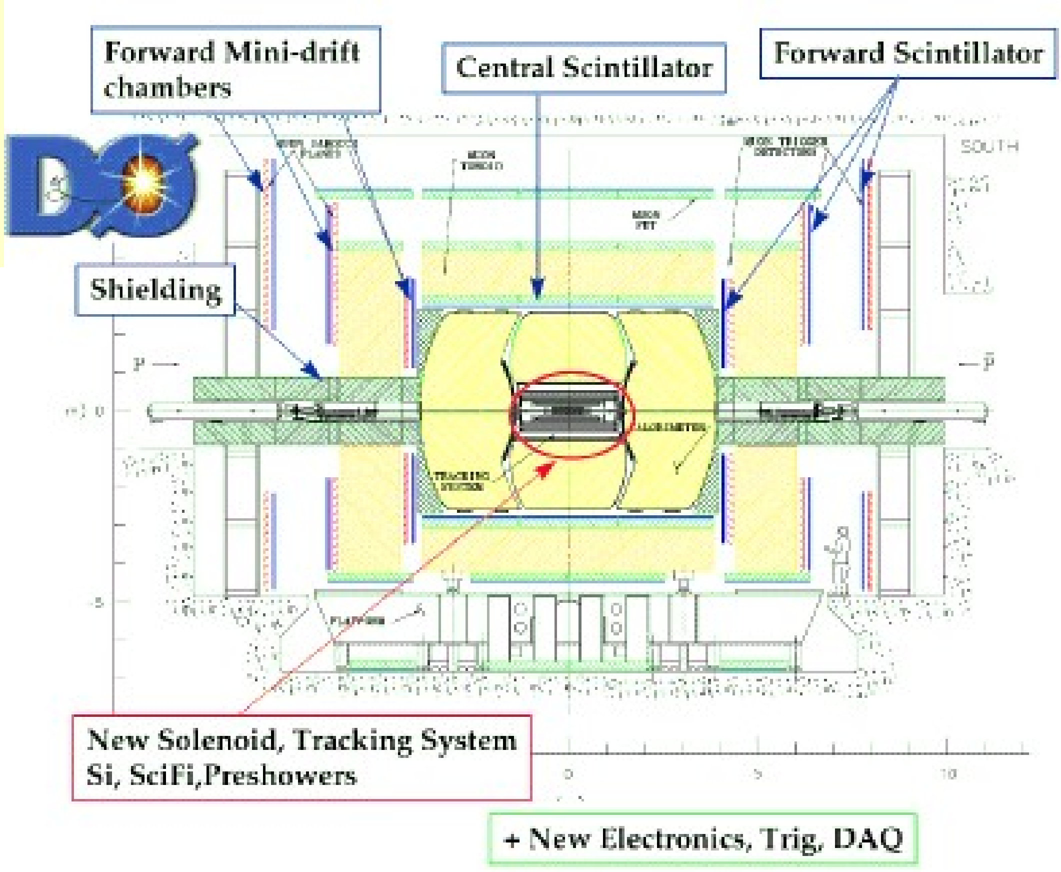
Summary and Future Perspectives

- Still no evidence for Higgs boson but the Tevatron is closing in on the SM at large values of Higgs mass
  - Current limit on the cross-section is only 1.4 times bigger then what we expect from Standard model for m_H = 160 GeV
- We expect further improvements from
  - More data (luminosity)
  - Further improvement of lepton identification
  - Optimization of multivariate techniques
  - Including new channels
- Look for better limits already next week and expect exciting summer

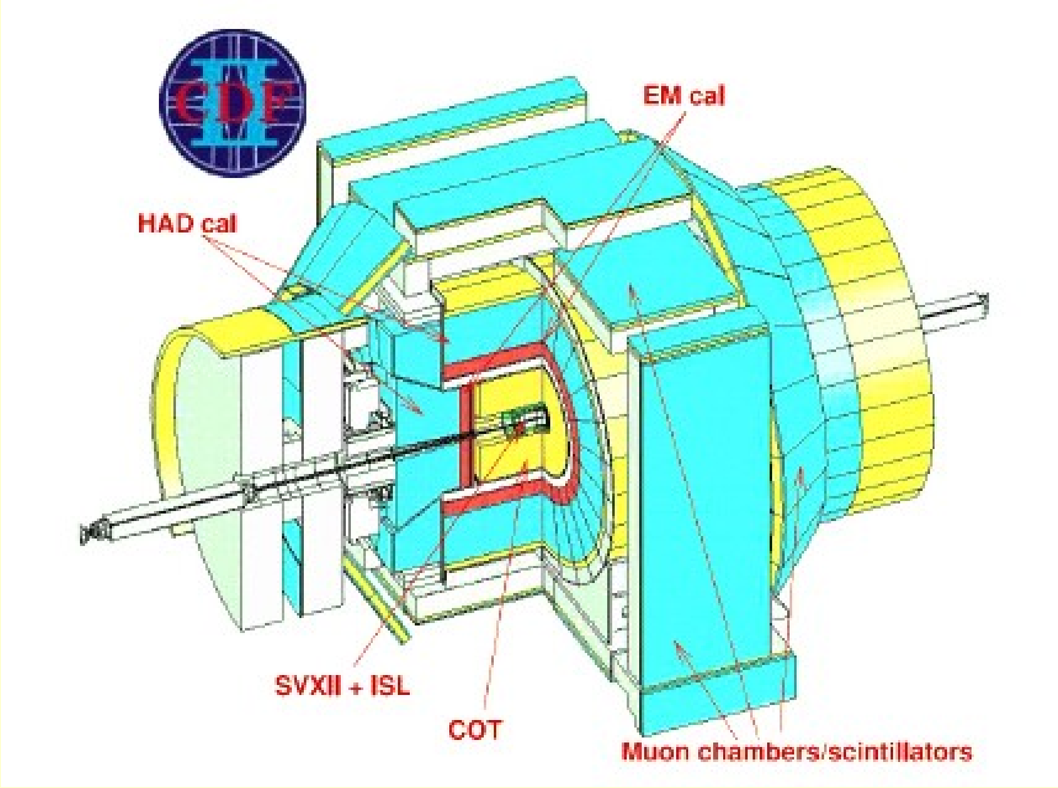
Backup

CDF and DØ experiments in Run II

- Both detectors are upgraded in Run II
  - New silicon micro-vertex trackers
  - New tracking systems
  - Upgraded muon chambers



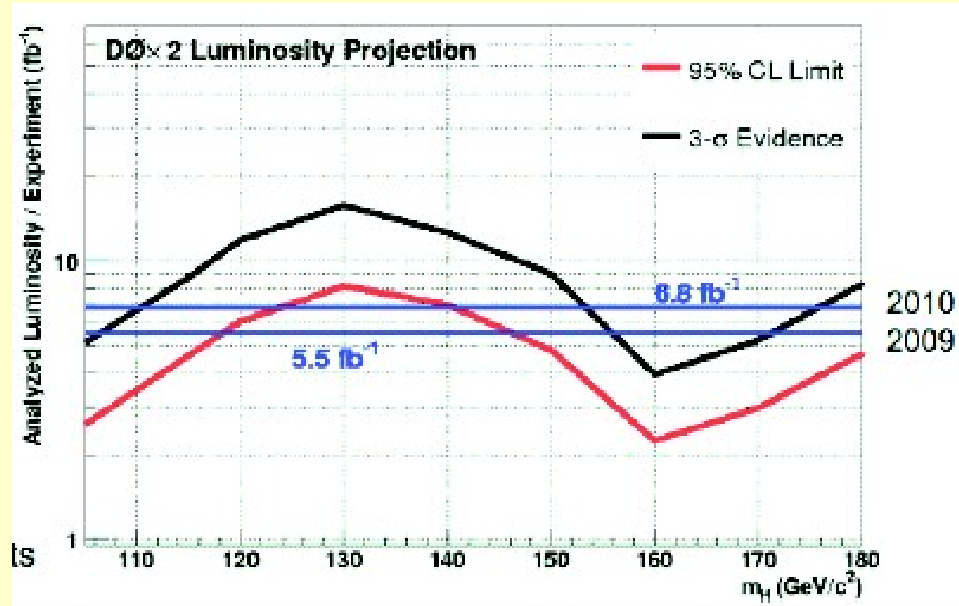
DØ: new solenoid, new pre-showers,
LØ for SMT in RunIIb, new L1Cal trigger

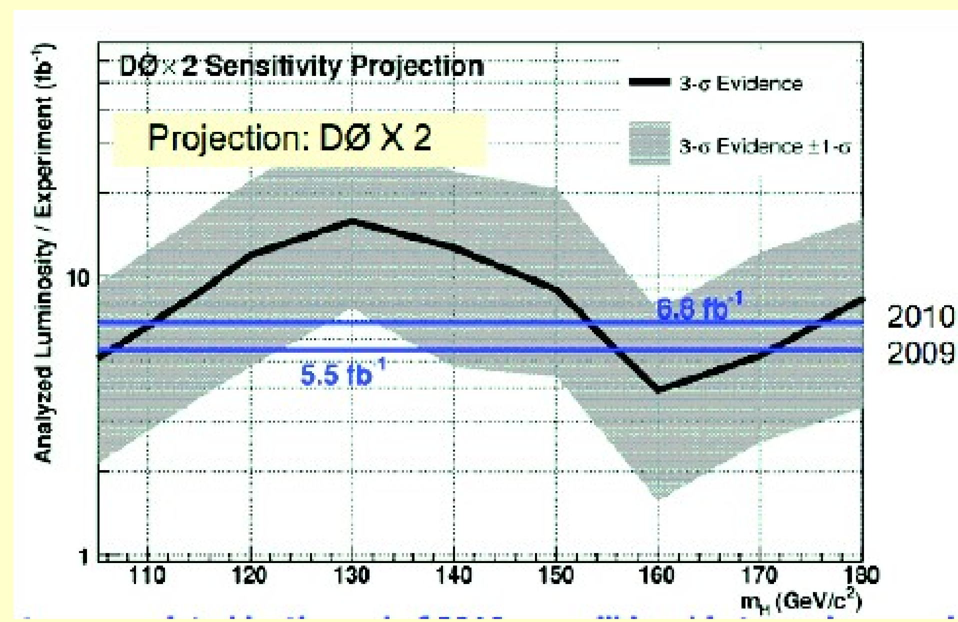


CDF: new Plug Calorimeters, new TOF

Tevatron projections

- Including data taking efficiency projected full data set will be:
  - 5.5 fb^{-1} by the end of 2009
  - 6.8 fb^{-1} by the end of 2010
- Assumption: projected sensitivity for mH = 115 GeV 2 times higher than current for full data set
  - Improvment from 2005-2007 was ~1.7
  - Possibilities:
    - Better b-tagging
    - Better dijet mass resolution
    - Better multivariate techniques





CDF WW limits

CDF WW	110	120	130	140	150	160	170	180	190	200
$-2\sigma/\sigma_{SM}$	31.24	9.99	4.85	3.05	2.21	1.31	1.43	2.05	3.19	4.31
$-1\sigma/\sigma_{SM}$	42.00	13.45	6.49	4.08	2.98	1.76	1.88	2.73	4.26	5.79
Median/σ_{SM}	**58.85**	**18.83**	**9.10**	**5.75**	**4.14**	**2.44**	**2.64**	**3.79**	**5.93**	**8.09**
$+1\sigma/\sigma_{SM}$	83.87	26.82	12.82	8.07	5.84	3.44	3.74	5.34	8.38	11.50
$+2\sigma/\sigma_{SM}$	116.11	36.63	17.77	11.14	8.04	4.78	5.11	7.41	11.44	15.83
Observed/σ_{SM}	**54.31**	**15.84**	**5.40**	**3.23**	**2.44**	**1.56**	**1.79**	**2.81**	**5.19**	**9.98**

Table 1: 95% C.L. using the Neural Network output templates.

DØ, Tevatron limits

DØ

TABLE IV: Combined 95% C.L. limits on $\sigma \times BR(H \to b\bar{b}/W^+W^-)$ for SM Higgs boson production. The limits are reported in units of the SM production cross section times branching fraction.

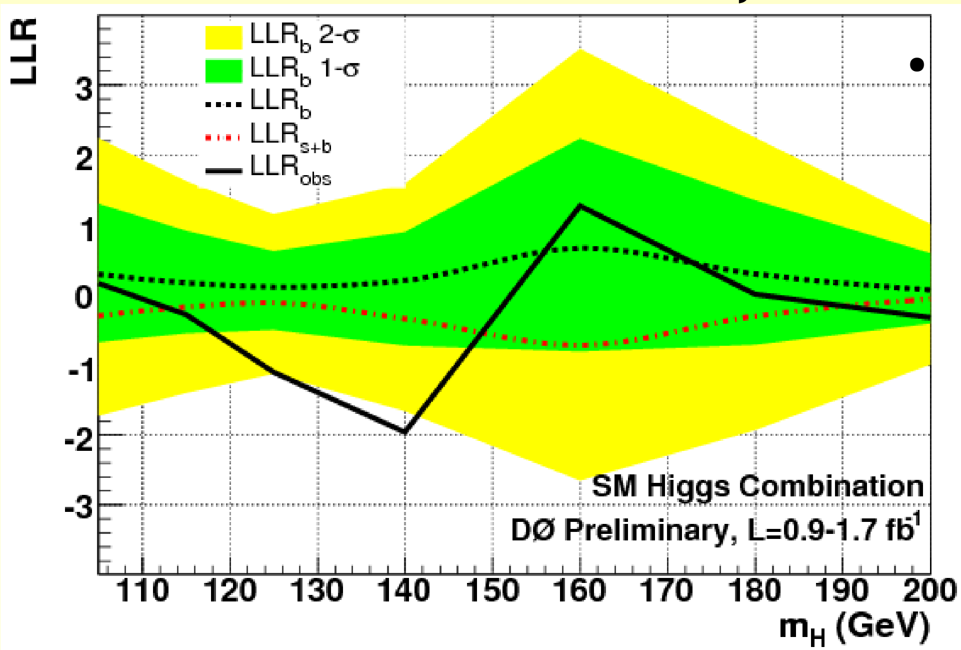
m_H (GeV/c^2)	105	115	125	140	160	180	200
Expected	4.4	5.8	7.5	5.7	2.8	4.4	10.5
Observed	4.5	6.4	10.9	10.2	2.6	5.0	12.7

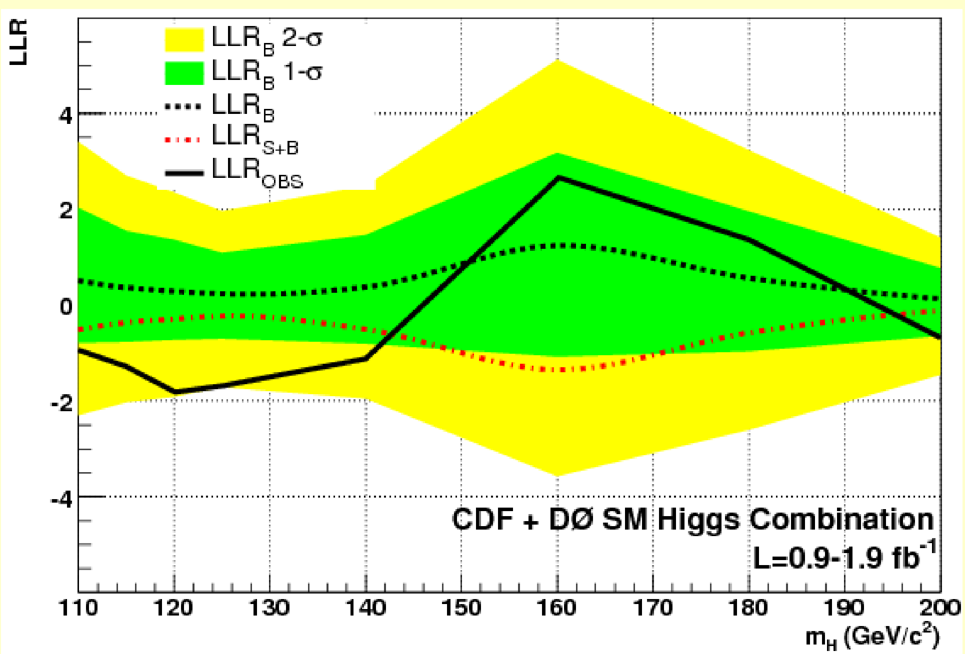
Tevatron

TABLE XII: Median expected and observed 95% CL cross section ratios for the combined CDF and DØ analyses.

	110 GeV/c^2	115 GeV/c^2	120 GeV/c^2	140 GeV/c^2	160 GeV/c^2	180 GeV/c^2	200 GeV/c^2
Expected	3.8	4.3	5.0	4.2	1.9	2.9	6.2
Observed	5.0	6.2	10.2	7.8	1.4	2.2	8.7

DØ, Tevatron LLR plots





Distributions can be interpreted as follows:

- The separation between LLR_b and LLR_{s+b} provides a measure of the discriminating power of the search. This is the ability of the analysis to separate the s + b and b-only hypotheses.
- The width of the LLRb distribution provides an estimate of how sensitive the analysis is to a signal-like fluctuation in data, taking account of the presence of systematic uncertainties. For example, when a 1σ background, fluctuation is large compared to the signal expectation, the analysis sensitivity is thereby limited.
- The value of LLR_{obs} relative to LLR_{s+b} and LLR_b indicates whether the data distribution appears to be more signal-like or background-like. As noted above, the signicance of any departures of LLR_{obs} from LLR_b can be evaluated by the width of the LLRb distribution.