Results on SM Higgs Searches @ the Tevatron

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for the CDF and DØ Collaboration

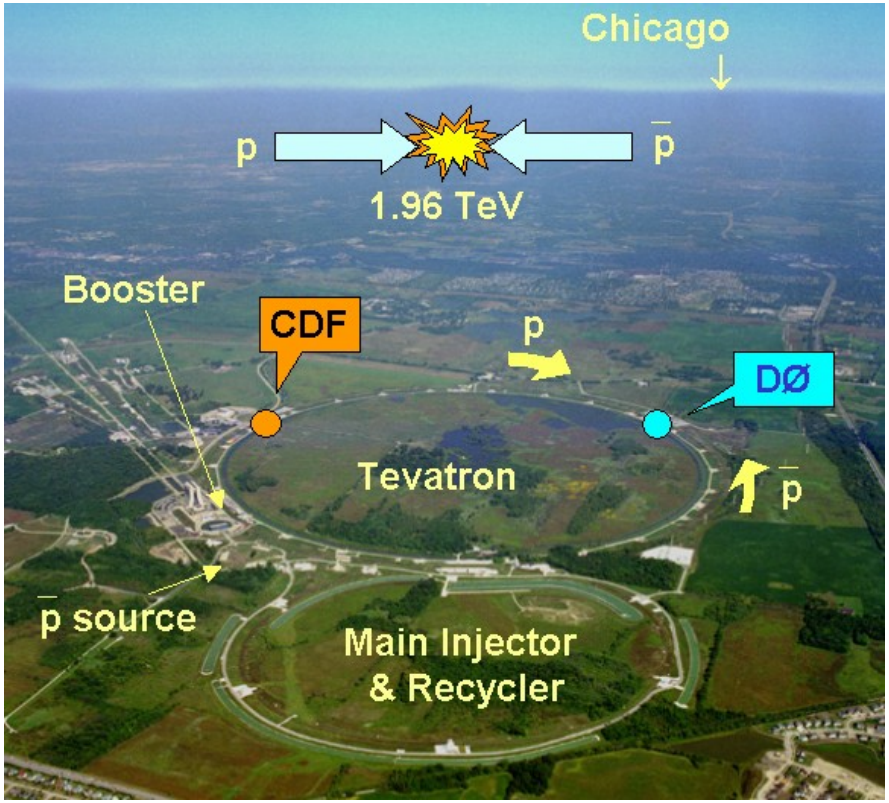
Luminosity

Introduction to Higgs

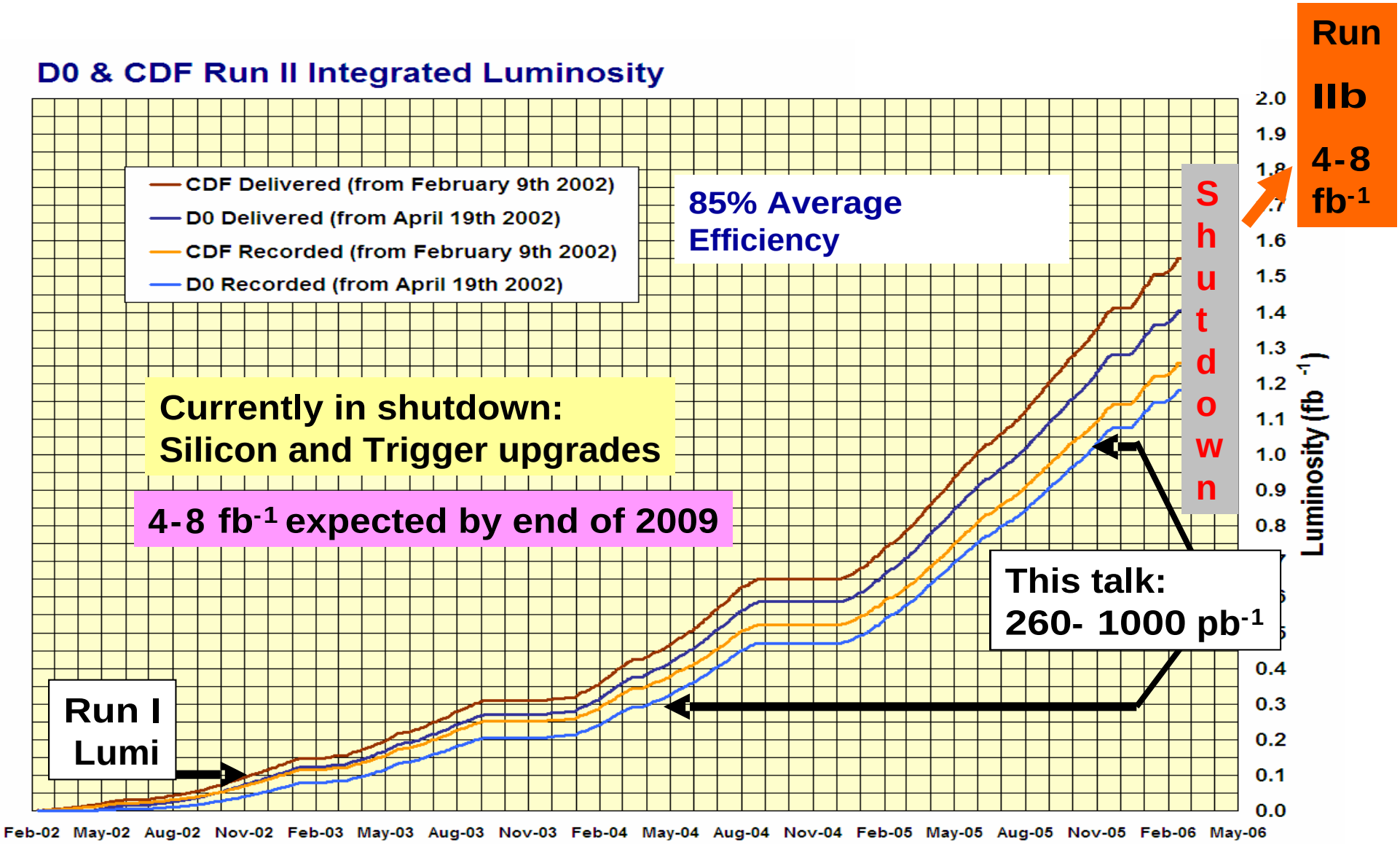
SM Higgs Searches at High mass

Combined CDF, D0 and CDF+ D0 results.

Sensitivity Prospects

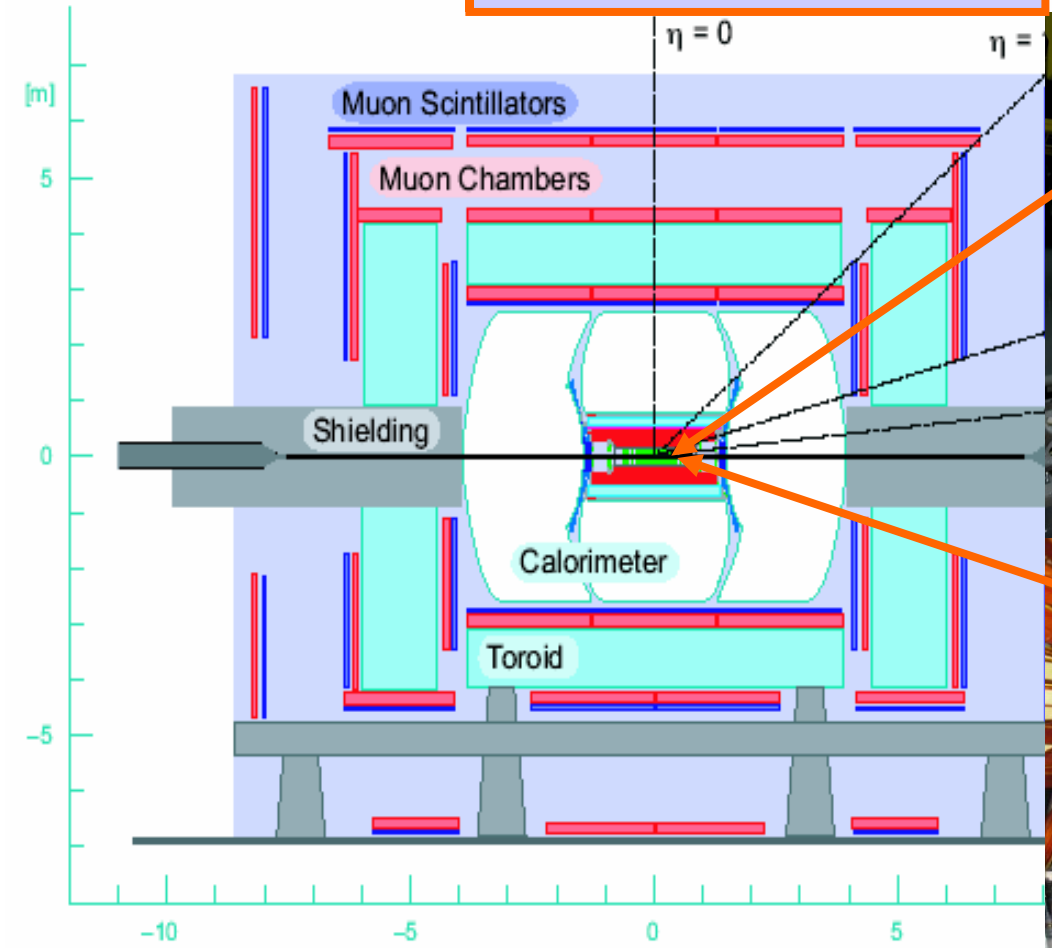


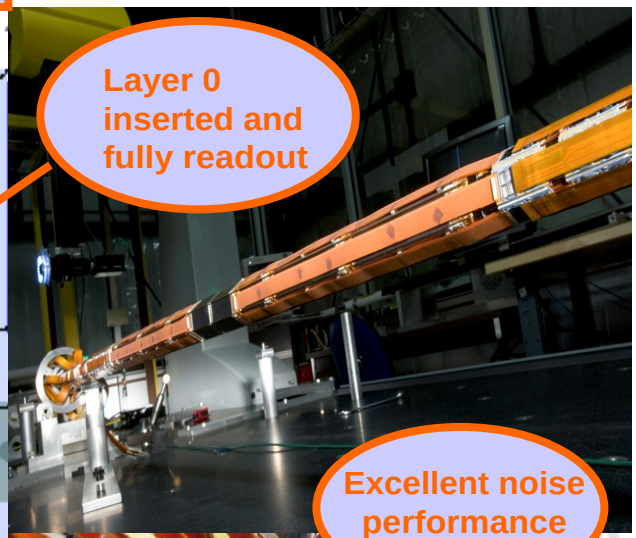
Tevatron Luminosity

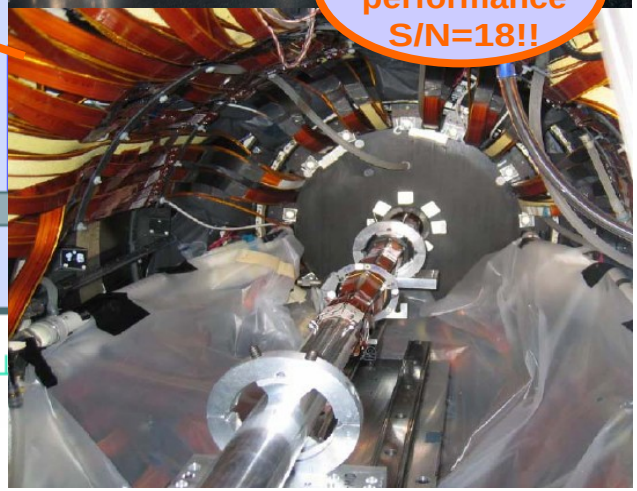


Shutdown Activities

Run IIb upgrade relevant for Higgs
- Layer Ø for DØ SMT
(already there for CDF)

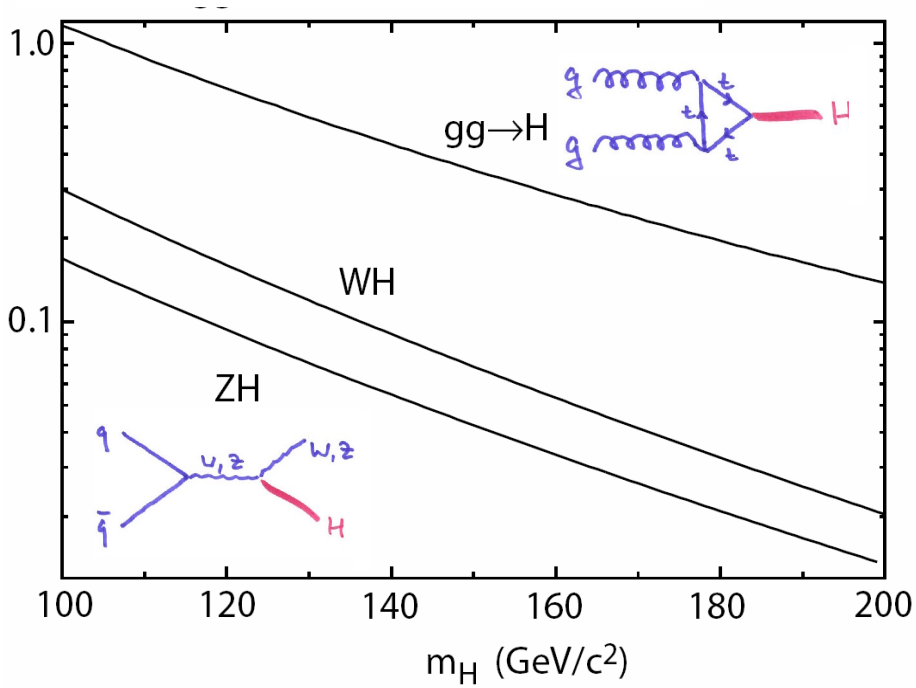




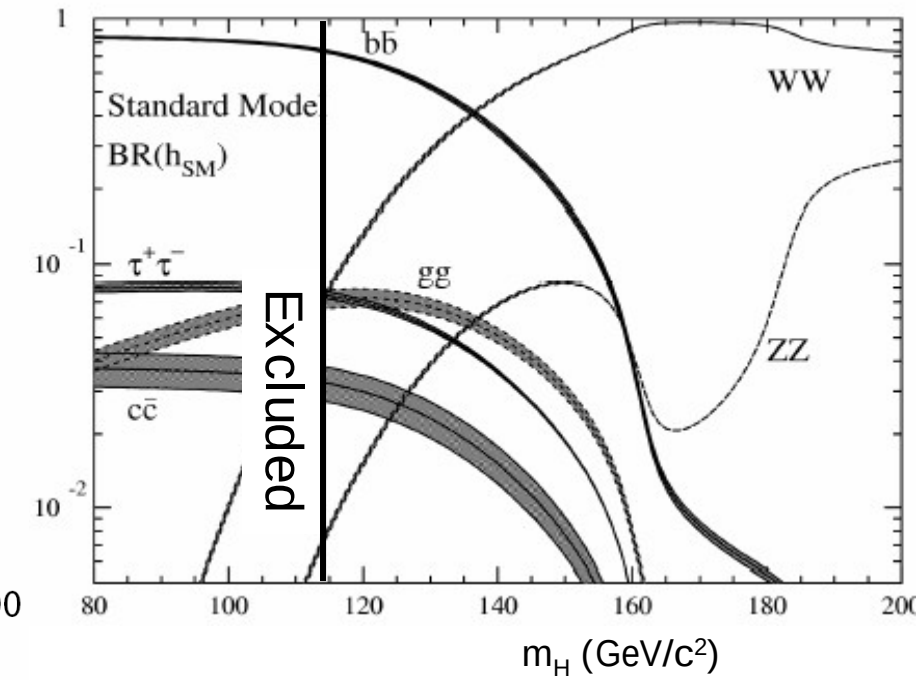


SM Higgs Production and Decays

Production



Decays



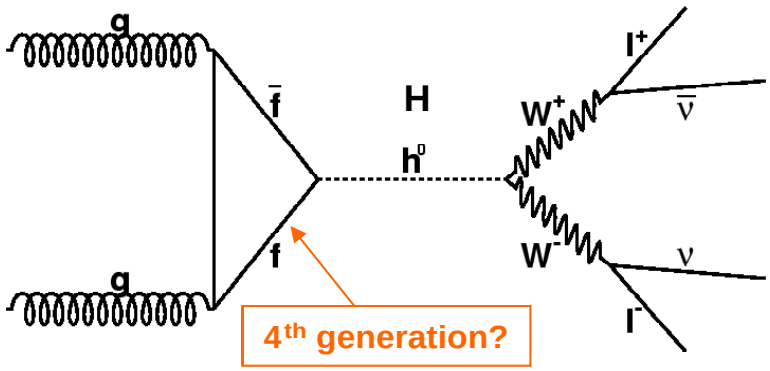
Production cross section (m_H 115-180)
→ in the 0.8-0.2 pb range for gg → H
→ in the 0.2-0.03 pb range for WH
associated vector boson production

Dominant Decays
→ $b\bar{b}$ for M_H < 135 GeV
→ WW* for M_H > 135 GeV

Search strategy:

M_H <135 GeV: associated production WH and ZH with H→bb decay
Backgrounds: Wbb, Zbb, top, WZ,QCD complement with WWW* & WW*
M_H >135 GeV: gg →H production with decay to WW*
Backgrounds: WW, DY, W/ZZ, tt, tW, ττ complement with WWW*

SM "Heavy" Higgs: H → WW* → lνlν

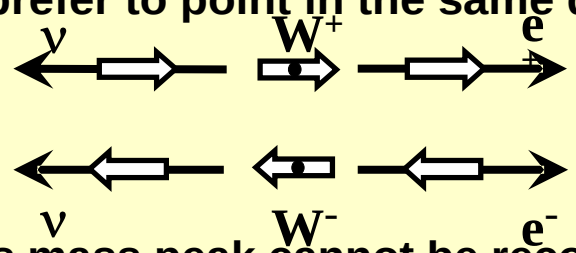


Search strategy:

→ 2 high P_t leptons and missing E_t

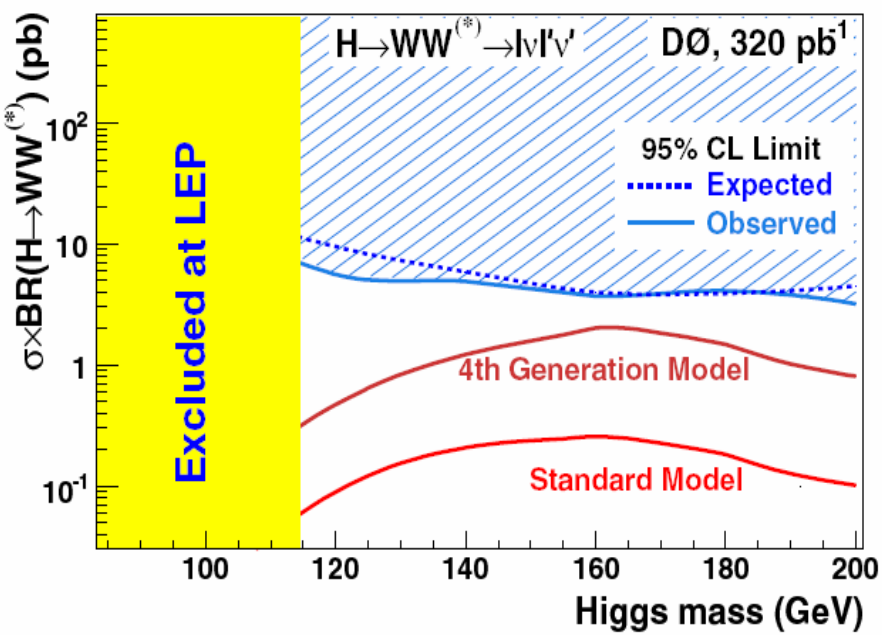
→ WW comes from spin 0 Higgs:

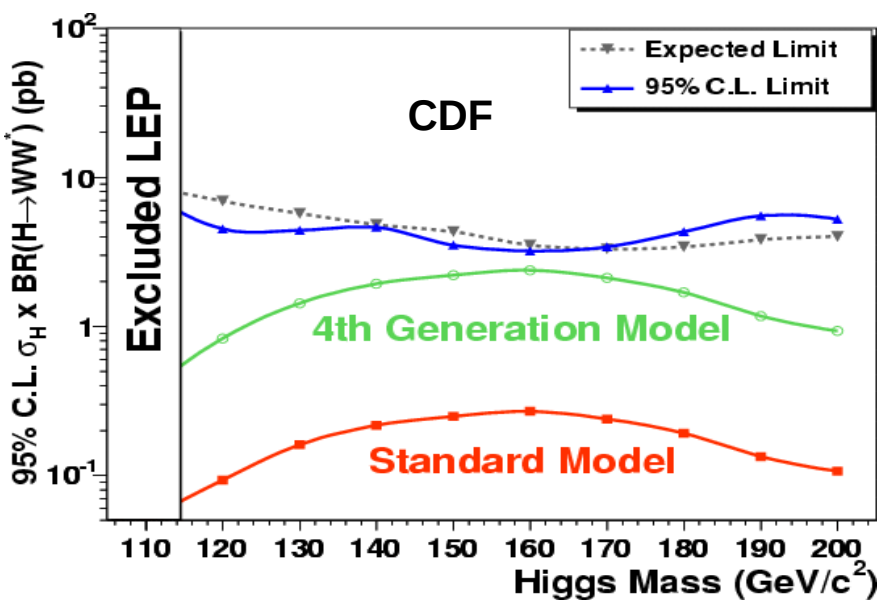
leptons prefer to point in the same direction.



But Higgs mass peak cannot be reconstructed due to the presence of 2 ν→ look for an excess

CDF and DØ already published on 0.3-0.4 fb^{-1}





H → WW* → lνlν

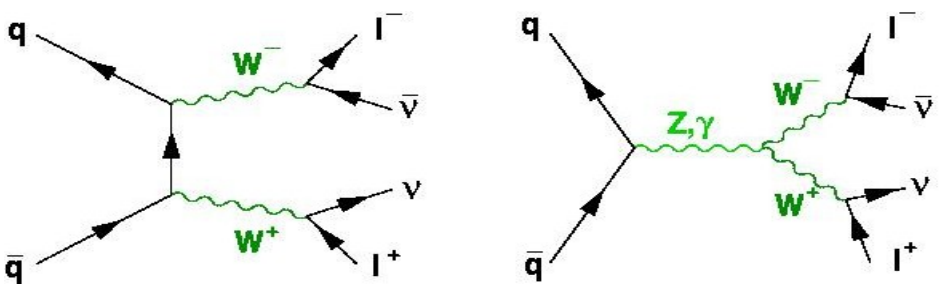
Updated DØ analysis: L ~ 950 pb^{-1} in H → WW* → ee and eμ
L ~ 930 pb^{-1} in H → WW* → μμ

Selection Strategy:

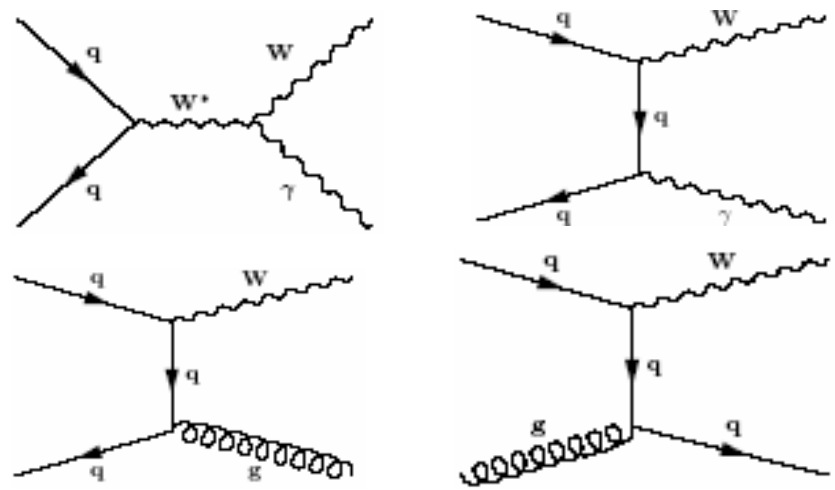
- **Presection:** lepton ID, trigger, opposite charge leptons
- **Remove QCD and $Z \to l^+ l^-$:** $\not{E}_T$ > 20 GeV
- **Higgs Mass Dependent Cuts:** Invariant Mass ($M_{l^+l^-}$); Min. Transverse Mass
  Sum of lepton p_T^l and E_T ($\Sigma\, p_T^l + E_T$)
- **Anti tt(bar) cut:** $H_T = \Sigma\, P_T^{jet} < 100$ GeV
- **Spin correlation in WW pair:** $\Delta\phi(l,l) < 2.0$

Major backgrounds

WW production



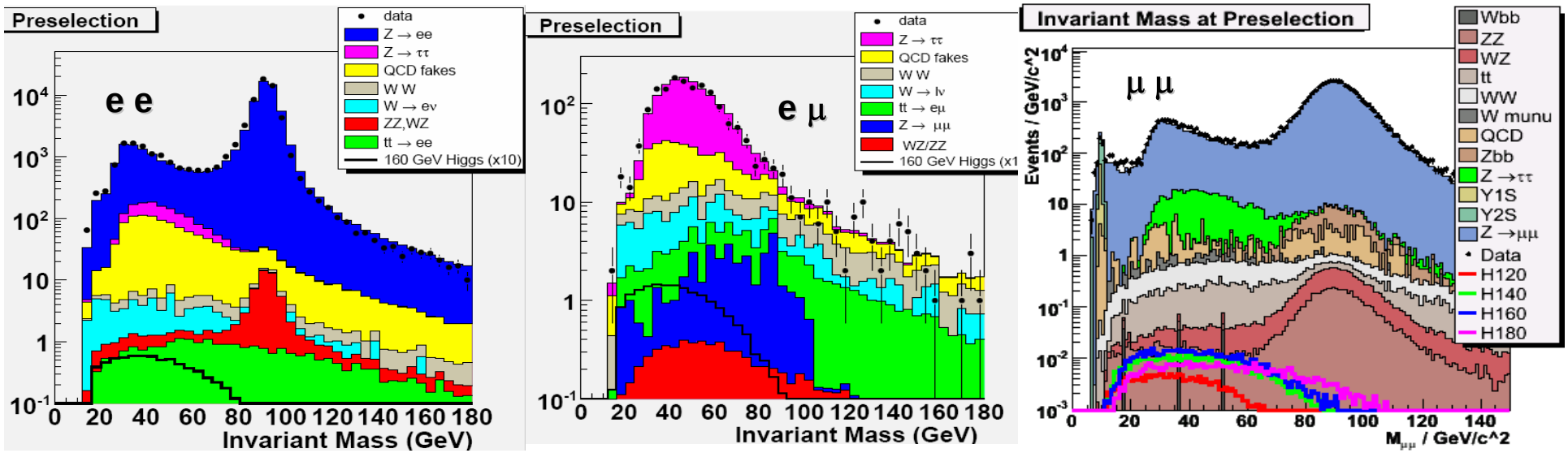
W + jet/γ production:



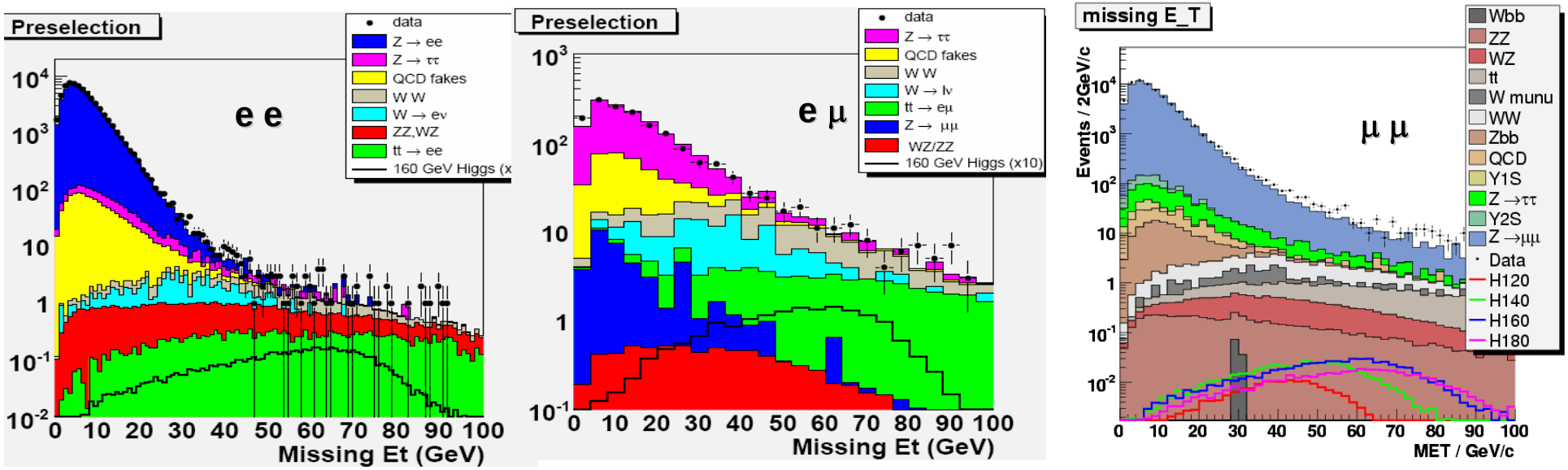
Now measured at the Tevatron by both expts. in agreement with NLO calculation: ~13.5 pb

H → WW* → ee / eμ / μμ (950-930 pb^{-1})

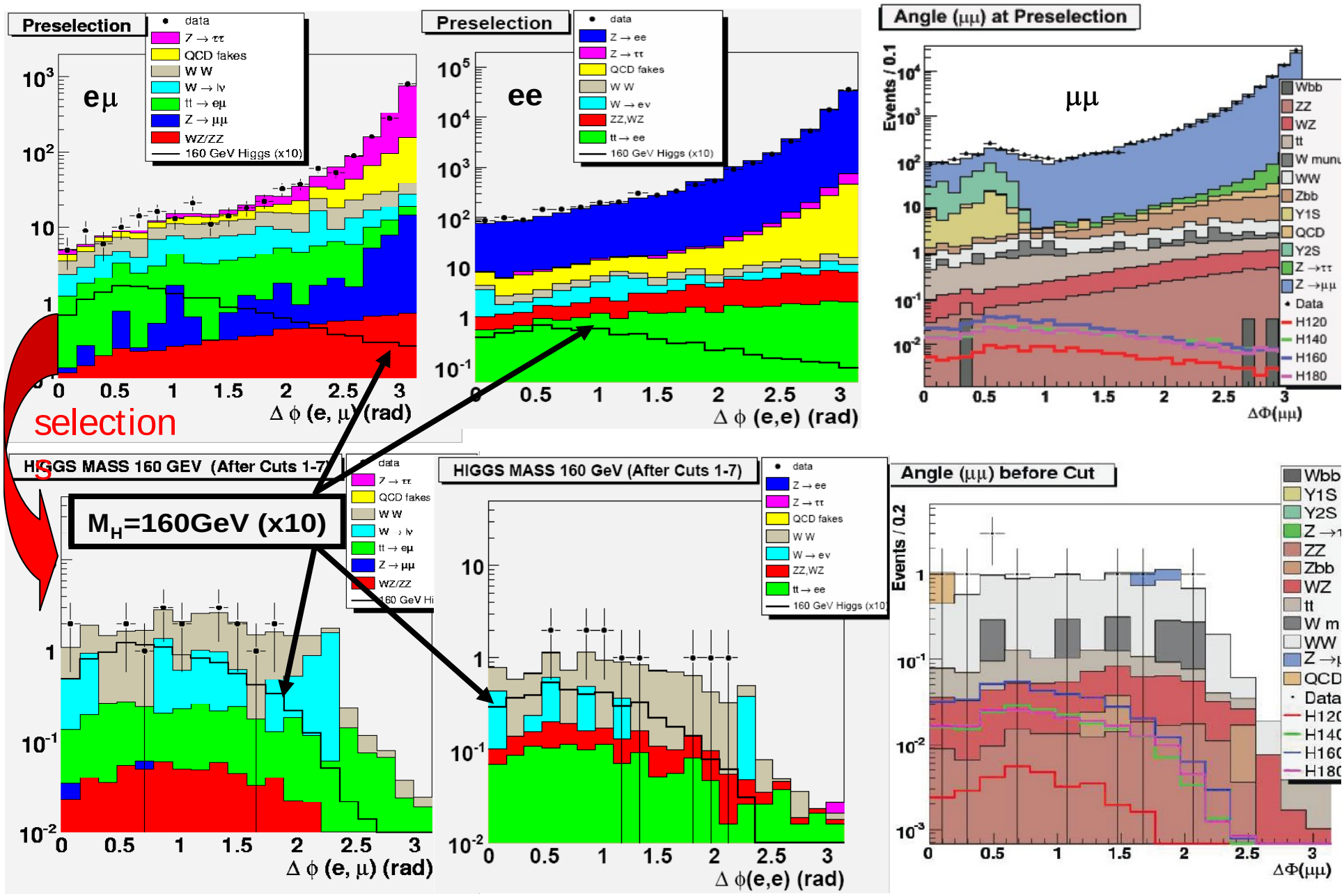
Preselection: Trigger, ID, leptons of opposite charge: p_T^{l1} = 15 GeV; p_T^{l2} = 10 GeV



Missing Transverse Energy > 20 GeV Cut (to suppress Z/γ* → l^+l^- background)



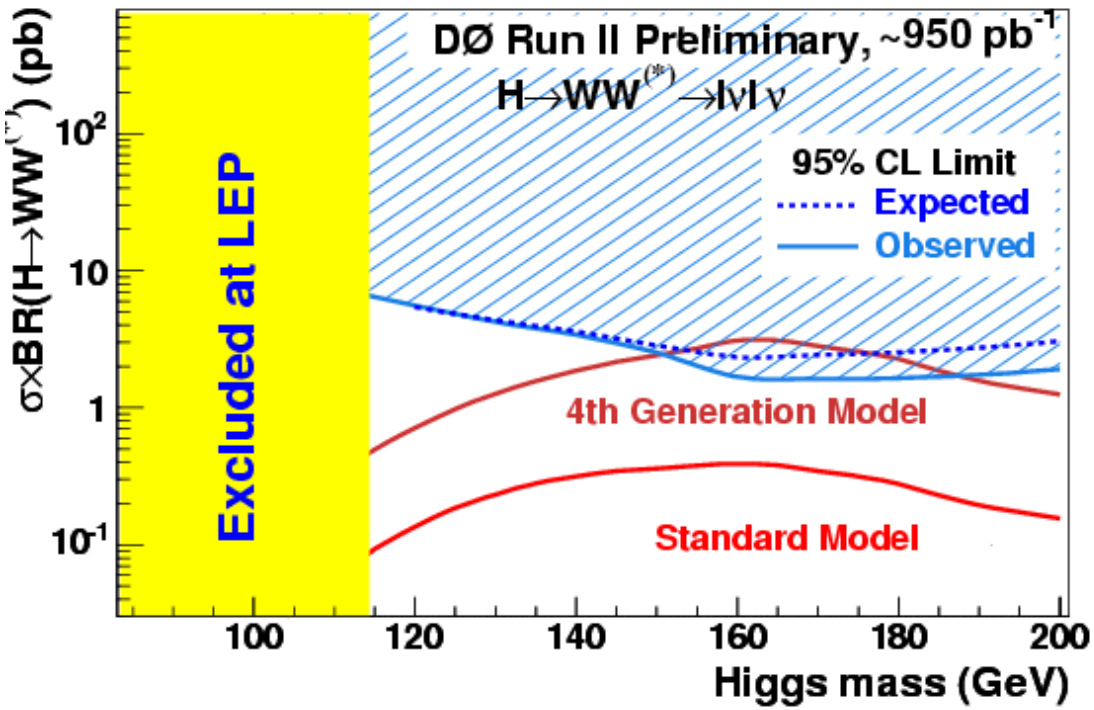
H→WW* : final selection



Results for H→WW*

Expected/ Observed # of events for m_H = 160 GeV (L ~ 950 pb^{-1}):

	Data	Sum BGND	WW	W+jet/γ	Z/γ *	tt(bar)	WZ / ZZ	QCD	H-> WW*
e e	10	10.3 ± 0.6	7.0 ± 0.2	1.4 ± 0.6	0.0 ± 0.0	1.1 ± 0.1	0.8 ± 0.1	0.06 ± 0.02	0.415
e μ	18	24.4 ± 1.5	16.4 ± 0.1	5.3 ± 1.5	0.02 ± 0.01	2.1 ± 0.1	0.6 ± 0.1	0.1 ± 0.05	0.97
μμ	9	9.8± 0.8	6.6± 0.1	1.0± 0.4	0.6± 0.4	0.5± 0.1	0.5± 0.1	0.6± 0.6	0.35



If m_H= 160 GeV, ➔ ~ 2 higgs in our sample!

SM only a factor 4 away

We exclude 4th generation models, for which m_H= 150-185 GeV

Search for WH→WWW* (2 like-sign leptons)

Low BR, but channel important in the "intermediate region" 125-145 GeV

Event preselection:

Same charge di-lepton from W's (one from H→WW, the other from prompt W)

Suppress SM backgrounds p_T (lepton)> 15 GeV, $|\eta| < 1.1/2.0$

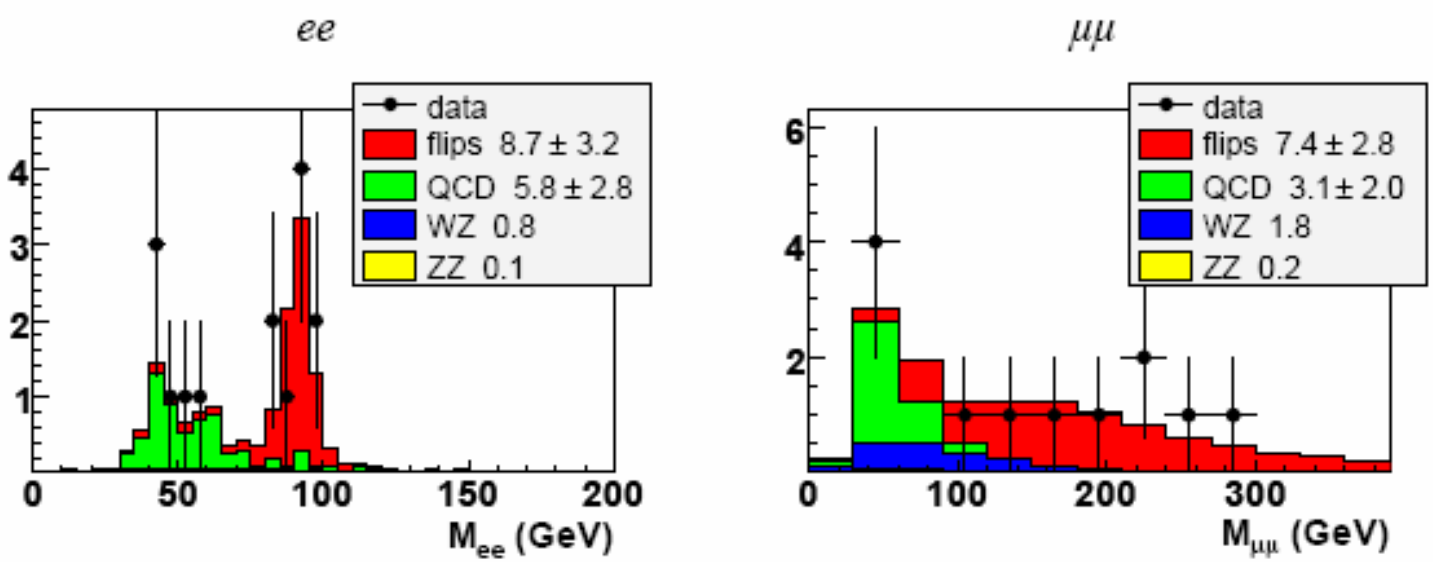
- physics background (WZ, ZZ)
  - kinematics taken from Monte Carlo
  - the number of predicted events calculated from theoretical cross sections
- charge flips
  - data selected as signal but unlike sign lepton pairs
- QCD
  - data selected as signal but muons fail isolation and electrons fail likelihood cut

How to calculate the background composition ?

- $ee/\mu\mu$: fit invariant mass of two leptons M_{ll} to a weighted sum of distributions for WZ/ZZ (fixed to the predicted number of events), charge flips, and QCD
- $e\mu$: obtain track flip probability from $ee/\mu\mu$, then multiply by the number of unlike sign events to get the number of like sign events due to charge flips
  - fraction of flips appears to be small (1-2%)

WH→WWW* (360-380 pb^{-1})

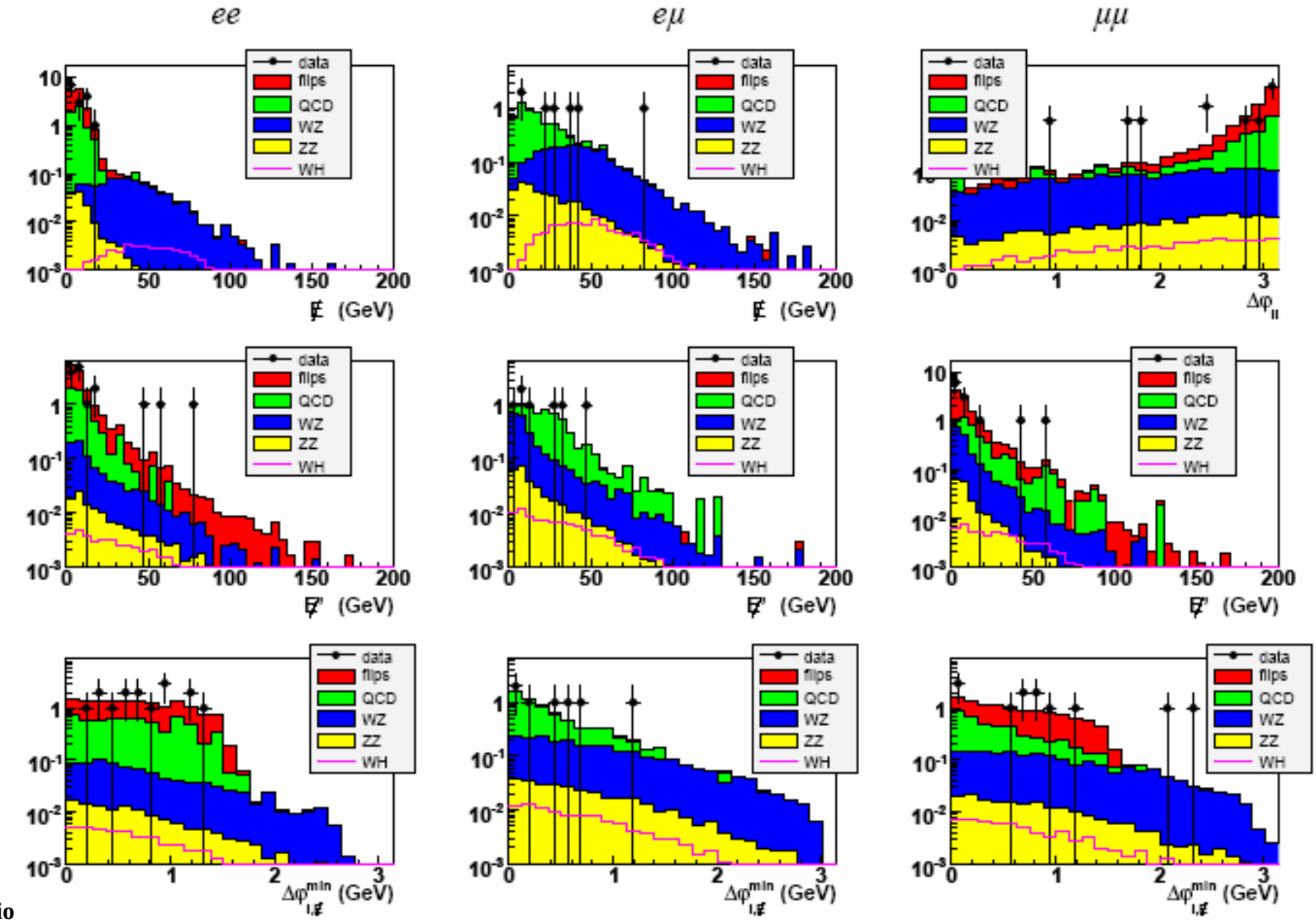
Events after preselection



	ee	$e\mu$	$\mu\mu$
data	15	7	12
charge flips	8.73± 3.33	0.17± 0.05	7.38± 2.91
W/QCD	5.80± 2.92	4.38± 0.26	3.11± 2.10
WZ	0.77± 0.08	2.11± 0.25	1.77± 0.25
ZZ	0.13± 0.01	0.31± 0.03	0.21± 0.03
total	15.43± 3.93	6.97± 0.37	12.47± 3.50

Final Selection for WWW*

Topological Likelihood discriminant, built on 3 variables per channel



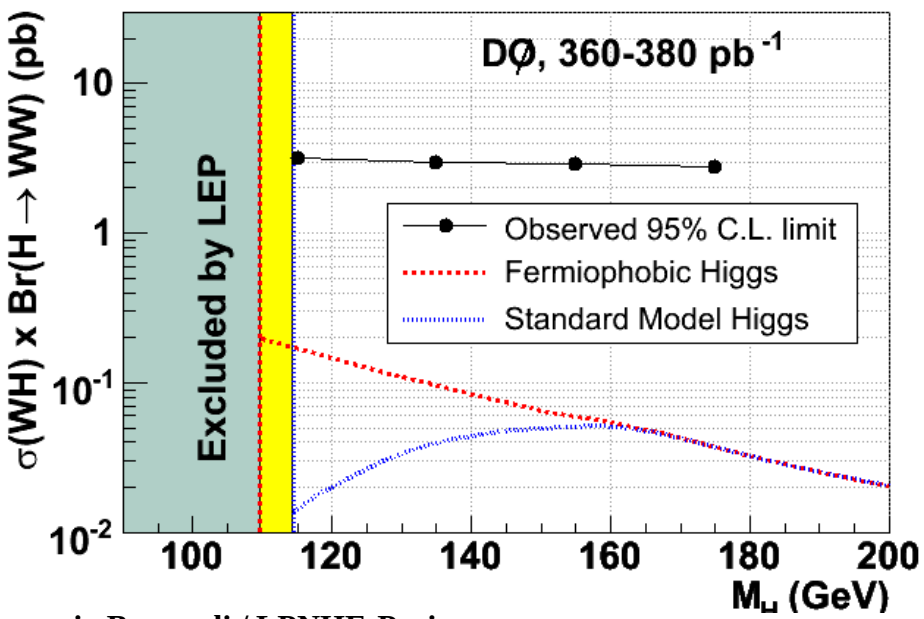
Exclusion limit for WWW*

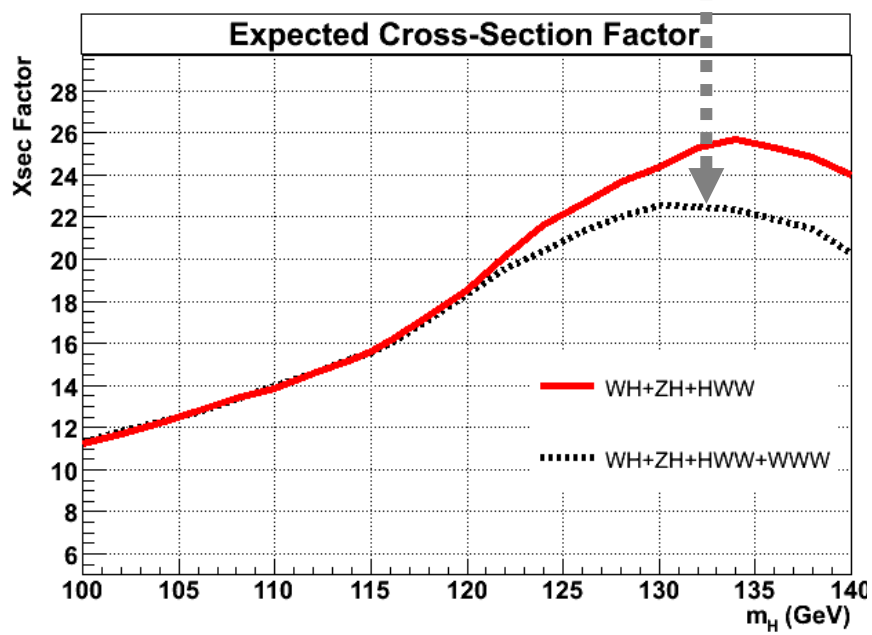
Events after Topological Likelihood discriminant

M_H =155 GeV

	ee	$e\mu$	$\mu\mu$
data	1	3	2
charge flips	0.16± 0.06	0.03± 0.01	0.96± 0.38
W/QCD	0.09± 0.04	0.70± 0.01	0.79± 0.54
WZ	0.31± 0.03	0.74± 0.09	0.46± 0.07
ZZ	0.02± 0.01	0.09± 0.01	0.06± 0.01
total	0.58± 0.09	1.55± 0.13	2.28± 0.65

Effect on global combination significant in the intermediate region (125-145 GeV)





Combining Higgs boson Searches

CDF uses a Bayesian approach

- Use Bayesian posterior probability
- Assume flat prior density for the number of Higgs events

- Combined Binned Poisson Likelihood:

$$\mathcal{L}(R,\vec{s},\vec{b}|\vec{n}) = \prod_{i=1}^{N_C}\prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}}/n_{ij}!$$

- Combined Posterior Density Function:

$$p(R|\vec{n}) = \int d\vec{s}\int d\vec{b}\mathcal{L}(R,\vec{s},\vec{b}|\vec{n}) \times s_{tot} / \int dR \int d\vec{s} \int d\vec{b}\mathcal{L}(R,\vec{s},\vec{b}|\vec{n}) \times s_{tot}$$

DØ uses the CLs (LEP) Method

the CL_S confidence interval is a normalization of CL_{S+B}

CL_{S+B} = signal + bkgd hypothesis, CL_B = bkgd only hypothesis

$CL_S = CL_{S+B}/CL_B$: CL_{S+B} & CL_B are defined using a "test statistic"

Test statistic used is the Log-Likelihood Ratio (LLR=-2 ln Q)

generated via Poisson statistics **($Q=e^{-(s+b)}(s+b)^d/e^{-b}b^d$) s,b,d=sig.,bkd,data)**

Tevatron Higgs combination is done with both methods

➔ they give results compatible within 10% .

Systematic Uncertainties @ CDF

Extracted from cdf-d0 combined Higgs search preprint:

TABLE V: The breakdown of systematic uncertainties for each individual CDF analysis. All positive-signed uncertainties within a group are considered 100% correlated across channels. Values with negative signs are considered uncorrelated.

Source	$WH \to \ell\nu b\bar{b}$ ST	$WH \to \ell\nu b\bar{b}$ DT	$ZH \to \nu\nu b\bar{b}$ ST	$ZH \to \nu\nu b\bar{b}$ DT	$ZH \to \ell\ell b\bar{b}$	$H \to W^+W^-$
Luminosity (%)	6.0	6.0	6.0	6.0	6.0	6.0
b-Tag Scale Factor (%)	5.3	16.0	8.0	16.0	8.0	n/a
Lepton Identification (%)	2.0	2.0	2.0	2.0	1.4	3.0
Jet Energy Scale (%)	3.0	3.0	6.0	(1.0-20.0)	(1.6-20.0)	1.0
I(S)R+PDF (%)	4.0	10.0	4.0	5.0	2.0	5.0
Trigger (%)	0.0	0.0	3.0	3.0	0.0	0.0
$Z + h.f.$ Shape (%)	n/a	n/a	n/a	n/a	-20	n/a
Backgrounds						
W/Z+HF(I) (%)	33.0	34.0	12.0	12.0	40.0	n/a
W+HF(II) (%)	0	0	-10.0	-42.0	0	n/a
Z+HF(II) (%)	0	0	-6.0	-19.0	0	n/a
Mistag (%)	22.0	15.0	17.0	17.0	17.0	n/a
Top I (%)	13.5	20.0	12.0	12.0	20.0	n/a
Top II (%)	n/a	n/a	-2.0	-3.0	n/a	n/a
QCD (%)	17.0	20.0	-10.0	-44.0	-50.0	n/a
Diboson I (%)	16.0	25.0	12.0	12.0	20.0	11.0
Diboson I (%)	n/a	n/a	-5.0	-10.0	n/a	n/a
Others (%)	n/a	n/a	n/a	n/a	n/a	-(12.0-18.0)

Combined Higgs boson Search @ CDF

All low mass channels analyses use 1 fb^{-1} of data !

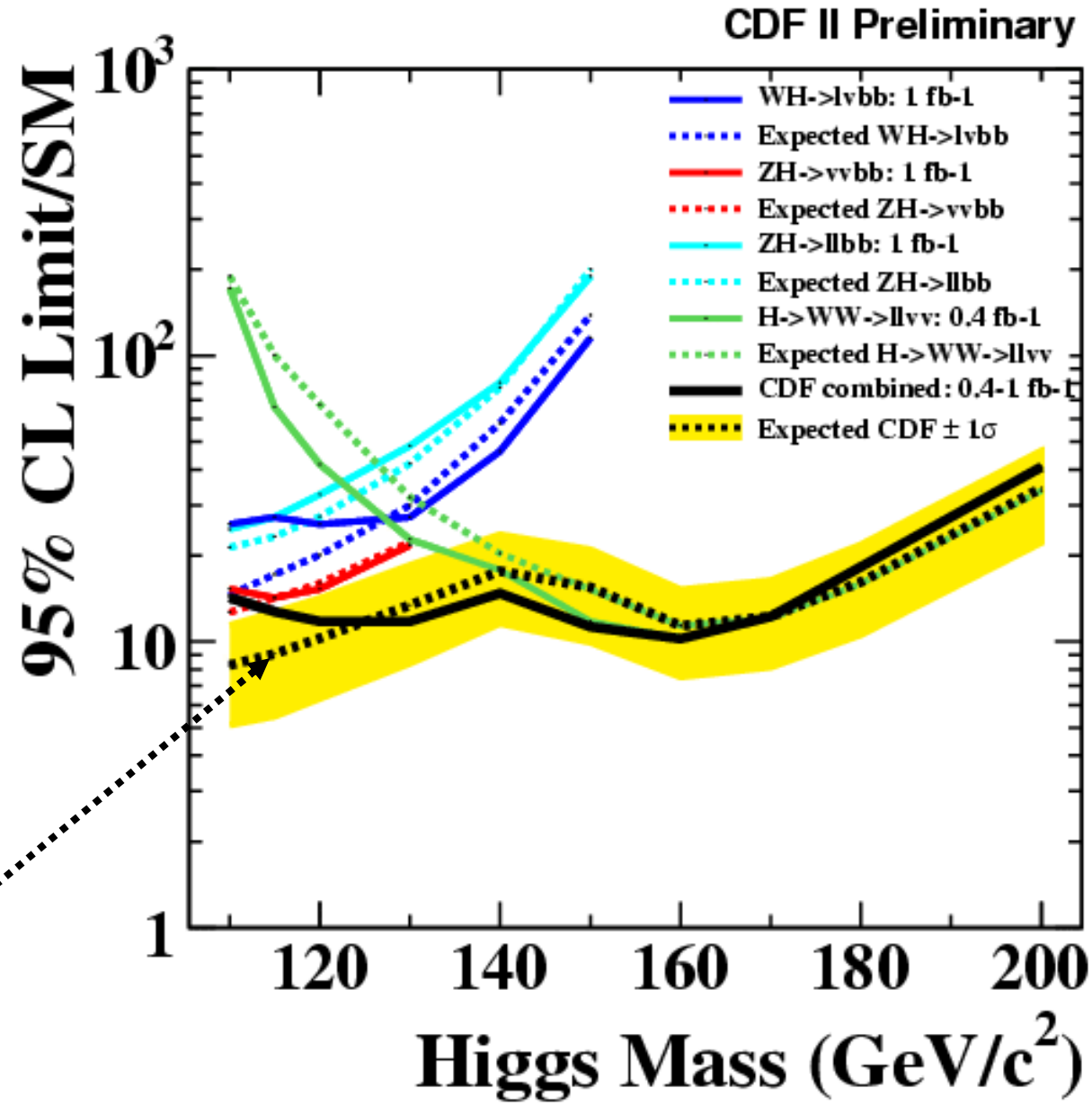
WH ($l\nu$ bb)

ZH ($\nu\nu$ bb)

ZH ($l^+ l^-$ bb)

H→WW >~ 120 GeV

For m_H = 115 GeV,
the 95%CL Limit/SM
is 9 (expected)
13 (observed)

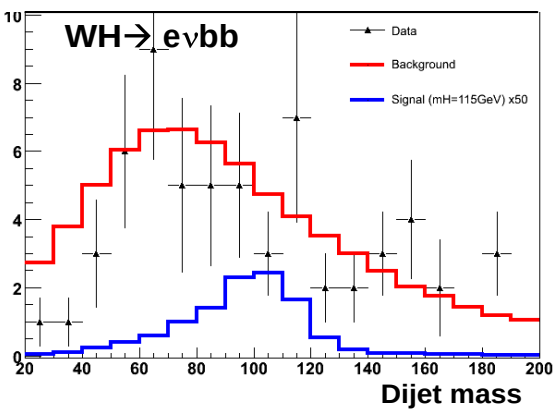


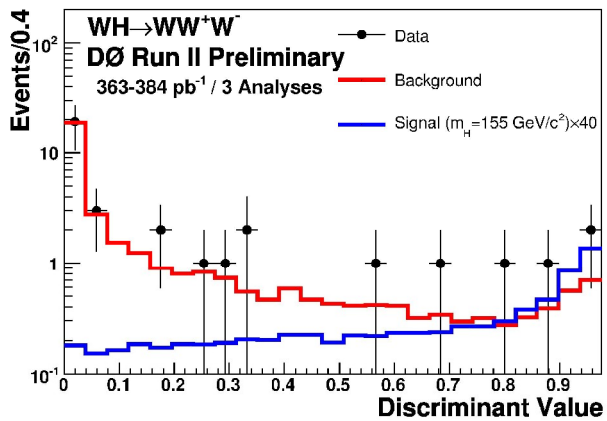
Combined Higgs boson Search @ DØ

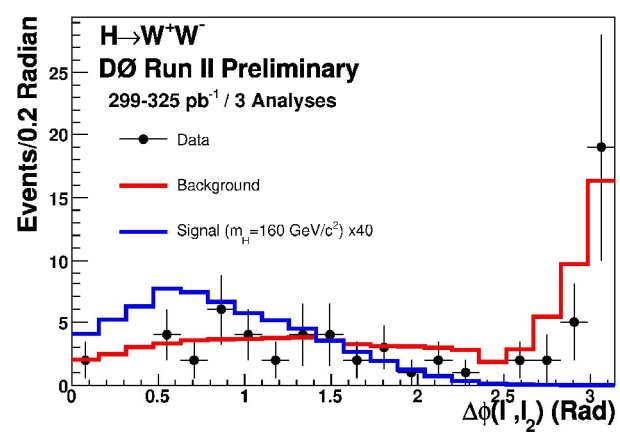
16 independent channels have been combined, taking into account correlated & uncorr. systematics

- WH (e) ST, DT
- WH (μ) ST,DT
- WH (~~l~~) ST DT
- ZH (νν) ST,DT
- ZH ($l^+ l^-$) DT
- WWW (ee,eμ,μμ)
- WW (ee,eμ,μμ) → 1 fb-1, others 260-390 pb^{-1})

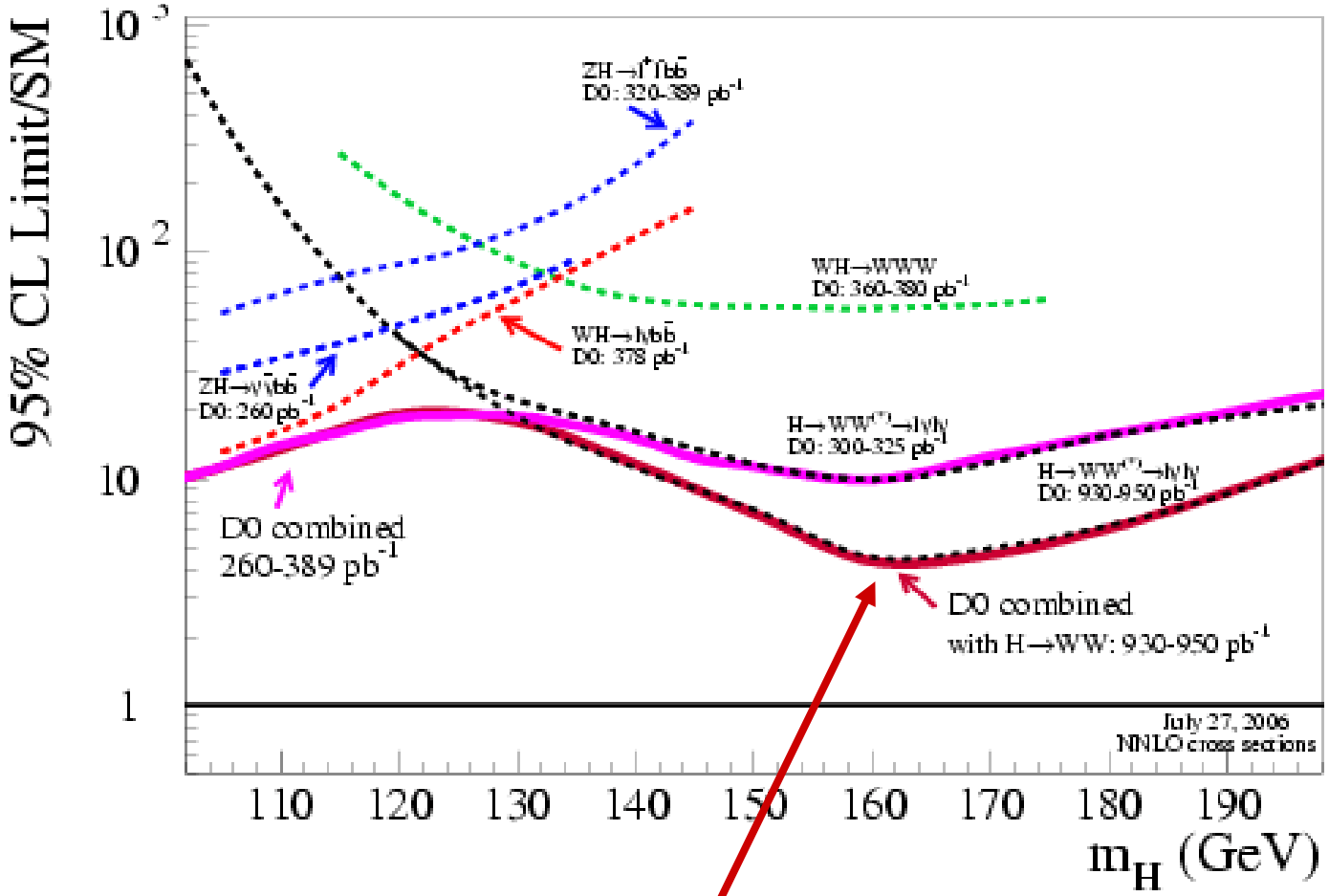
Source	$WH \to e\nu b\bar{b}$	$WH \to \mu\nu b\bar{b}$	$WH \to \not{\ell}\nu b\bar{b}$	$ZH \to \nu\nu b\bar{b}$	$WH \to WW^+W^-$	$H \to W^+W^-$
Luminosity	X	X	X	X	X	X
Jet Energy Scale	X	X	X	X		X
Jet ID	X	X	X	X		
Electron ID	X				X	X
Muon ID		X			X	X
b-Jet Tagging	X	X	X	X		
Background σ	X	X	X	X	X	X







Combined Higgs boson Search @ DØ



With low statistics (0.3 fb^{-1}),
the cross-section factors
Data/SM = ~ 15 at 115 GeV
~ 9 at 160 GeV

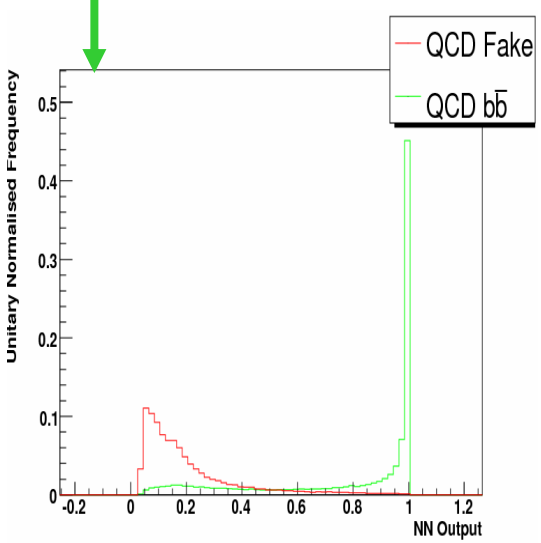
With higs statistics (1 fb^{-1})
Data/SM = ~ 5 at 160 GeV

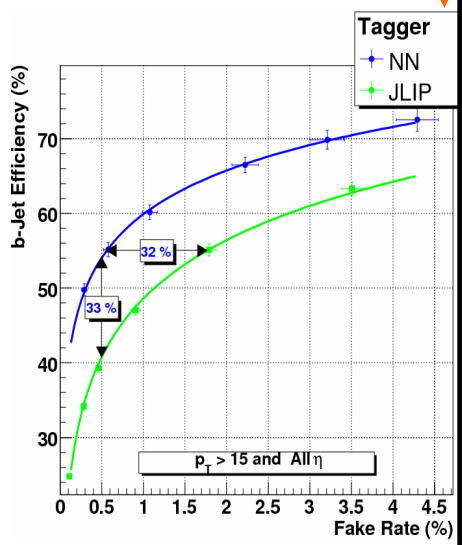
Based on our first experiences with Data, can cdf+ dØ reach exclusion for a 115 GeV Higgs with 2 fb^{-1} of data, as early simulation studies were expecting ?

Expected Improvements @ DØ

New b-tagging tool at DØ (bh)

- Combines various variables from the track based b-tagging tools in a Neural Network, trained on Monte Carlo
- Performance measured on data
- Substantial improvement in performance over constituent input b-taggers
- Increase of 33% in efficiency for a fixed fake rate of 0.5 %





- Jet energy resolution (recalibration + track-jet algorithm)
  - Subtract expected energy deposition in cal
  - Add the track momentum
  - Add the energy of out-of-cone tracks

Improve the jet energy resolution by ~20%

- Use improved calorimeter calibration Z→ bb to calibrate b-jet response

- L1-cal Trigger (DØ Upgrade)
  - Important for difficult channels → efficiency improvement (ZH→ννbb, hbb)

Addition of SMT Layer 0 (DØ Upgrade)

- r@L1 = 2.7 cm → r@L0 = 1.6 cm
  ➔ better impact parameter resolution
- redundancy in pattern recongnition for higher luminosity reduce fake track
- Keep performance if degradation of Layer 1 due to radiation damage

➔ further b-tag improvement (~15%)

➔ improvement on Higgs sensitivity

CDF: Expected Improvements

Increase acceptance

- inclusion of forward muons
- improved tracking and b-tagging in the forward region

Add additional channels:

- in the WH and WW analyses tau-leptons have not been used.

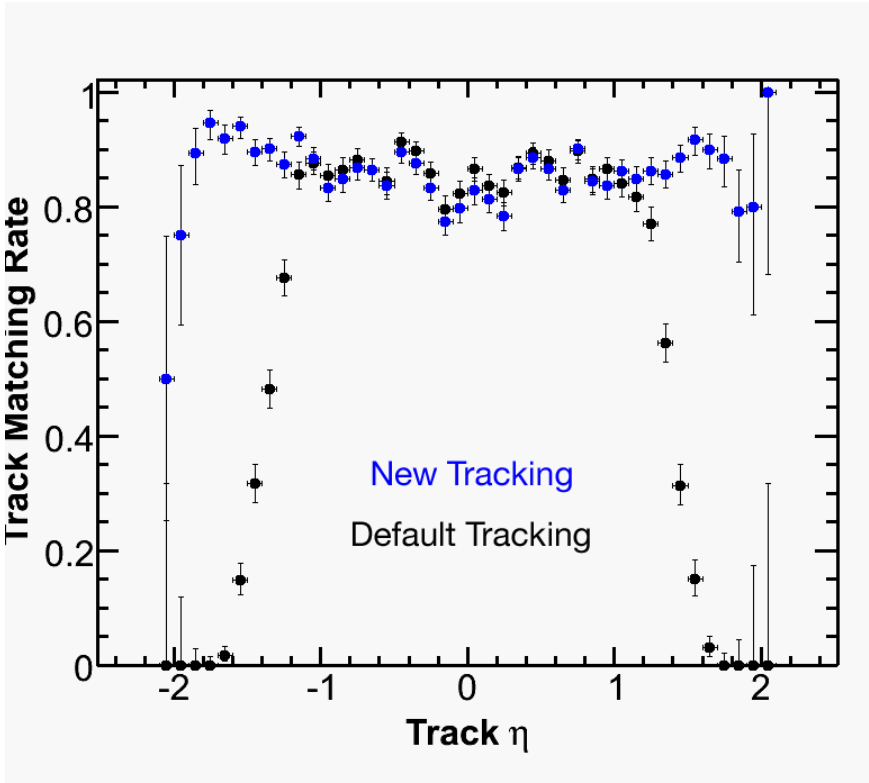
Improve jet resolution

Improve analysis techniques

- Neural Networks, better optimisation

Recent experience:

- in B_s mixing analysis a factor 4 in sensitivity was achieved just by improving analysis techniques

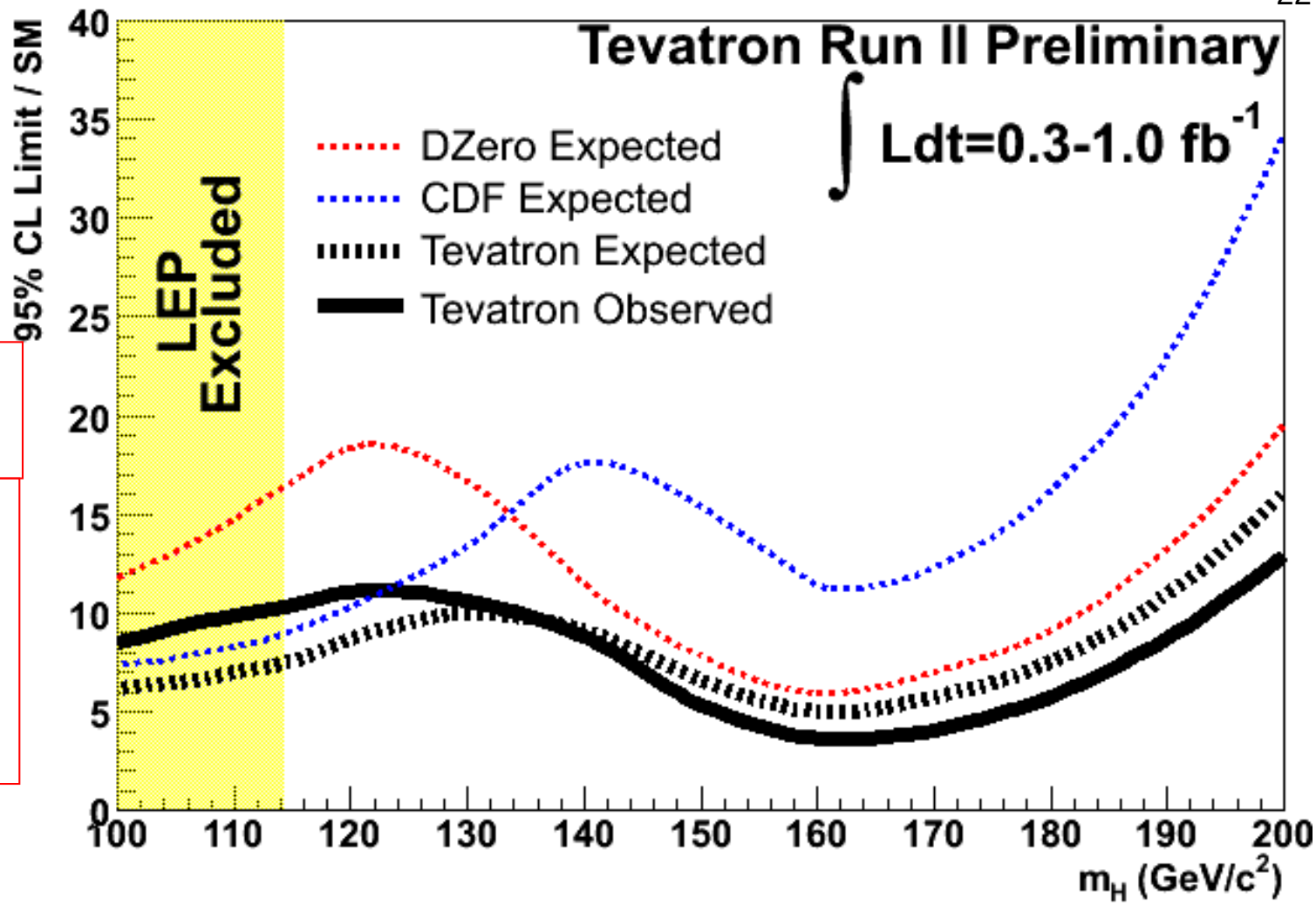


How does these CDF and DØ improvements translate in sensitivity?

Tevatron SM Higgs Combination

All CDF and DØ results now combined for the first time ➔

m_H (GeV)	Limit/SM Exp.	Limit/SM Obs.
115	7.6	10.4
130	10.1	10.6
160	5.0	3.9
180	7.5	5.8



Note: the combined result is essentially equivalent to one experiment with 1.3 fb^{-1}, since both experiments have "complementary" statistics at low and high mass

➔ we are indeed already close to the sensitivity required to exclude or "evidence" the higgs at the Tevatron

SM Higgs Summary

First time with essentially complete result

- All channels have been analyzed with ~ 1 fb^{-1} of data
- Full impact of systematics uncertainties is included
- Analyses are steadily improving due to optimization, already close to the Prospective reports

Combined limit looks very promising

- High mass region benefits a lot from $H \rightarrow WW^*$ type analyses (H and WH production), but low mass as well, as low as 120 GeV → enhanced sensitivity at low mass.

Our outlook for the future looks very interesting

- LHC experiments will have to work hard to get the signal before Tevatron, if the Higgs is light (< 130 GeV)
- But the Tevatron has insight also if it is close to 160 GeV and can exclude at 95% CL from 115 to 185 GeV.
- Barring accidents, the Tevatron could have evidence by 2009-2010, if it's there…

If the Higgs is light we might end-up combining with LHC!

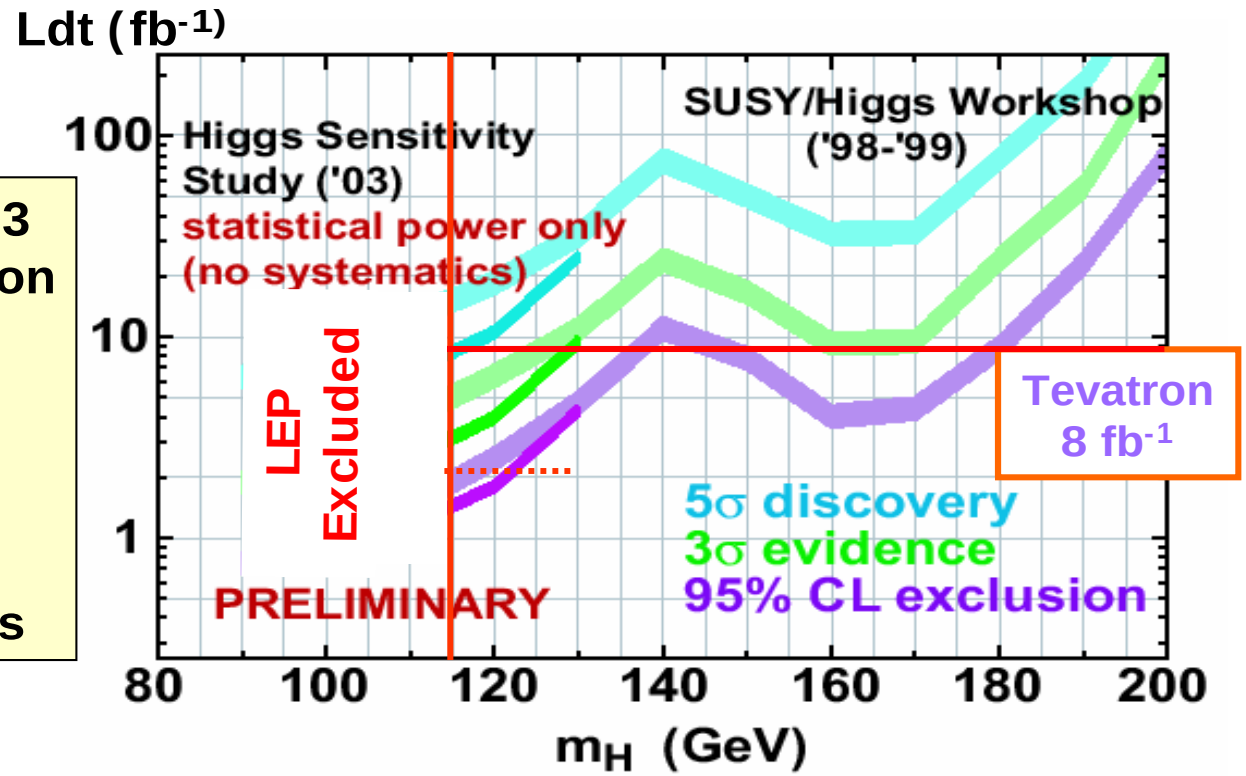
Backup Slides

Tevatron SM Higgs Search: Outlook

Prospects updated in 2003 in the low Higgs mass region

W(Z) H→ lν(νν,ll) $b\bar{b}$

→ better detector understanding
→ optimization of analysis



Sensitivity in the mass region above LEP limit (114 GeV) starts at ~2 fb^{-1}
With 8 fb^{-1}: exclusion 115-135 GeV & 145-180 GeV,
5 - 3 sigma discovery/evidence @ 115 – 130 GeV

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