Direct Standard Model Higgs searches at the Tevatron

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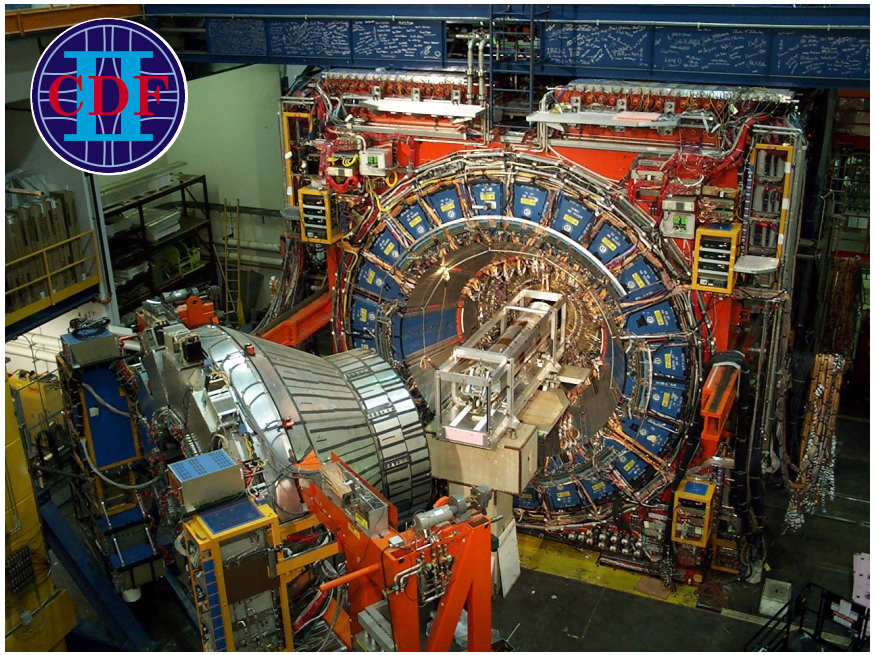
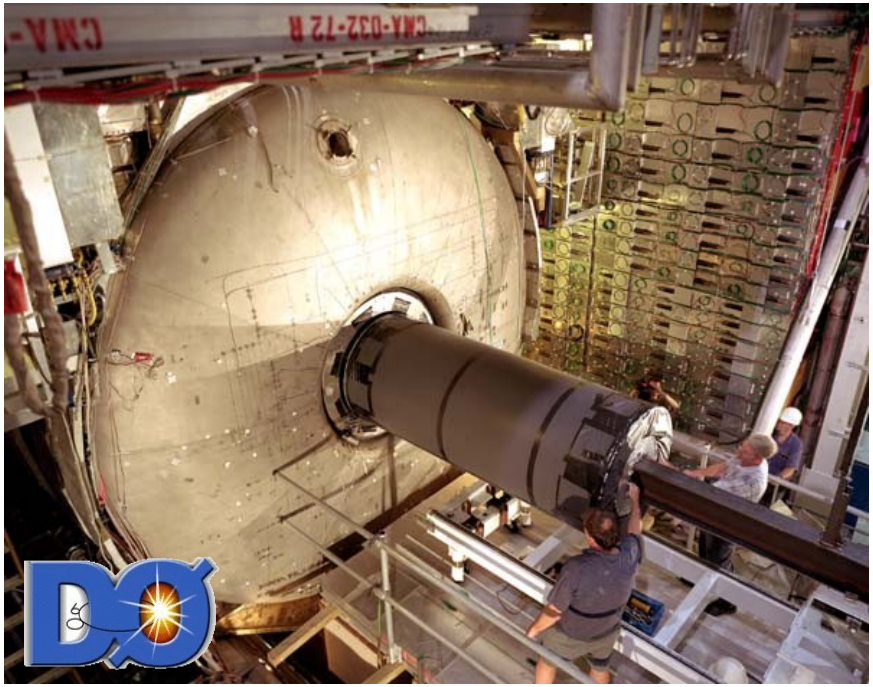
Talk outline

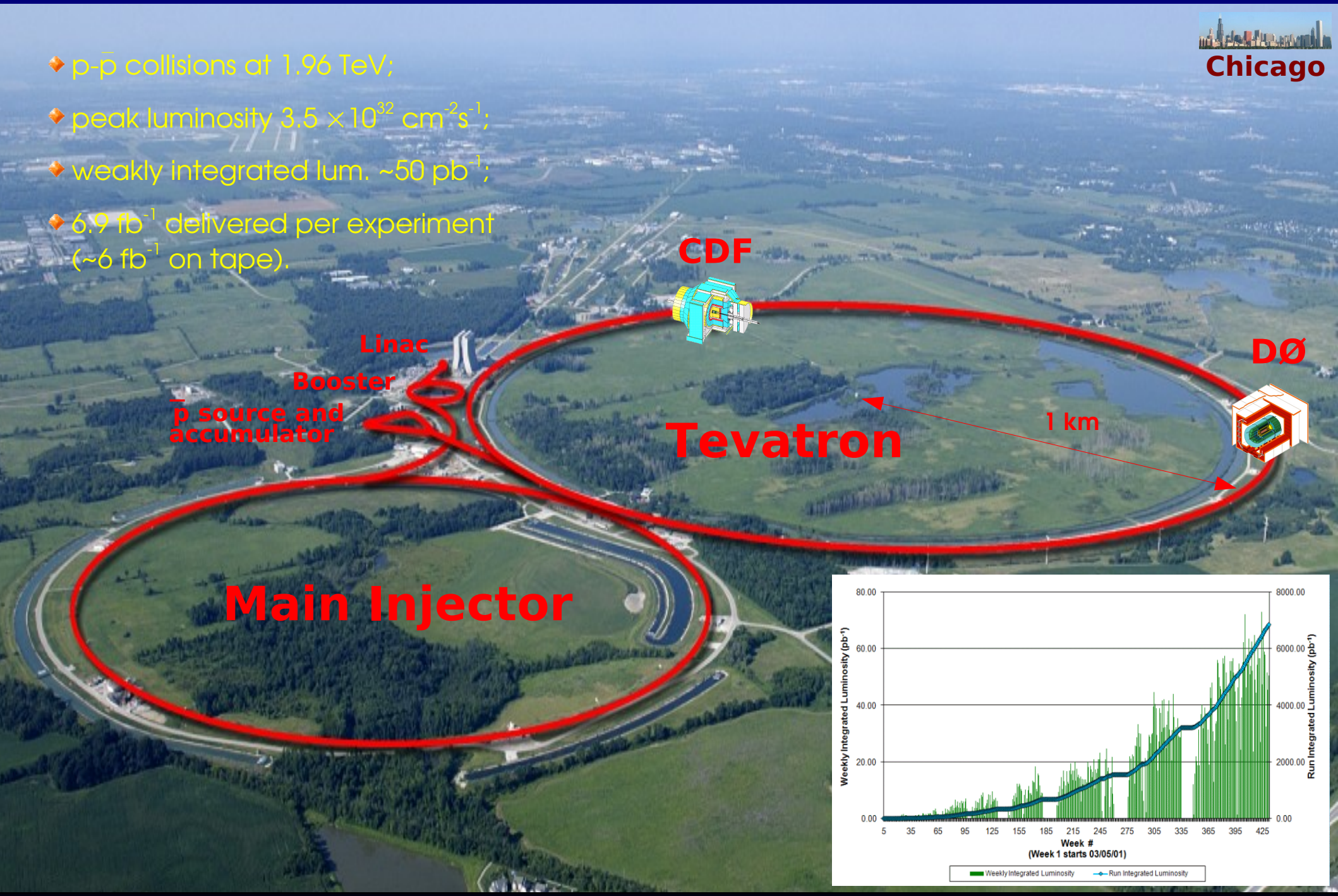
- The experimental apparatuses:
  - the Tevatron accelerator,
  - the CDF and DØ detectors.
- Previous experimental information on the Standard Model Higgs.
- Standard Model Higgs production at the Tevatron and decay modes.
- Experimental strategy and tools:
  - reconstructed objects;
  - jet b-tagging;
  - multivariate techniques.
- CDF and DØ results (I will focus on the most recent ones, which use up to 5 fb^{-1} of data).
- Combined upper limits on the production cross-sections and projections.
- Conclusions.



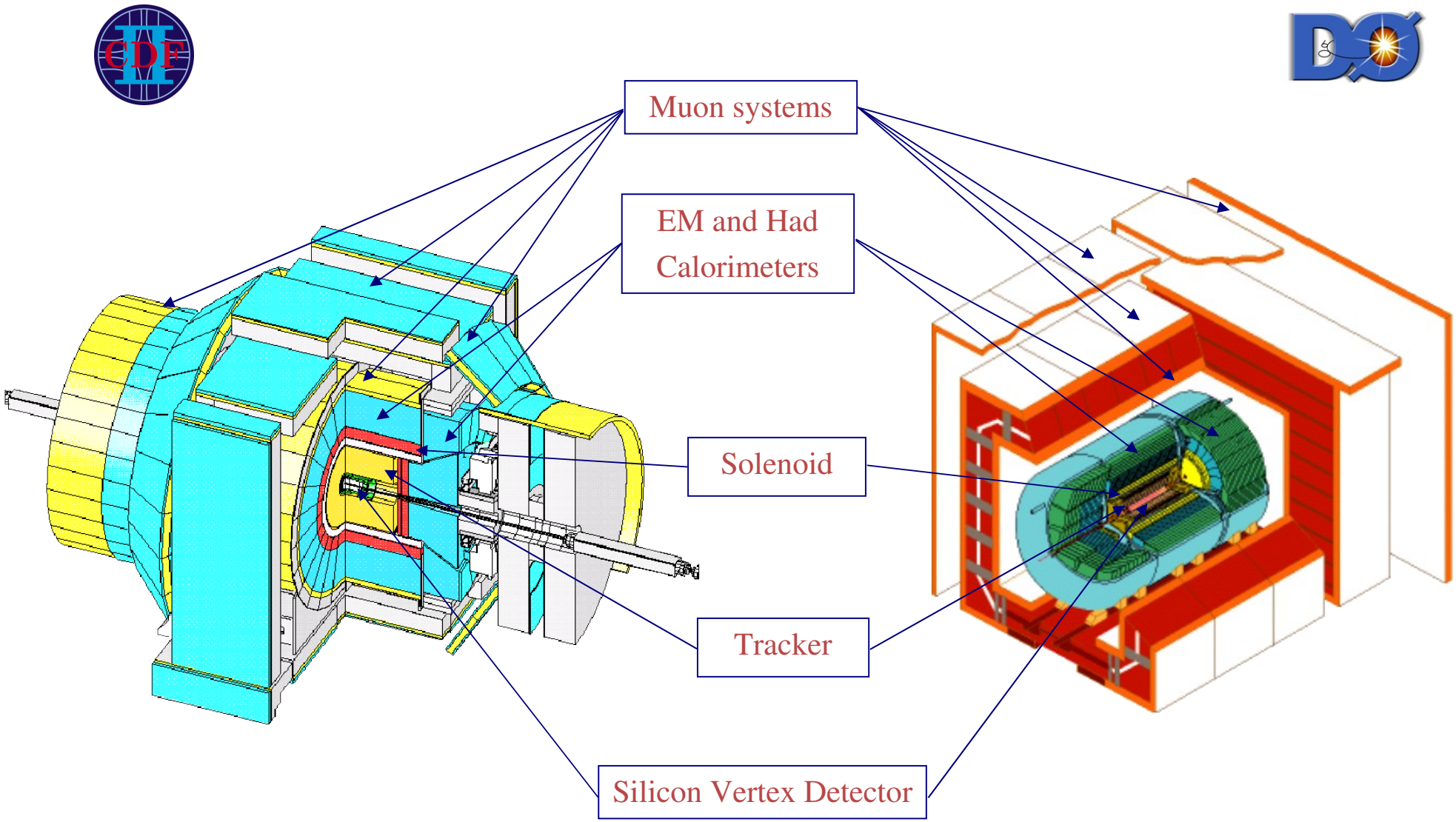


The Tevatron accelerator

- p-$\bar{p}$ collisions at 1.96 TeV;
- peak luminosity 3.5×10^{32} $cm^{-2}s^{-1}$;
- weakly integrated lum. ~50 pb^{-1};
- 6.9 fb^{-1} delivered per experiment (~6 fb^{-1} on tape).



The CDF and DØ detectors

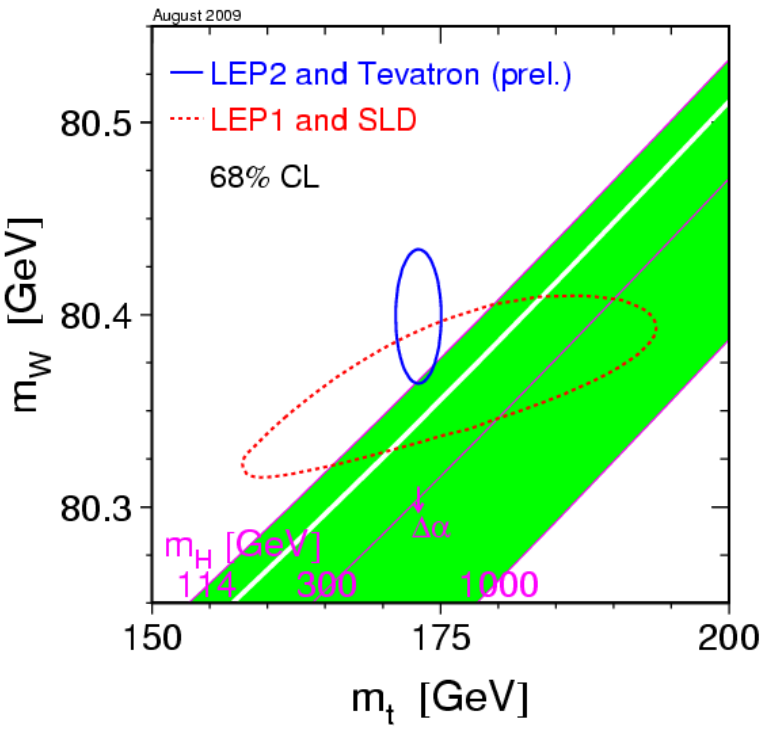


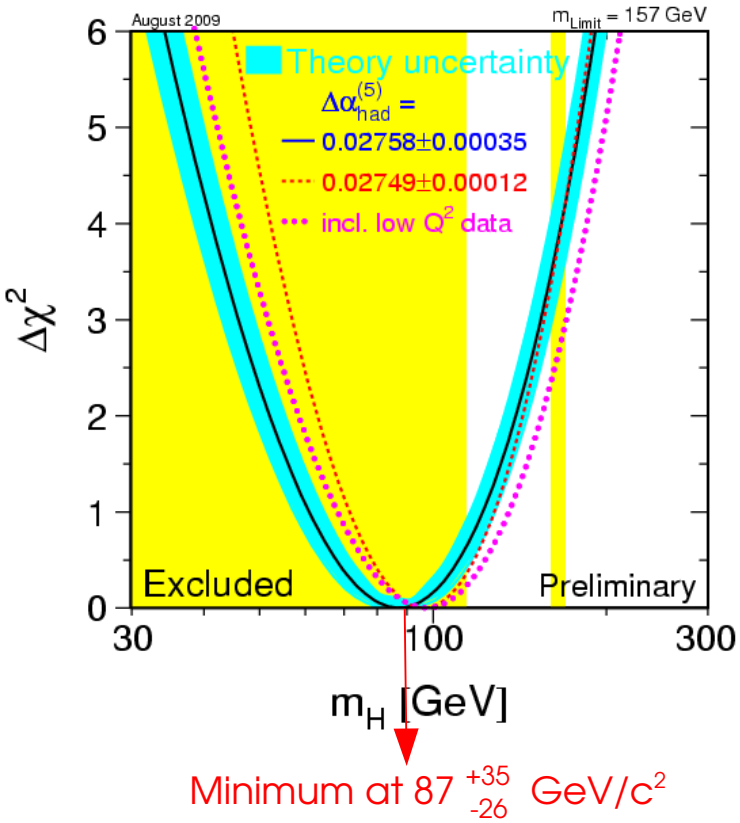
Current information on the SM Higgs

http://lepewwg.web.cern.ch/LEPEWWG

- LEP direct searches for a Standard Model Higgs boson:
  $M_H > 114.4$ Gev/c^2 at 95% C.L.

- Indirect SM constraints and global EWK fits seem to prefer a light Higgs boson:
  $M_H < 157$ GeV/c^2 at 95% C.L.

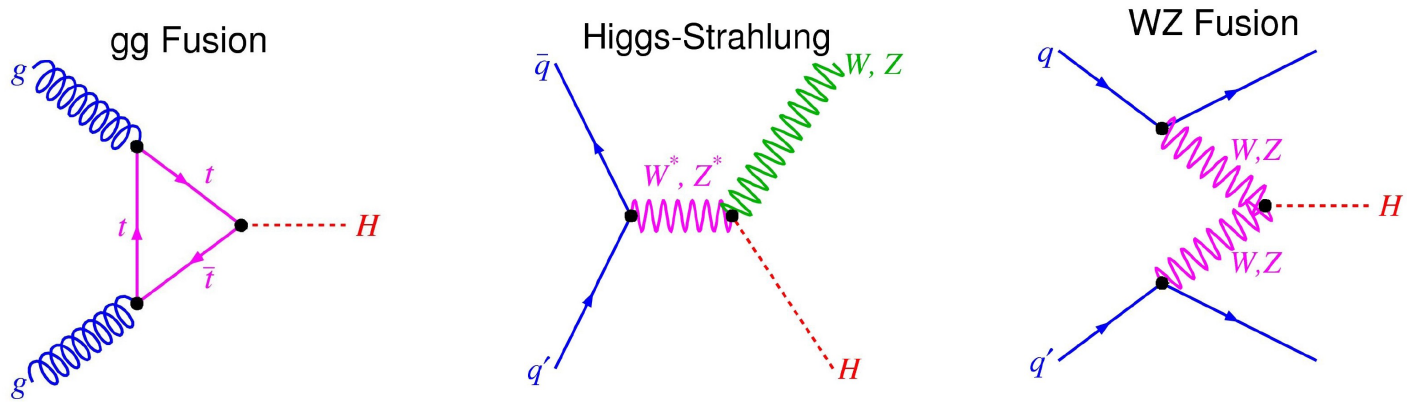


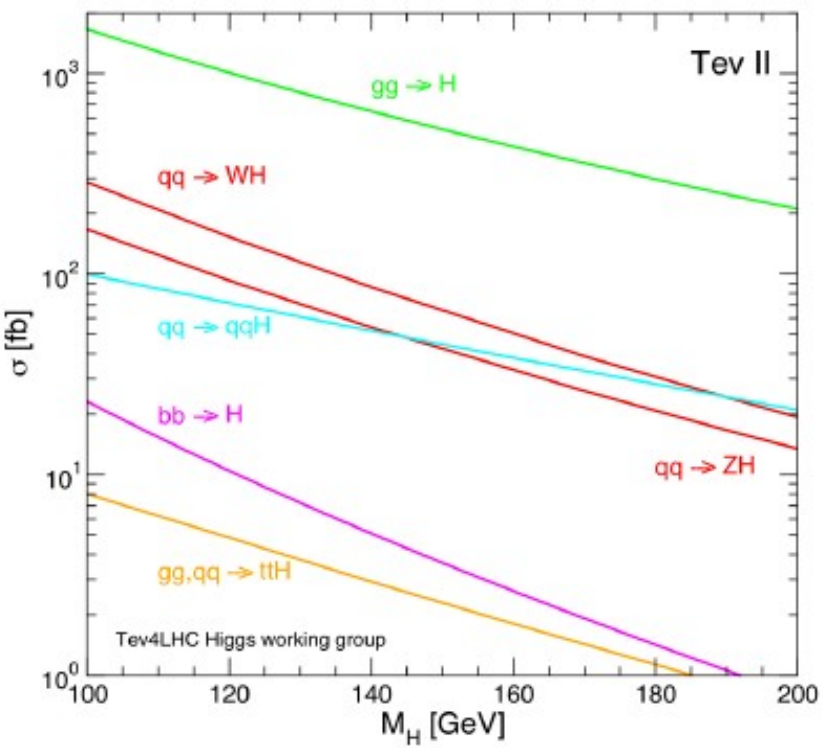


- CDF and DØ are pursuing a direct search for a SM Higgs over a wide mass range:
  $100 < M_H < 200$ GeV/c^2.

SM Higgs Production at the Tevatron

- Dominant Standard Model Higgs boson production channels at 1.96 TeV:





- gluon-gluon fusion:

$$\sigma(gg \to H) = \begin{cases} 1.2 \text{ pb at } M_H = 115\ \text{GeV}/c^2 \\ 0.39 \text{ pb at } M_H = 165\ \text{GeV}/c^2 \end{cases}$$

- associated production with a vector boson:

$$\sigma(qq \to WH) = \begin{cases} 0.18 \text{ pb at } M_H = 115\ \text{GeV}/c^2 \\ 0.04 \text{ pb at } M_H = 165\ \text{GeV}/c^2 \end{cases}$$

$$\sigma(qq \to ZH) = \begin{cases} 0.11 \text{ pb at } M_H = 115\ \text{GeV}/c^2 \\ 0.03 \text{ pb at } M_H = 165\ \text{GeV}/c^2 \end{cases}$$

- vector boson fusion (VBF):

$$\sigma(qq \to qqH) = \begin{cases} 0.08 \text{ pb at } M_H = 115\ \text{GeV}/c^2 \\ 0.04 \text{ pb at } M_H = 165\ \text{GeV}/c^2 \end{cases}$$

SM Higgs Decays

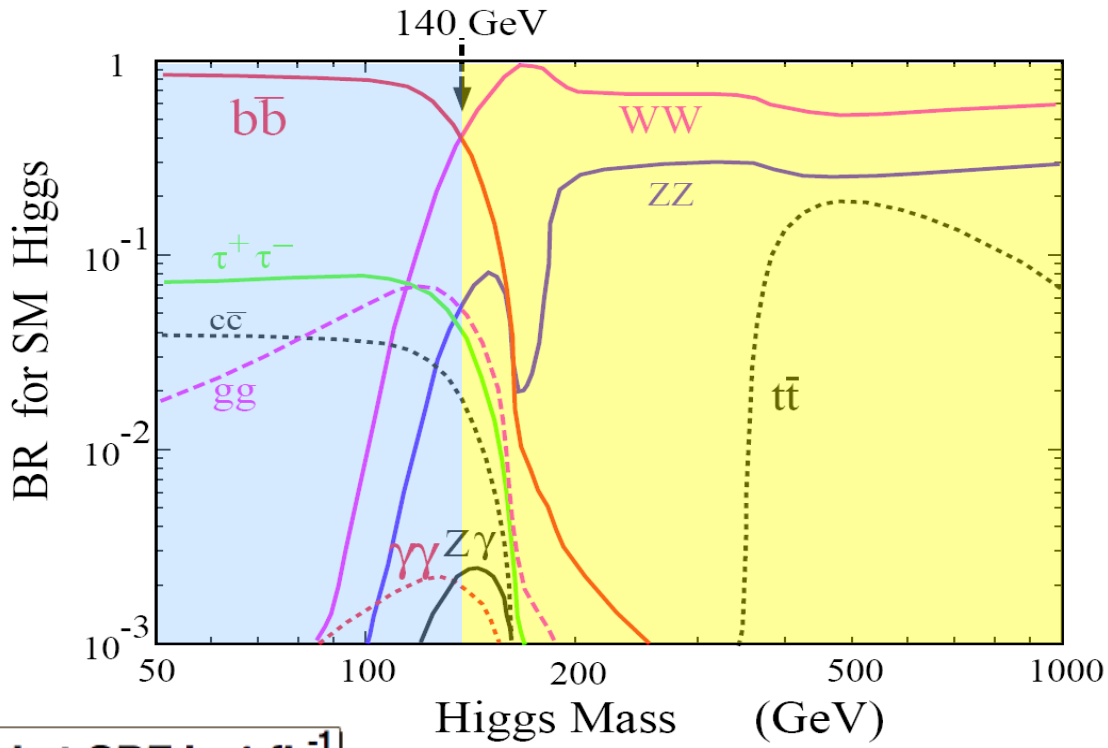
Low mass region

At M_H = 115 GeV/c^2:

BR(H → bb) = 0.73

BR(H → WW) = 0.08

BR(H → ττ) = 0.07



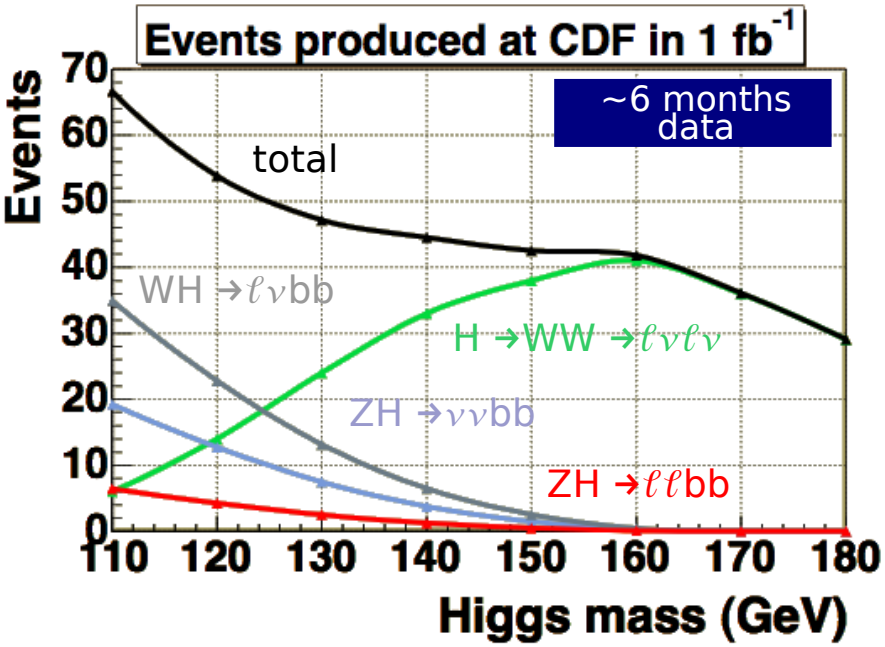
High mass region

At M_H = 165 GeV/c^2:

BR(H → WW) = 0.96

BR(H → ZZ) = 0.02

BR(H → bb) = 0.01

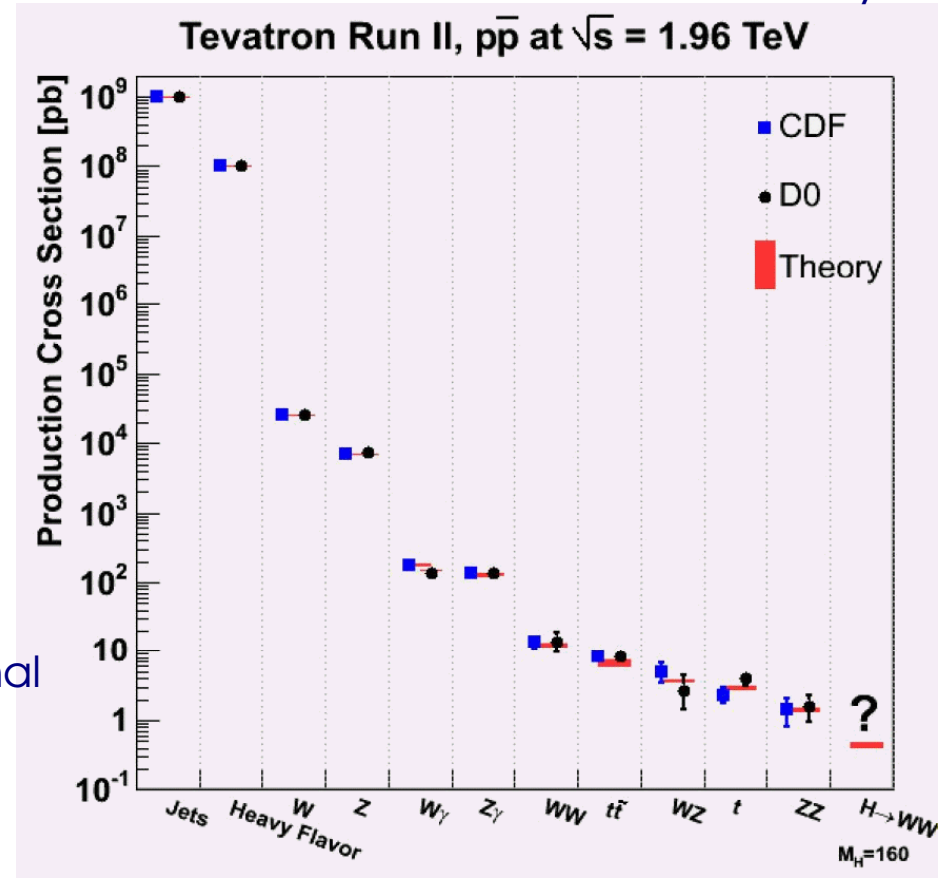


- Expected yields per fb^{-1}:

channel	events @ 115	events @ 165
WH→ℓνbb	28	0.1
ZH→ννbb	16	0.07
ZH→ℓℓbb	5	0.02
H→WW→ℓνℓν	9	38
total	58	38

Higgs search strategy

- At the Tevatron the Higgs boson production is a very rare process: S/B ~ $1/10^{10}$.
- Difficult but not impossible task: with the current datasets CDF and DØ are already probing directly processes with σ ~1 pb.
- The search strategy is driven by the Higgs boson dominant decay mode:
  - $H \rightarrow \bar{b}b$ for $M_H < 135$ GeV/c^2:
    - gg→H not viable, overwhelming multijet bkg;
    - associated production provides cleaner experimental signatures.
  - $H \rightarrow WW^*$ for $M_H > 135$ GeV/c^2:
    - since the leptonic W decays provide clean final states, can take advantage of the more abundant gluon-gluon fusion production.



- In order to reach the needed sensitivity as many search channels as possible are covered and CDF and DØ results are combined.
- To better characterize the backgrounds and increase the S/B discriminating power each channel is further divided in "sub-channels" that are analised separately.

Tools

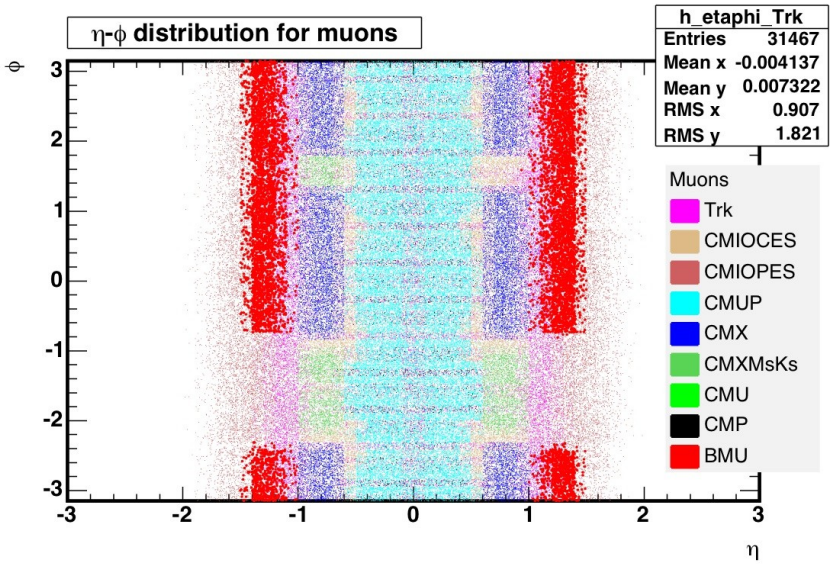
- Leptons, jets and missing transverse energy are the main ingredients of the Higgs searches.

- Leptons:
  - standard muons and electrons;
  - additional looser categories for μ and e extend the detector coverage and improve the signal acceptance;
  - dedicated algorithms are used to reconstruct hadronically decaying taus.

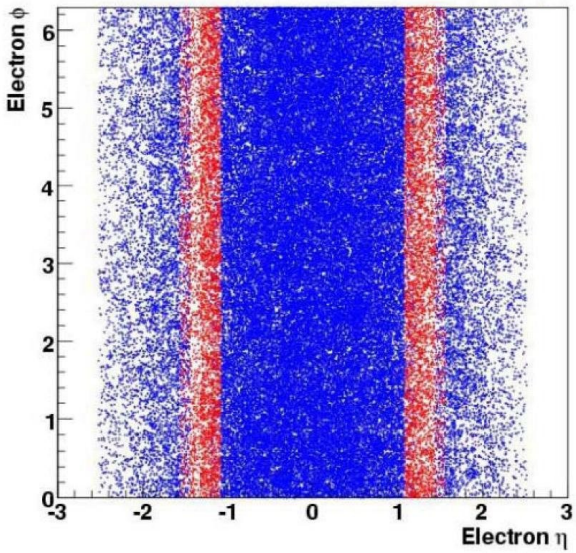
- Jets:
  - reconstructed with cone algorithms;
  - jet energy corrected to account for detector effects clustering algorithm, multiple interactions, ...

- Missing transverse energy (MET):
  - defined as an imbalance of the energy deposited in the calorimeters;
  - accounts for neutrinos that escape detection.

CDF muon coverage



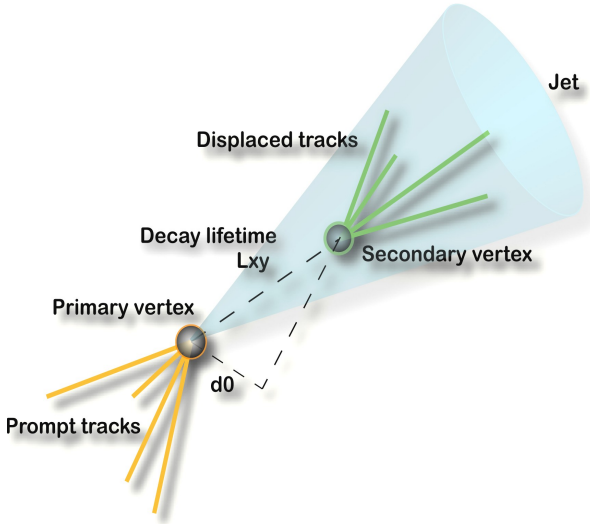
DØ electron coverage



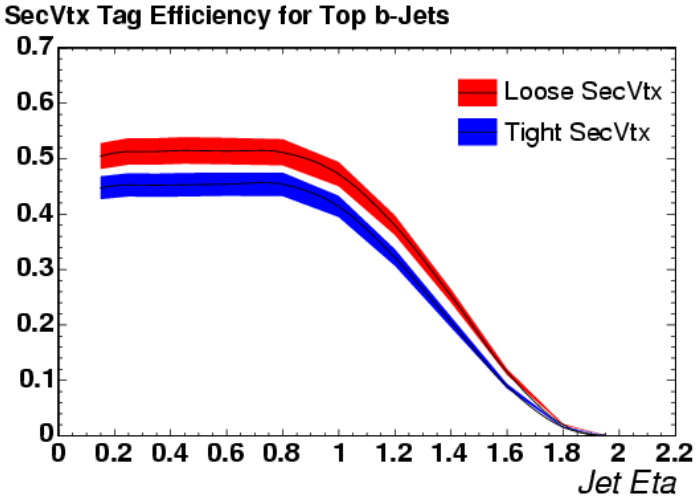
$\eta = -\log \tan \vartheta/2$

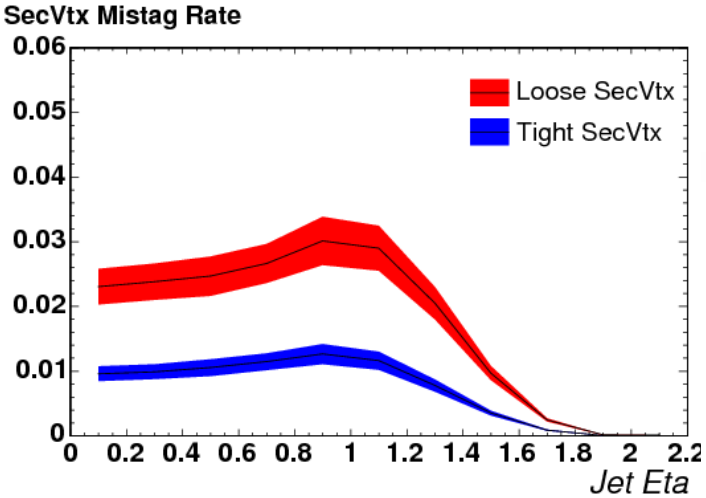
Jet b-tagging

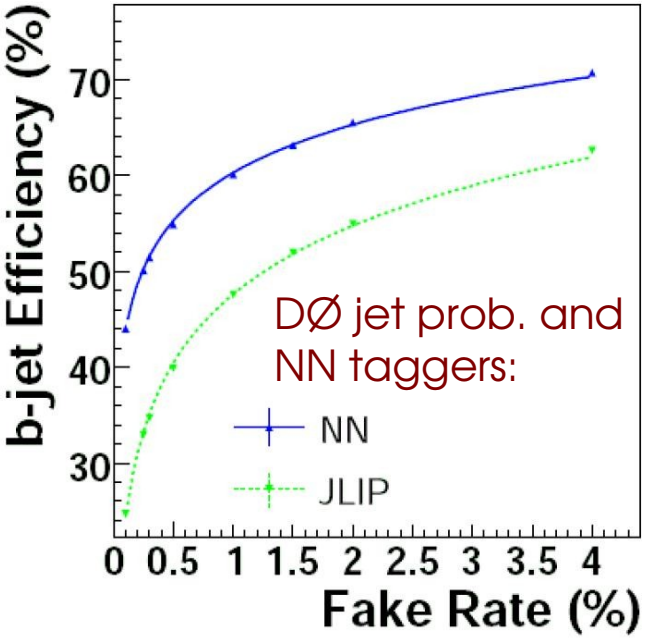
- In low mass searches an essential tool to enhance S/B is to identify the b jets (b-tagging).
- B-tagging techniques exploit the peculiarities of b quarks: relatively long lifetime, high mass, and soft lepton decays.
- Main b-tagging algorithms used in CDF and DØ analyses:
  - jet probability, based on track impact parameters, for jets to originate from the interaction point;
  - reconstruction inside jets of secondary vertices, displaced from the interaction point.
  - artificial neural networks which exploit a full set of jet variables.



CDF displaced secondary vertex tagger



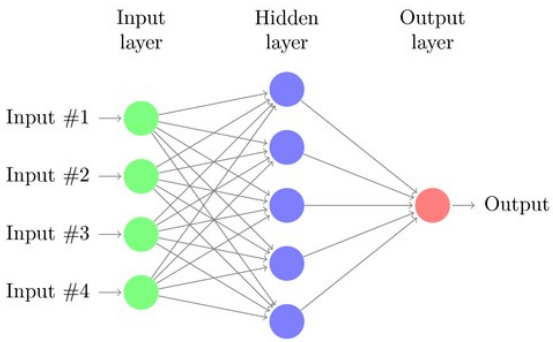


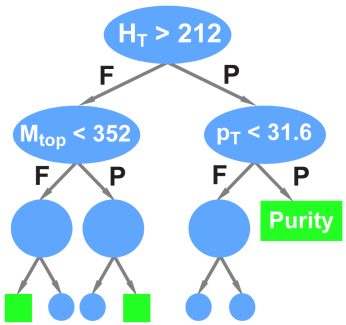


Multivariate techniques

- Both experiments use advanced multivariate techniques, which combine information from kinematical, event global and particle identification variables, to enhance the signal/background discrimination:

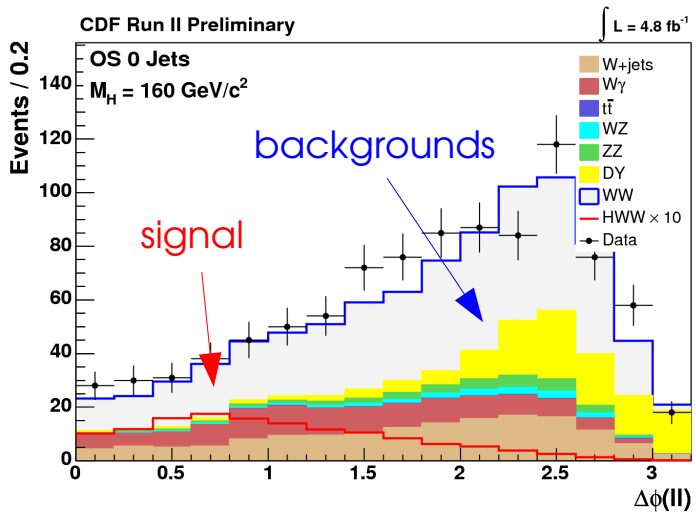
  - Artificial neural networks (NN)
  - Boosted Decision Trees (BDT)
  - Matrix Element (ME):
    - calculates event probability integrating the LO matrix elements.



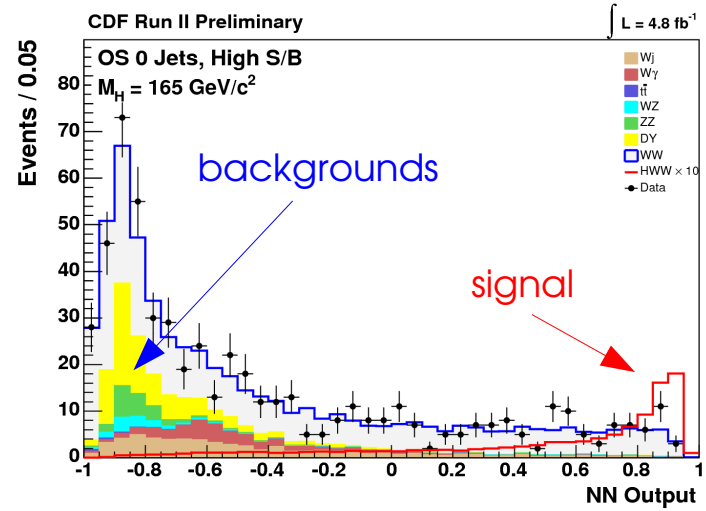


$$d\sigma(\vec{x}) = \sum_{i,j} \int d\vec{y} \left[\underbrace{f_i(q_1,Q^2)dq_1 \times f_j(q_2,Q^2)dq_2}_{p.d.f} \times \underbrace{\frac{\partial \sigma_{hs,ij}(\vec{y})}{\partial \vec{y}}}_{\mathbf{ME}} \times \overbrace{W(\vec{x},\vec{y})}^{\text{Detector response (Transfer function)}} \times \underbrace{\Theta_{parton}(\vec{y})}_{\text{Parton level cut}} \right]$$

single variable discriminant

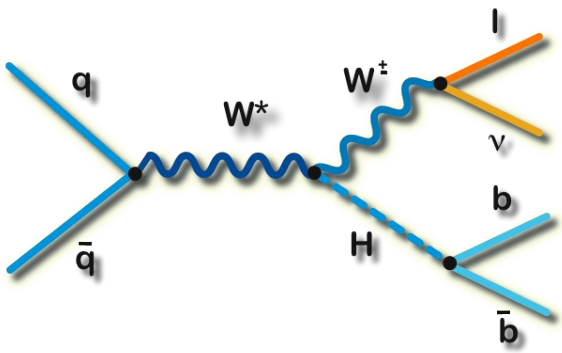


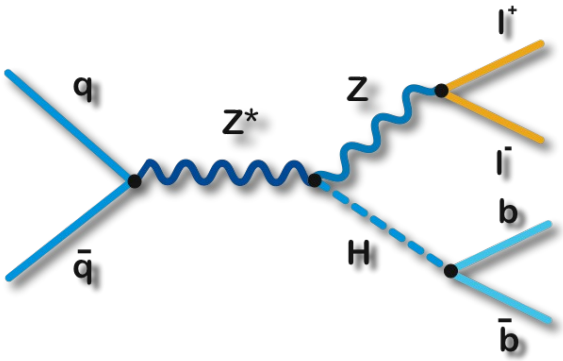
neural-network output

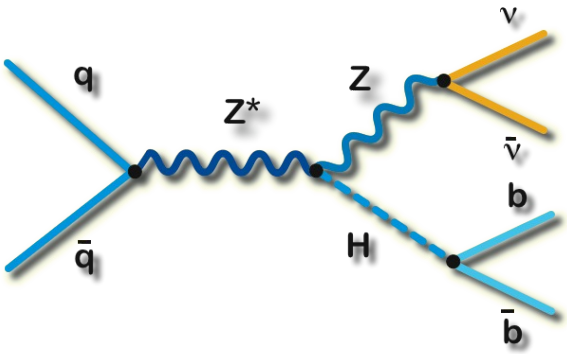


Low mass searches

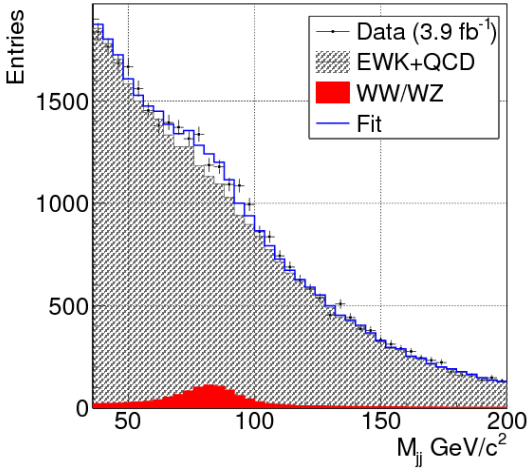
- Main searches in the low mass range:
  - WH → $\ell\nu$bb
    - experimental signature: an energetic lepton, large missing energy and two jets;
    - the best compromise between signal yield and background level.
  - ZH → $\ell\ell$bb
    - looks for two leptons and two jets;
    - the cleanest mode, but suffers from low statistics;
  - ZH → $\nu\nu$bb
    - two jets and missing energy;
    - good signal acceptance, huge multijet backgrounds.
- A benchmark analysis will be WZ → $\ell\nu$bb.

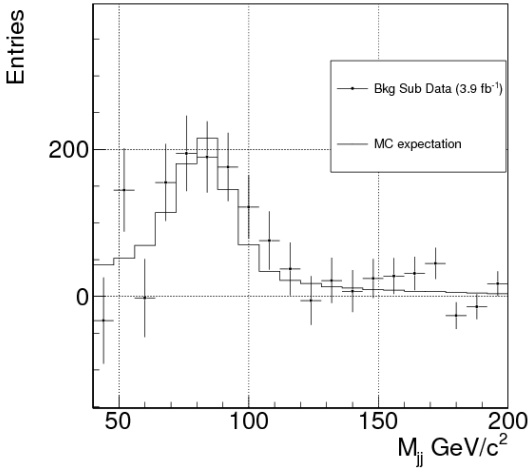






CDF's WW/WZ → $\ell\nu$jj measurement



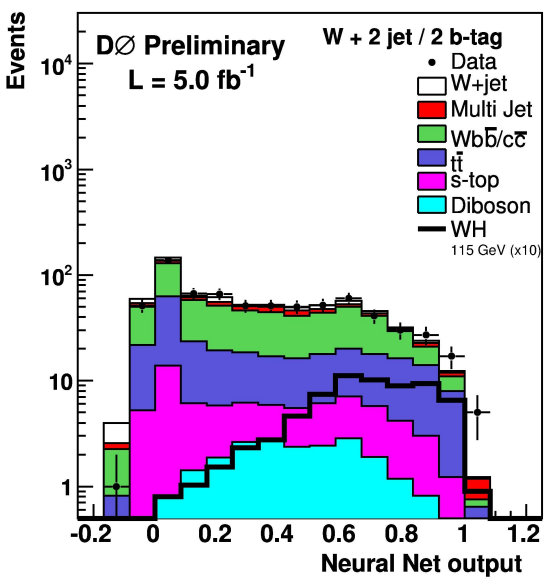


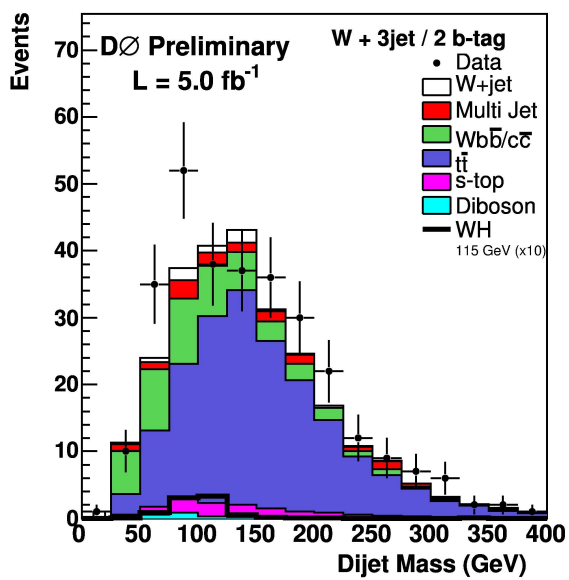
$WH \rightarrow \ell \nu b\bar{b}$

- Event selection:
  - one high momentum lepton [ℓ=e,μ] + missing transverse energy + two or three jets.
- Analysis technique:
  - eight sub-samples: μ or e, two or three jets, one tight b-tagged or two loose b-tagged jets (NN b-tagging);
  - NNs to separate signal from bkg in W+2 jets samples;
  - dijet invariant mass as discriminant in the W+3 jets samples.

channel	W + 2j/2 b tag	W + 3j/2 b tag
W/Z + bb	293	39
tt	201	182
single t	55	12
WW,WZ,ZZ	22	2
W/Z + jets	101	17
multijet	48	14
WH (M_H=115)	6.5	0.8
Tot bkg	720	267
data	707	305

5.0 fb^{-1}





For M_H = 115 GeV/c^2:

- expected limit = 5.1 $\times \sigma_{SM}$
- observed limit = 6.9 $\times \sigma_{SM}$

CDF result **4.3 fb^{-1}**

For M_H = 115 GeV/c^2:

- expected limit = 4.0 $\times \sigma_{SM}$
- observed limit = 5.3 $\times \sigma_{SM}$

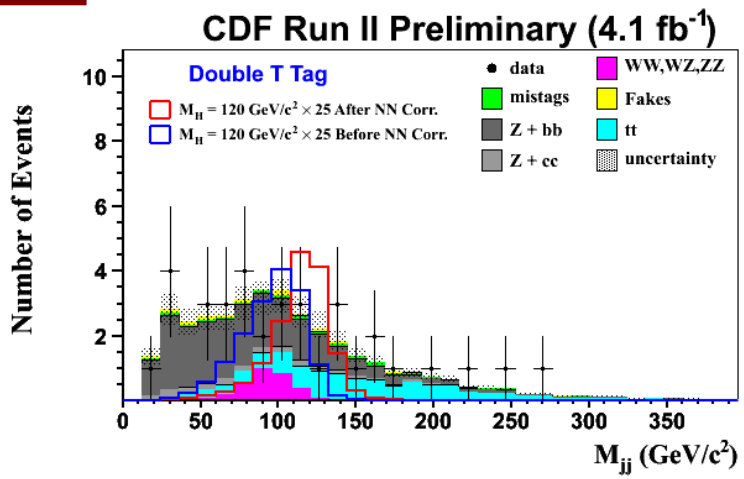
http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H78/

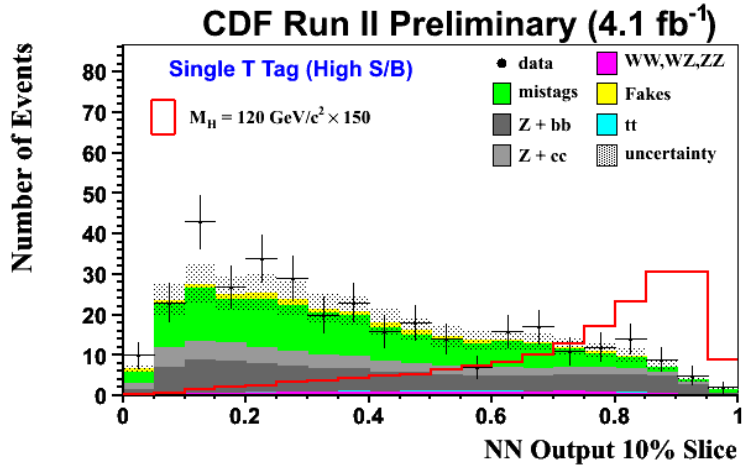
$ZH \rightarrow \ell^+\ell^- b\bar{b}$

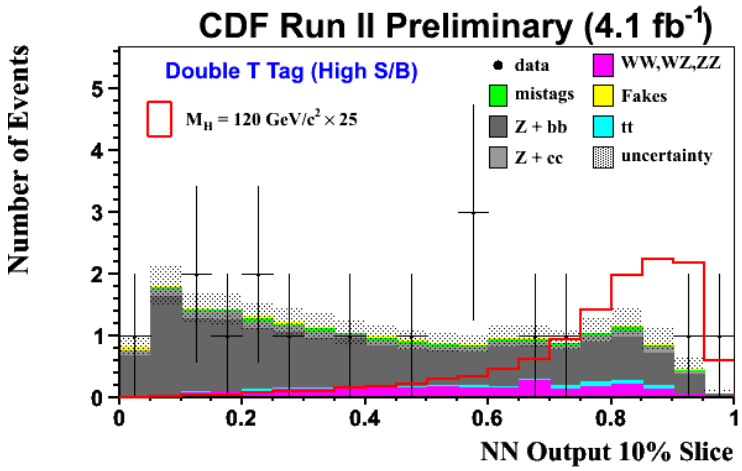
- Event selection:
  - a Z candidate decaying to ee or $\mu\mu$ + at least 2 jets.

4.1 fb^{-1}

- Analysis technique:
  - jets corrected for missing energy to improve M_{jj} resolution;
  - 6 sub-samples based on Z rec. quality and b-tagging type;
  - Matrix Elements and NN for event selection.







channel	single tag	double tag
tt	17	7
WW ,WZ, ZZ	16	2.8
Z + bb	105	16
Z + cc	54	1.8
Z+mistags	153	0.9
fakes	22	0.7
ZH (M_H=120)	1.4	0.5
Tot bkg	367	29
data	406	23

For M_H = 115 GeV/c^2:

- expected limit = 6.8 × σ_{SM}
- observed limit = 5.9 × σ_{SM}

DØ result

4.2 fb^{-1}

For M_H = 115 GeV/c^2:

- expected limit = 8.0 × σ_{SM}
- observed limit = 9.1 × σ_{SM}

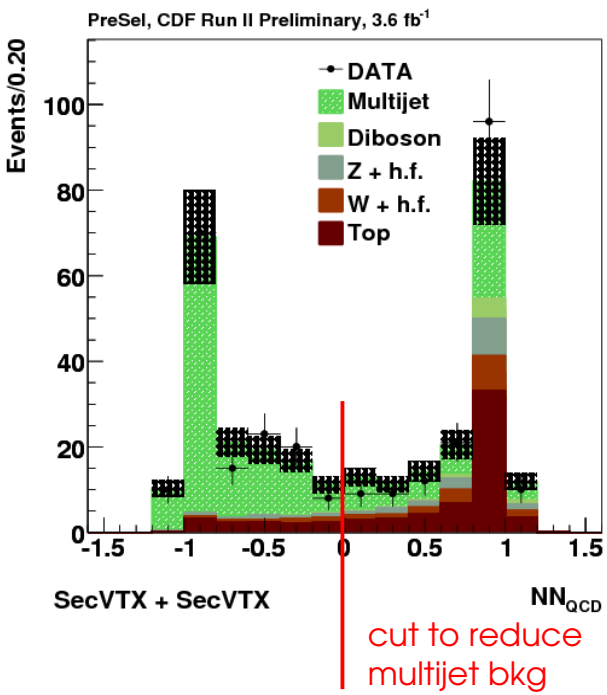
http://www-cdf.fnal.gov/physics/new/hdg/results/zhllbb_090724/PAGE/index.htm

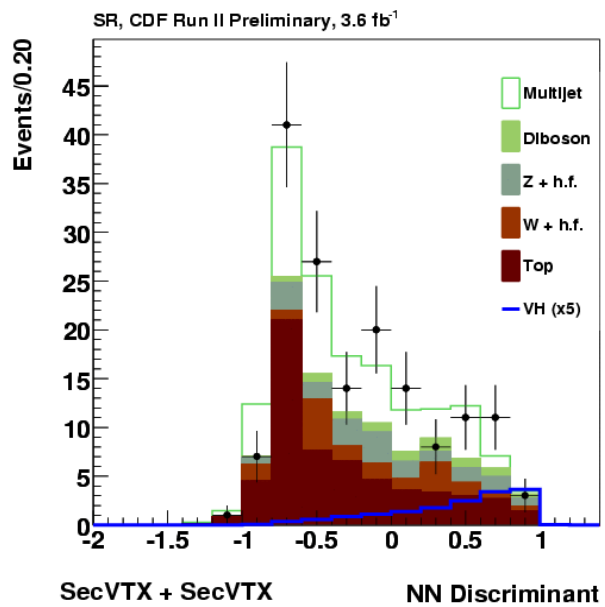
$ZH \to \nu\nu b\bar{b}$ and $WH \to (\ell)\nu b\bar{b}$

- Event selection:
  - missing transverse energy + 2 jets
  - sensitive to $ZH \to \nu\nu bb$, $ZH \to (\ell\ell)bb$ and $WH \to (\ell)\nu bb$.
- Analysis technique:
  - NN to remove overwhelming multijet background;
  - three b-tag categories;
  - second NN for event selection.

3.6 fb^{-1}

channel	2 tags
multijet	55
single t	14
tt	45
WW,WZ,ZZ	8
W+bb/cc	18
Z+bb/cc	18
ZH/WH (M_H=115)	3.1
Tot bkg	166
data	157





For M_H = 115 GeV/c^2:

- expected limit = 4.2 $\times\ \sigma_{SM}$
- observed limit = 6.1 $\times\ \sigma_{SM}$

DØ result **2.1 fb^{-1}**

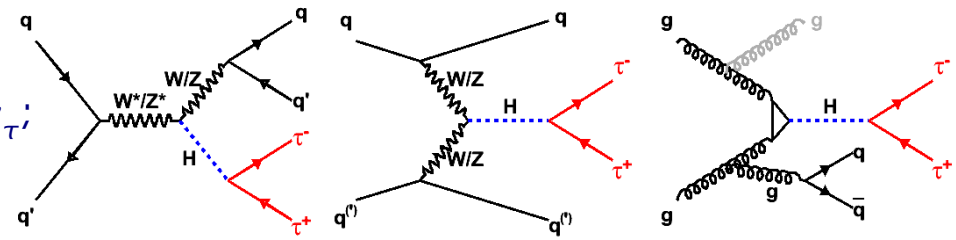
For M_H = 115 GeV/c^2:

- expected limit = 8.4 $\times\ \sigma_{SM}$
- observed limit = 7.5 $\times\ \sigma_{SM}$

http://www-cdf.fnal.gov/physics/new/hdg/results/vhmetbb_090814/

$\tau^+\tau^-qq$ final state

- Event selection: 1 muon + 1 tau + 2 jets
  - one tau decays to $\mu\nu_\mu\nu_\tau$, the other to hadrons + ν_τ;
  - sensitive to ZH→ττqq, HZ→ττqq, HW→ττqq', Hqq→ττqq, gg→H→ττ + 2 additional jets.

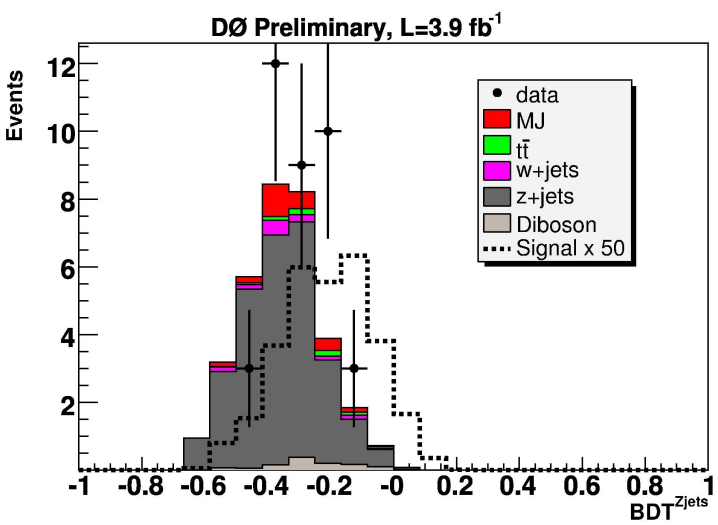


- Analysis technique:
  - no b-tagging, tau selection provides good bkg rejection;
  - NN to identify taus;
  - different BDTs to discriminate signal processes from different background categories.

4.9 fb^{-1}

For M_H = 115 GeV/c^2:

- expected limit = 15.9 × σ_{SM}
- observed limit = 27.0 × σ_{SM}



channel	events
tt	0.7
W + jets	1.2
Z + jets	28
WW,WZ,ZZ	1.1
multijet	2.3
signal (M_H=115)	0.6
Tot bkg	33
data	37

CDF result **2.0 fb^{-1}**

For M_H = 115 GeV/c^2:

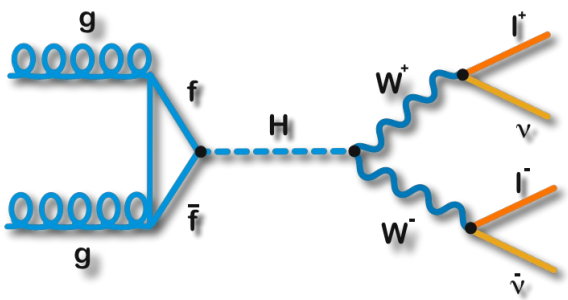
- expected limit = 25 × σ_{SM}
- observed limit = 31 × σ_{SM}

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H79/

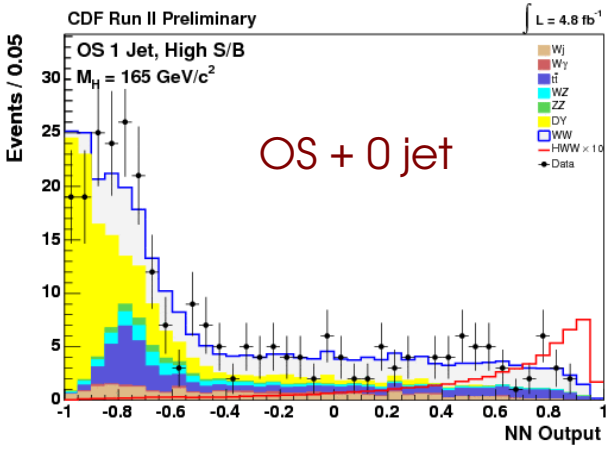
$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$

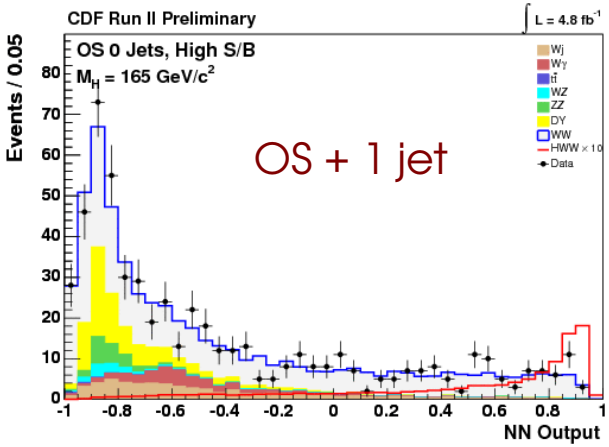
4.8 fb^{-1}

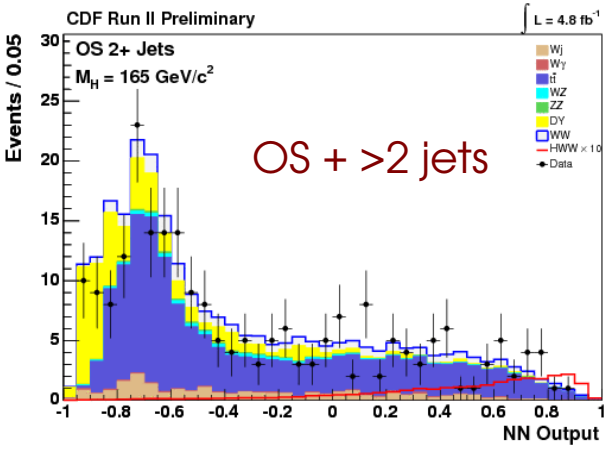
- Event selection: 2 leptons [ℓ=e,μ] + large missing transverse energy;
  - also taus decaying to muons or electrons enter the sample;
  - signal acceptance is enhanced by WH, ZH, and VBF production processes.



- Analysis strategy:
  - exploit 2 electron categories, 7 muon categories, and tracks not fiducial neither to the calorimeter nor the muon detectors;
  - 5 distinct searches on different subsamples to optimize the signal/background separation;
  - events with two opposite sign (OS) leptons separated by jet multiplicity: 0 jets, 1 jet, 2 or more jets;
  - NNs to discriminate signal from backgrounds.





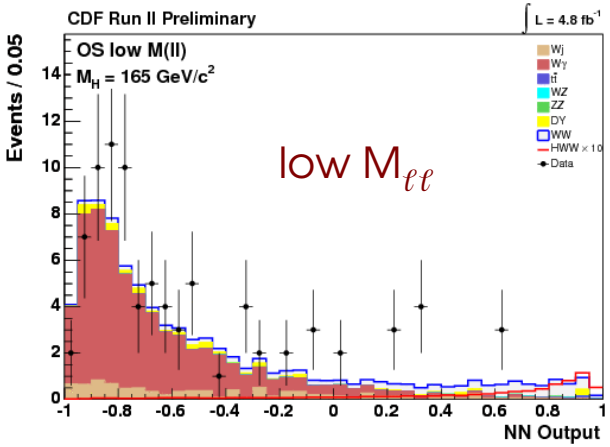


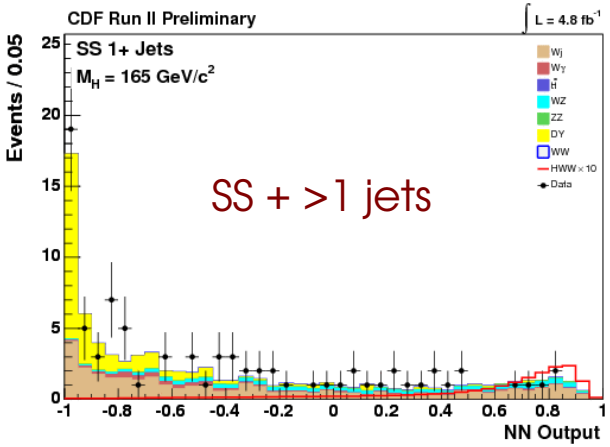
$H \to WW^* \to \ell\nu\ell\nu$

- To squeeze every little drop of sensitivity out, CDF uses also two kinematical regions which do not enter the primary sample:
  - the kinematical region with $M_{\ell\ell}$<16 GeV/c^2;
  - two same-sign (SS) leptons + >1 jets, potentially coming from WH → WWW* and ZH → ZWW*.

4.8 fb^{-1}

channel	OS	OS low $M_{\ell\ell}$	SS
tt	195	0.3	0.2
Drell-Yan	312	3.6	27
WW	594	11	0.04
WZ	45	0.3	9
ZZ	40	0.1	2
W + jets	235	10	34
W + photon	131	56	4
gg→H (M_H=165)	21.5	0.8	-
WH (M_H=165)	2.8	-	1.6
ZH (M_H=165)	1.3	-	0.3
VBF (M_H=165)	1.6	-	-
Tot bkg	1552	81	77
data	1567	85	81





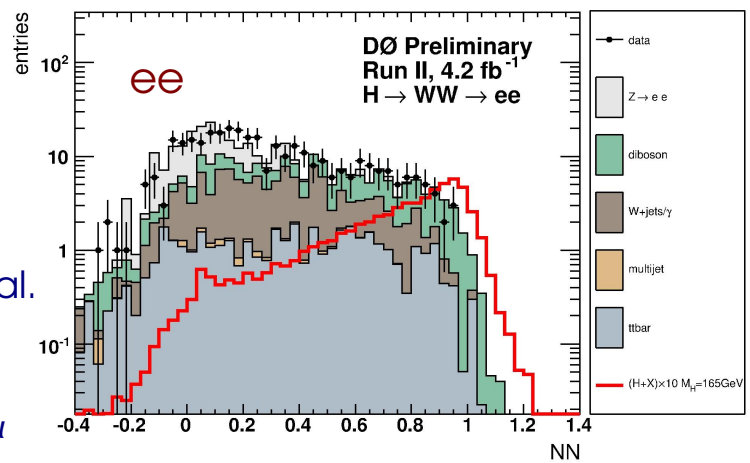
For M_H = 165 GeV/c^2:

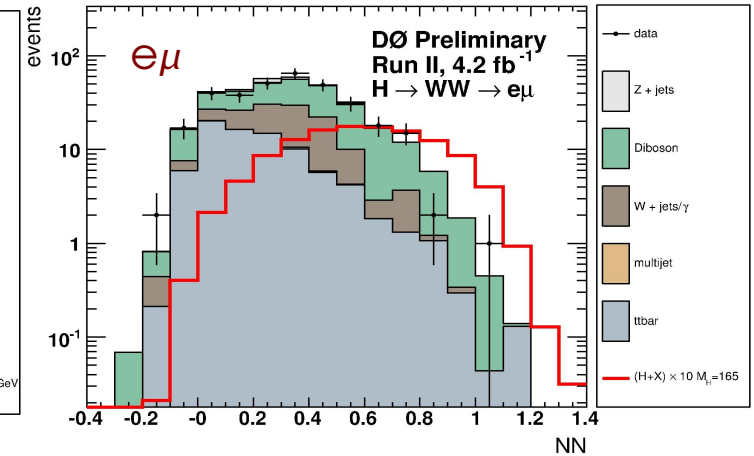
- expected limit = 1.2 × σ_{SM}
- observed limit = 1.2 × σ_{SM}

http://www-cdf.fnal.gov/physics/new/hdg/results/hwwmenn_090814/index.htm

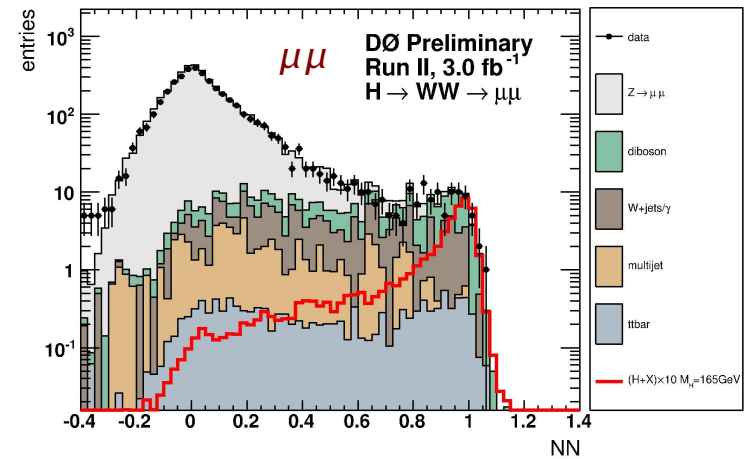
$H \to WW^* \to \ell\nu\ell\nu$

- Event selection: 2 opposite-sign leptons [ℓ=e,μ] + large MET:
  - leptonic tau decays are included;
  - gg→H, WH, ZH, and VBF processes contribute to the signal.
- Analysis strategy:
  - three different NNs for $\mu\mu$, eμ and ee final states.





4.2 fb^{-1}



channel	ee	eμ	$\mu\mu$
tt	40	83	12.5
Drell-Yan	109	13	3987
WW	67	155	93
WZ	10	7	19
ZZ	8	0.6	15
W + jets	98	79	134
multijet	2	1	64
H (M_H=165)	6	12	5
Tot bkg	334	338	4325
data	336	329	4084

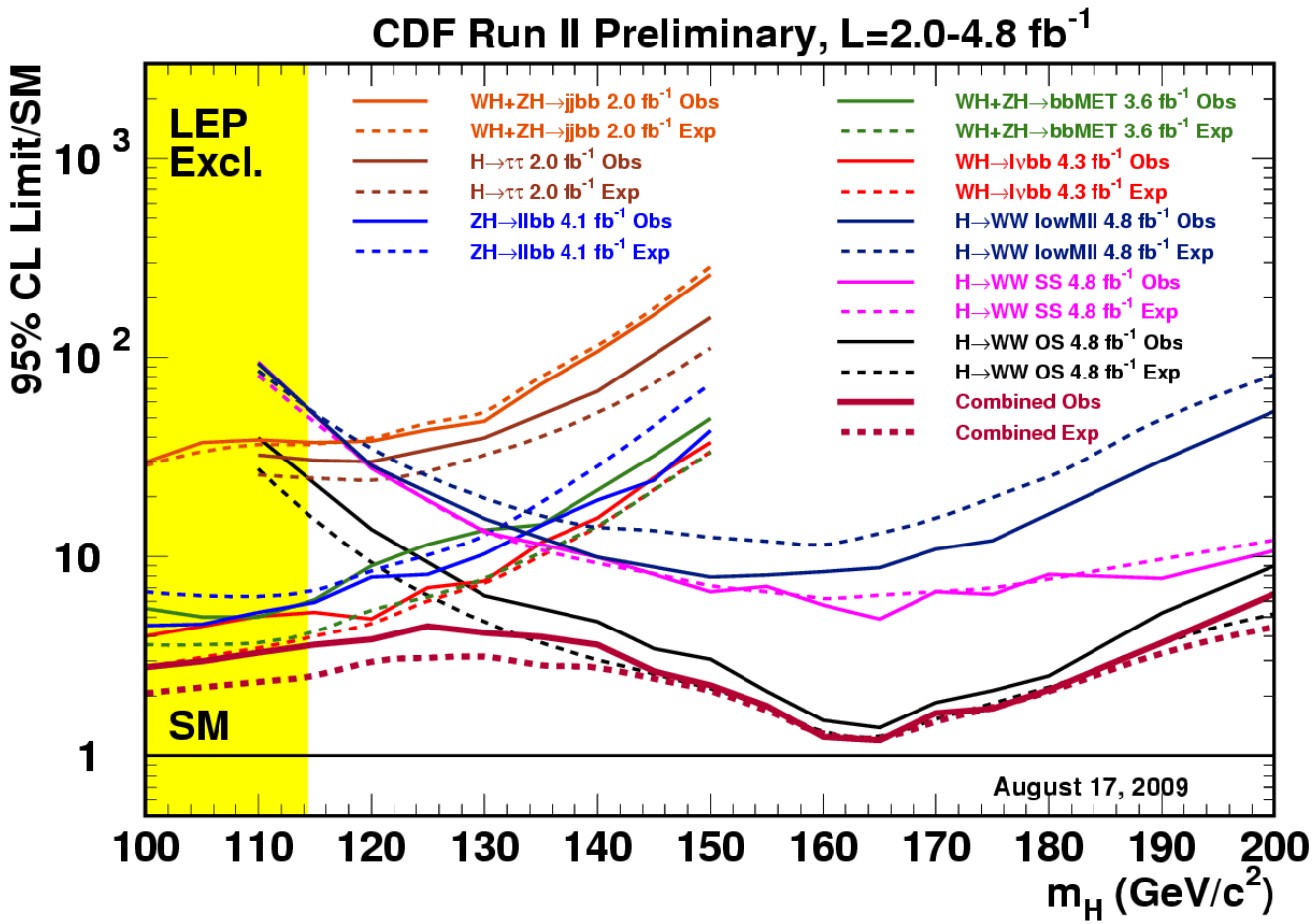
For M_H = 165 GeV/c^2:

- expected limit = 1.7 × σ_{SM}
- observed limit = 1.3 × σ_{SM}

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H68/

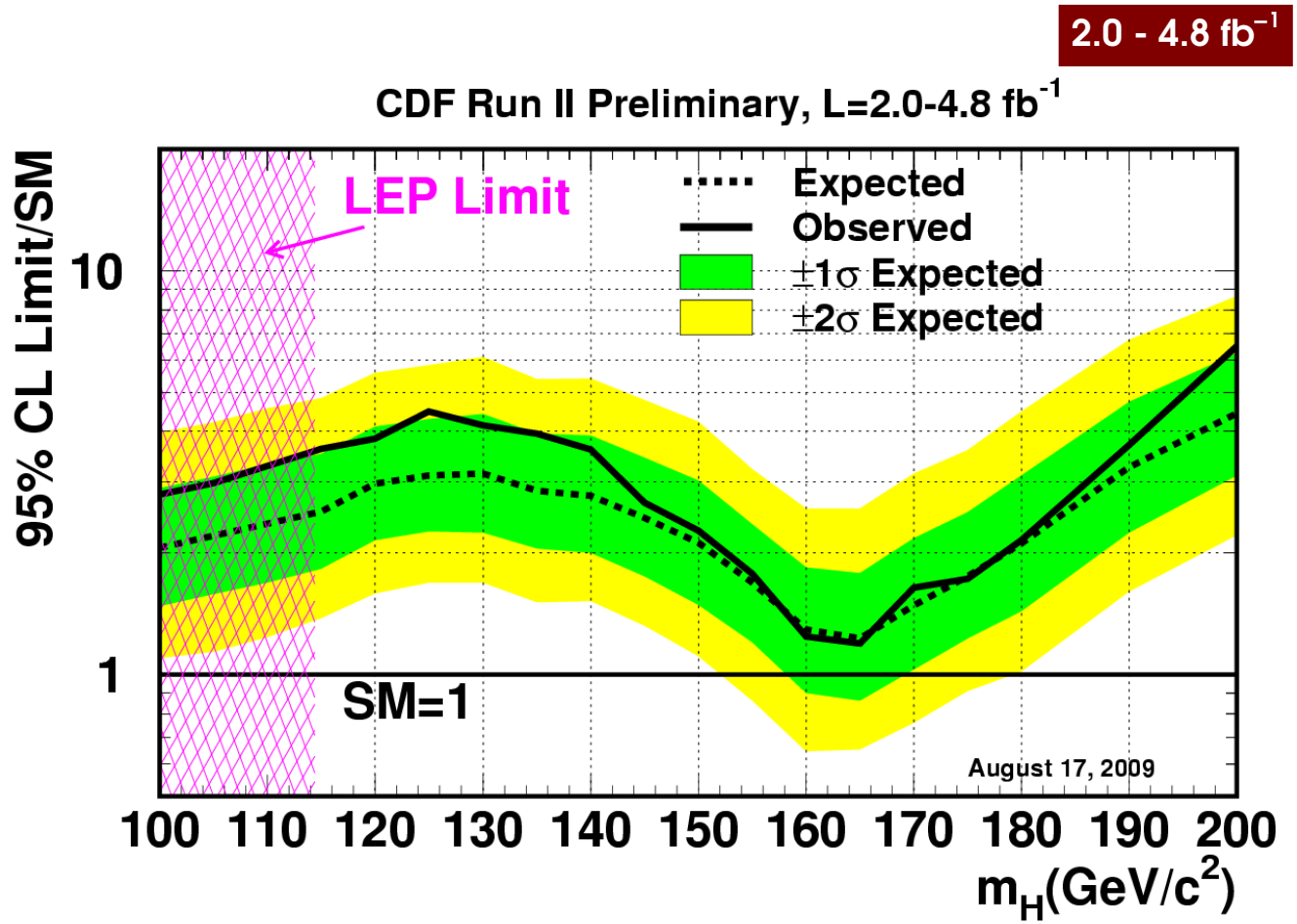
Limit combination

- Combining is the leitmotif of Higgs searches: in order to maximize its sensitivity each experiment combines the results from different analyses.
- Systematics are taken into account in the combination and their correlations are treated consistently.



CDF combined limit

- Combined channels:
  - $WH \to \ell\nu bb$ 4.3 fb^{-1}
  - $WH/ZH \to (\ell)\nu bb/\nu\nu bb$ 3.6 fb^{-1}
  - $ZH \to \ell\ell bb$ 4.1 fb^{-1}
  - $H \to WW^*$ 4.8 fb^{-1}
  - $WH \to WWW^*$ 4.8 fb^{-1}
  - $WH+ZH \to jjbb$ 2.0 fb^{-1}
  - $H \to \tau\tau$ 2.0 fb^{-1}



For M_H = 115 GeV/c^2:

- **expected limit = 2.5 × σ_{SM}**
- **observed limit = 3.6 × σ_{SM}**

For M_H = 165 GeV/c^2:

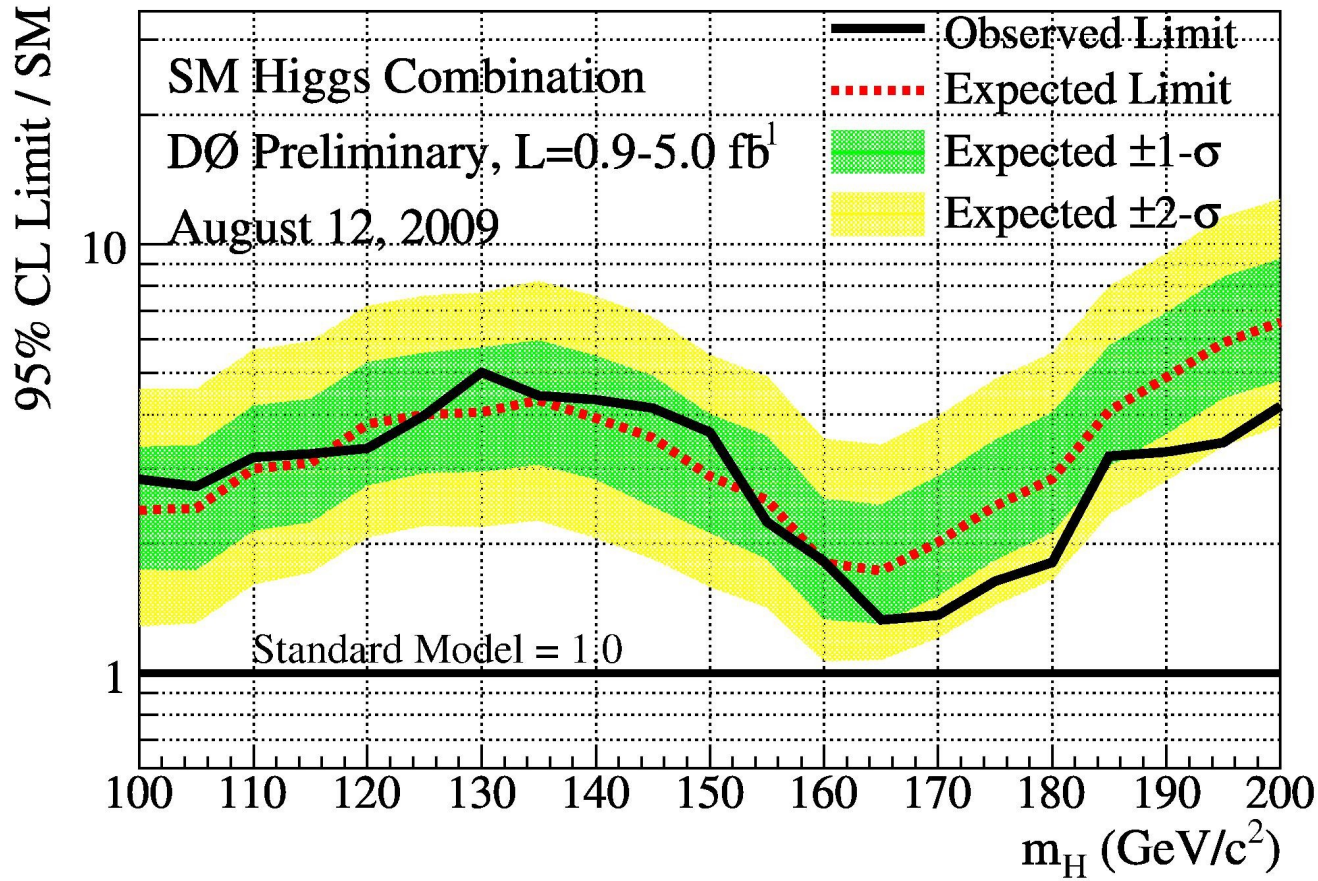
- **expected limit = 1.2 × σ_{SM}**
- **observed limit = 1.2 × σ_{SM}**

http://www-cdf.fnal.gov/physics/new/hdg/results/combcdf_aug09/

DØ combined limit

0.9 – 5 fb^{-1}

- Combined channels:
  - $WH \to \ell\nu bb$ 5.0 fb^{-1}
  - $WH \to \tau\nu bb$ 0.9 fb^{-1}
  - $WH/ZH \to \tau\tau bb/qq\tau\tau$ 4.9 fb^{-1}
  - $ZH \to \nu\nu bb$ 2.1 fb^{-1}
  - $ZH \to \ell\ell bb$ 4.2 fb^{-1}
  - $HW \to WWW^*$ 3.6 fb^{-1}
  - $H \to WW^*$ 4.2 fb^{-1}
  - $H \to \gamma\gamma$ 4.2 fb^{-1}
  - $ttH \to ttbb$ 2.1 fb^{-1}



For M_H = 115 GeV/c^2:

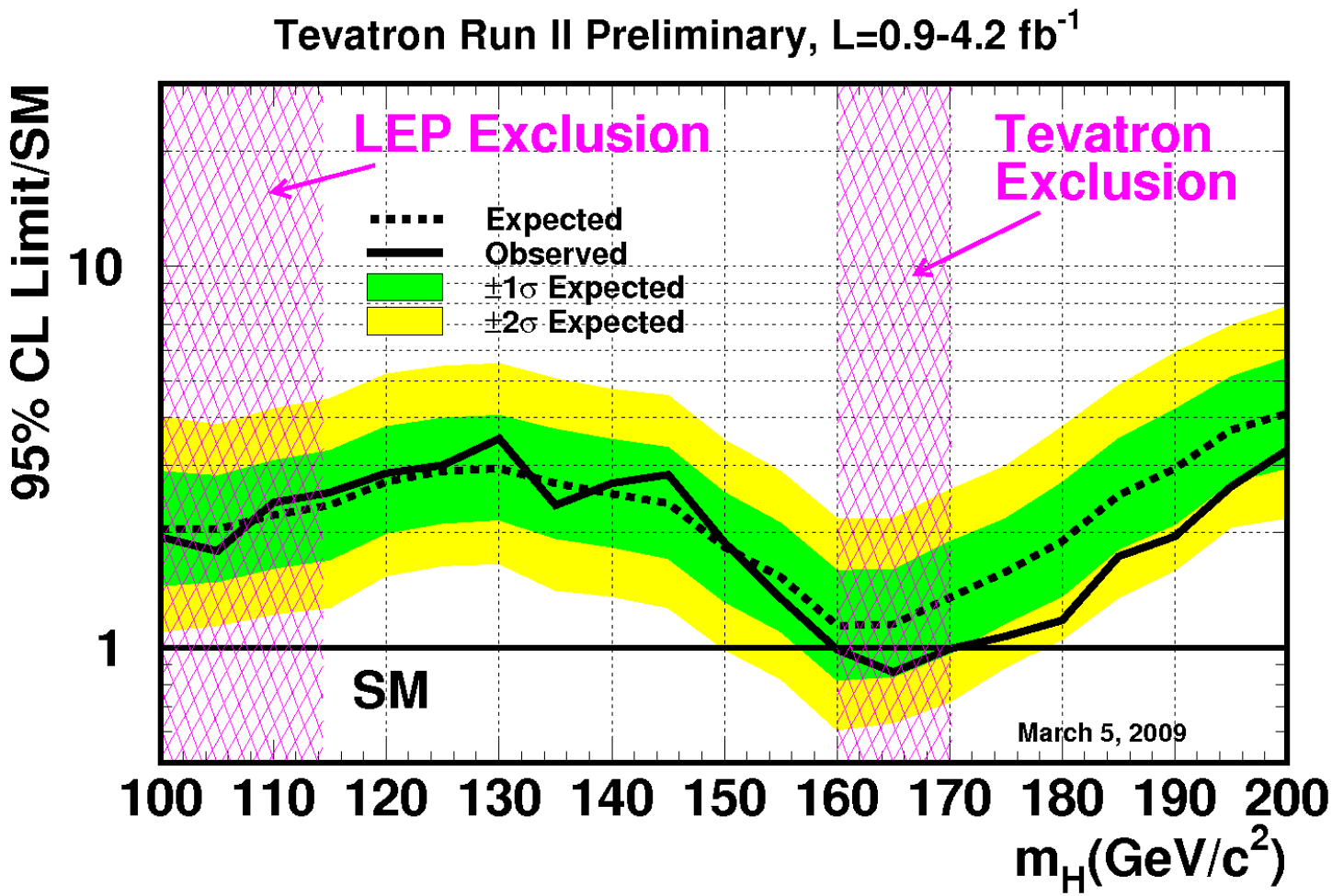
- **expected limit = 3.1 $\times\ \sigma_{SM}$**
- **observed limit = 3.2 $\times\ \sigma_{SM}$**

For M_H = 165 GeV/c^2:

- **expected limit = 1.7 $\times\ \sigma_{SM}$**
- **observed limit = 1.3 $\times\ \sigma_{SM}$**

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H81/

Spring '09 Tevatron combination



For M_H = 115 GeV/c^2:

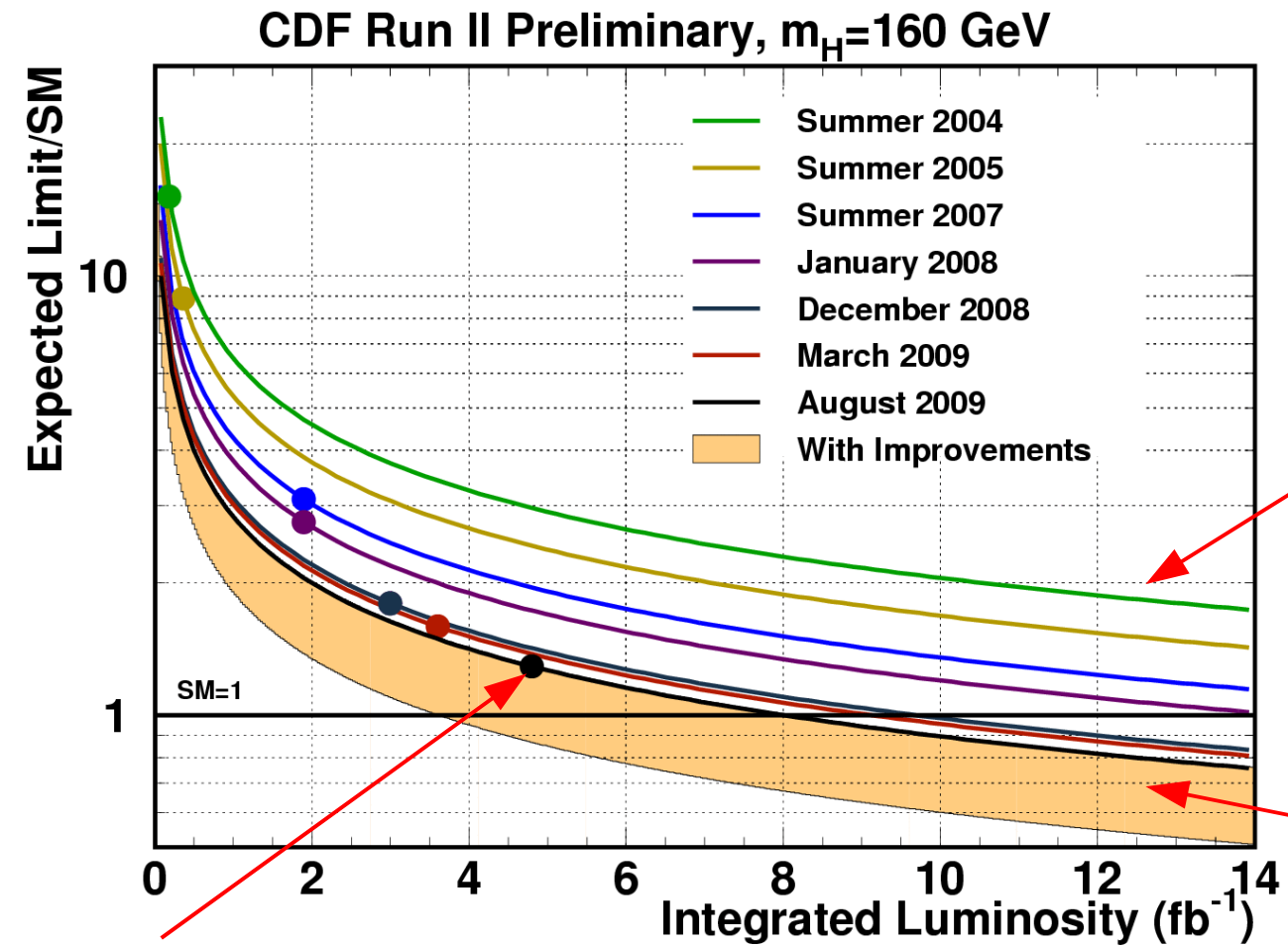
- expected limit = 2.4 × σ_{SM}
- observed limit = 2.6 × σ_{SM}

95% C.L. exclusion of the mass range 160 < M_H < 170 GeV/c^2

http://www-cdf.fnal.gov/physics/new/hdg/results/comb_090313/

Expected limit projections

- CDF projections for the expected upper limit on the SM Higgs boson production cross section at M_H = 165 GeV/c^2:



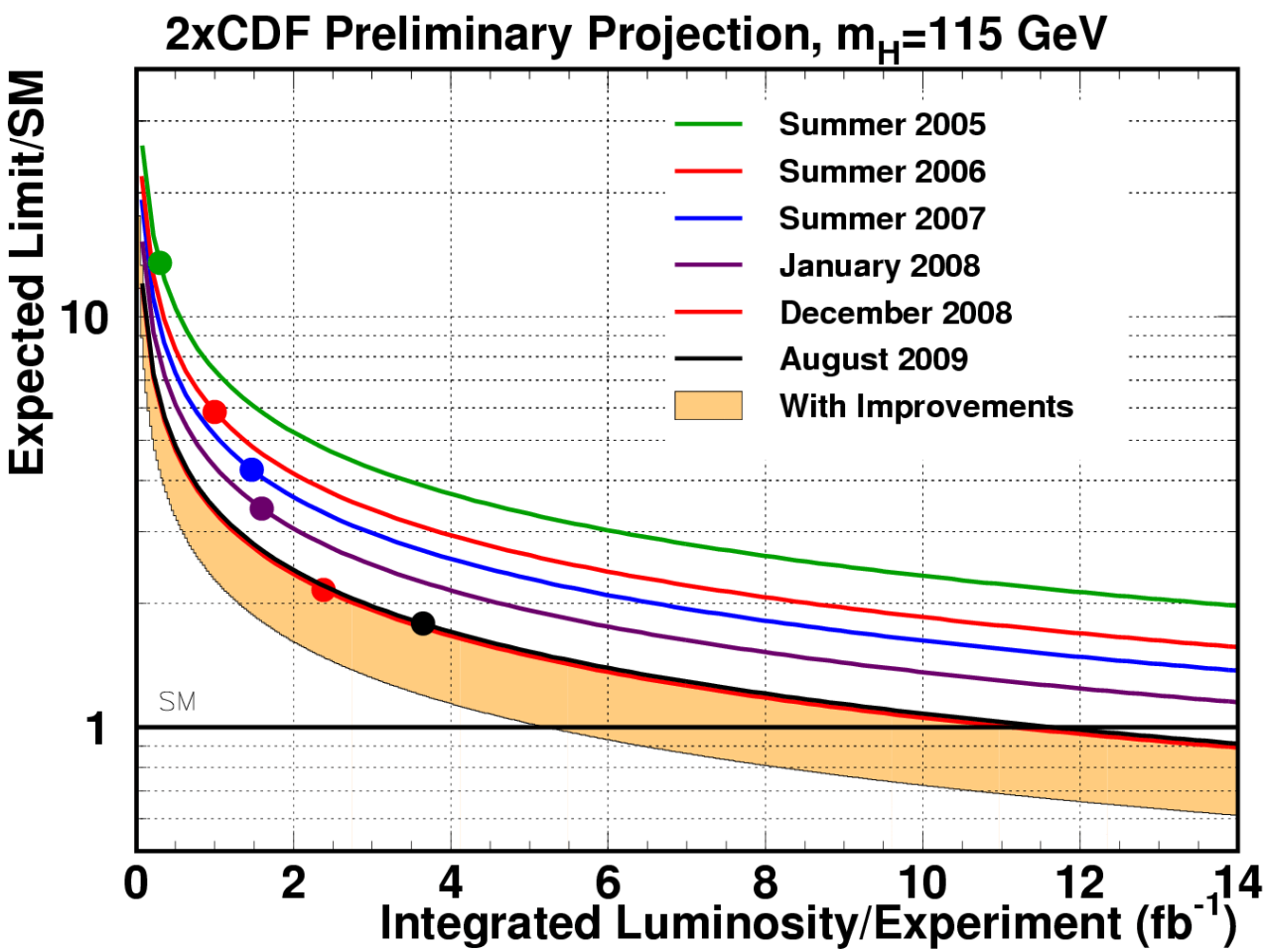
scales with $1/\sqrt{\int \mathscr{L}\, dt}$

expected improvements as estimated in Summer 2007

analyses updates

Expected limit projections

- 2xCDF projections for the expected upper limit on the SM Higgs boson production cross section at M_H = 115 GeV/c^2:



Conclusions

- CDF and DØ are pursuing an extensive direct search for a Standard Model Higgs boson over a wide mass range which covers $100 < M_H < 200$ GeV/c^2.

- An overview of the most recent results, which analyze up to 5 fb^{-1}, has been presented:
  - CDF combined upper limits $\begin{cases} 3.6 \times \sigma_{SM} \text{ at 95\% C.L. for } M_H = 115 \text{ GeV}/c^2 \\ 1.2 \times \sigma_{SM} \text{ at 95\% C.L. for } M_H = 165 \text{ GeV}/c^2 \end{cases}$
  - DØ combined upper limits $\begin{cases} 3.2 \times \sigma_{SM} \text{ at 95\% C.L. for } M_H = 115 \text{ GeV}/c^2 \\ 1.3 \times \sigma_{SM} \text{ at 95\% C.L. for } M_H = 165 \text{ GeV}/c^2 \end{cases}$

- A new Tevatron combination is in progress:
  - in Spring '09 combination CDF and DØ excluded at 95% C.L. a Standard Model Higgs boson with a mass in the range $160 < M_H < 170$ GeV/c^2.

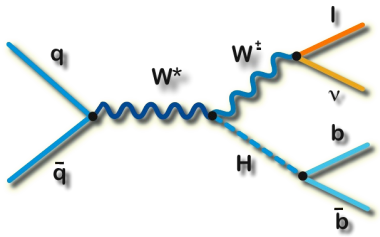
- More interesting results to come:
  - the Tevatron collider is expected to deliver ~12 fb^{-1} by 2011;
  - experiments' sensitivity continue to improve faster than luminosity scaling.

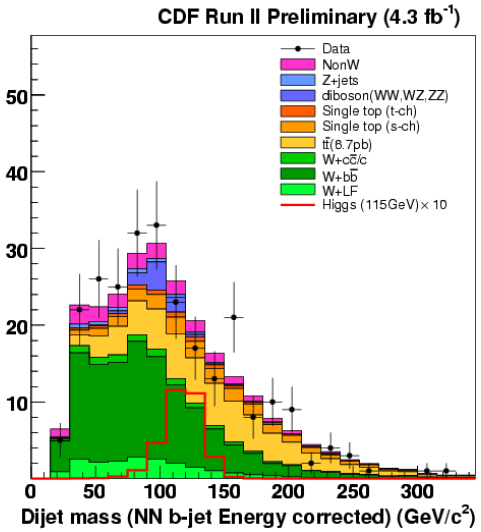
Back-up slides

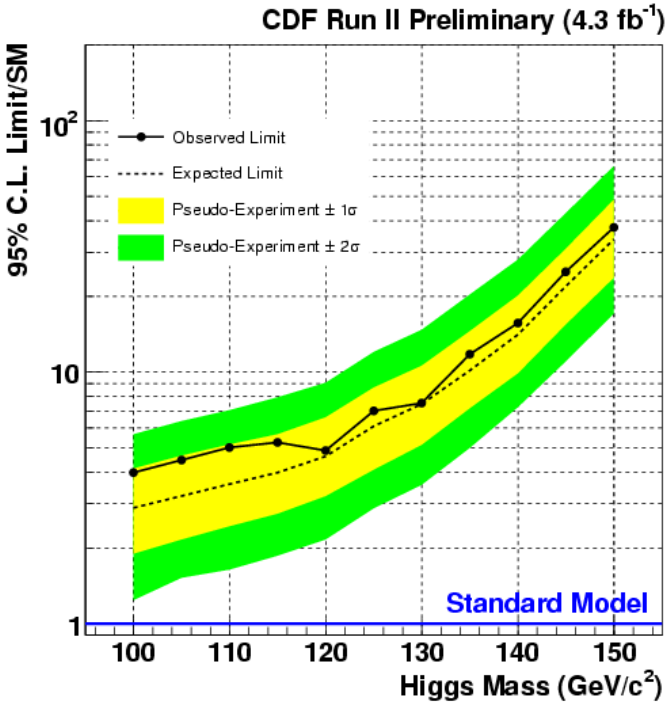
$WH \to \ell \nu b\bar{b}$

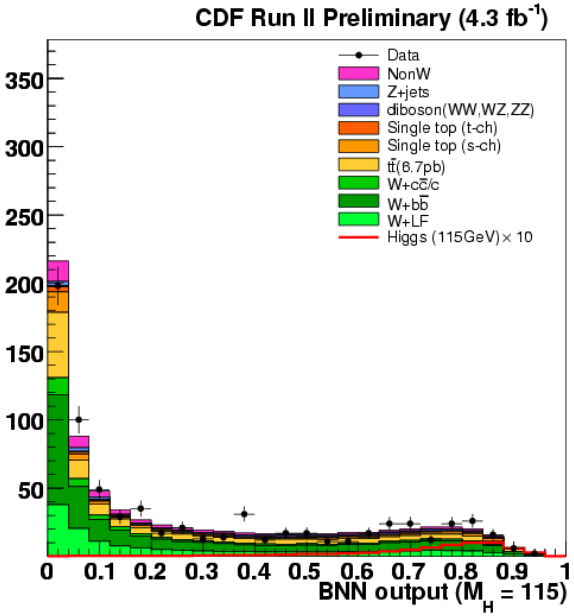
- Exp. signature: 1 lepton [ℓ=e,μ] + missing E_T + 2 jets.
- Analysis technique:
  - Central leptons, forward electrons, isolated tracks.
  - new NN b-jet energy correction;
  - four b-tag categories (new NN b-tag);
  - NN to discriminate signal from bkg.

4.3 fb^{-1}









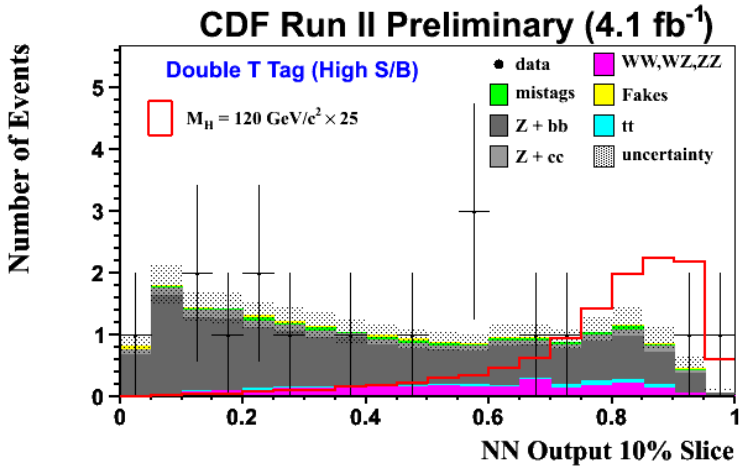
channel	Double tag
Mistag	151
W + bb	249
Z + cc/c	44
tt	141
single t	60
WW,WZ,ZZ	23
Z + jets	15
non-W QCD	59
WH (M_H=115)	7
Tot bkg	742
data	726

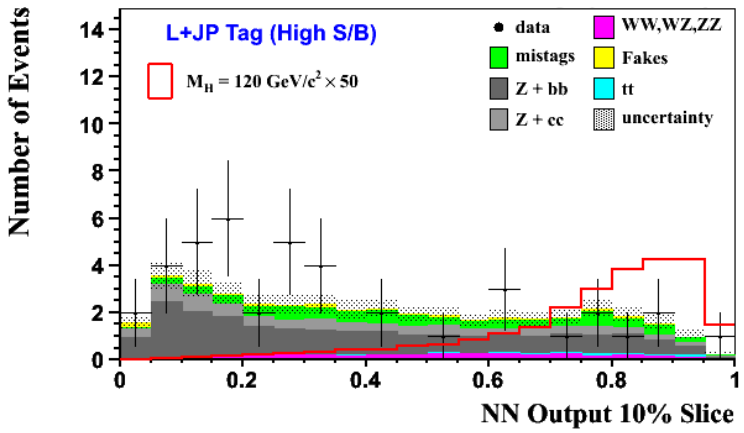
For M_H = 115 GeV/c^2:

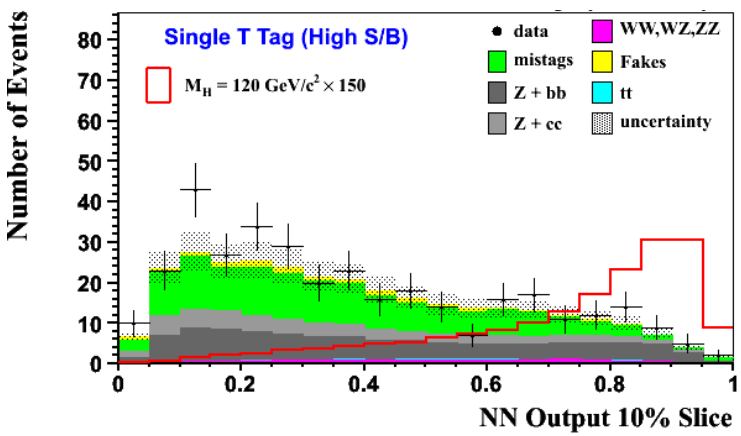
- expected limit = 4.0 $\times$ σ_{SM}
- observed limit = 5.3 $\times$ σ_{SM}

http://www-cdf.fnal.gov/physics/new/hdg/results/whlnubb_090814/WH4.3fb.html

$Z \to \ell^+\ell^- b\bar{b}$







4.1 fb^{-1}

(High S/B Categories)

Source	Double T Tag	L+JP Tag	Single T Tag
tt	7.0 ± 1.5	8.1 ± 1.9	17.3 ± 3.6
WW	0.02 ± 0.003	0.1 ± 0.01	0.2 ± 0.03
WZ	0.1 ± 0.01	0.5 ± 0.1	4.8 ± 0.7
ZZ	2.7 ± 0.4	3.4 ± 0.6	11.1 ± 1.5
Z+jets (bb)	16.1 ± 6.8	21.5 ± 9.2	105.4 ± 44.3
Z+jets (cc)	1.8 ± 0.7	8.0 ± 3.3	53.7 ± 22.6
Z+Mistags	0.9 ± 0.3	9.4 ± 3.2	151.6 ± 22.7
fakes	0.7 ± 0.3	1.8 ± 0.9	22.0 ± 11.0
ZH ($120\,\mathrm{GeV}/c^2$)	0.5 ± 0.1	0.6 ± 0.1	1.4 ± 0.1
Total Background	29.3 ± 7.0	52.8 ± 10.5	366.1 ± 55.9
Data	23	56	406

systematic uncertainty		Samples affected
Tevatron Luminosity	0.05	All MC
CDF Luminosity	0.04	All MC
Z+h.f cross-section	0.40	$Z+bb$, $Z+cc$
$t\bar{t}$ cross-section	0.20	$t\bar{t}$
Diboson cross-sections	0.115	ZZ, ZW, WW
Mistag errors	NN Output Shape & Acceptance	Mistags
Lepton ID	0.01	All MC
B-tag scale factor	0.04	All single tag MC
	0.08	All double SecVtx tag MC
	0.11	All Loose + JP tag MC
Fakes	0.50	Fake ee, $\mu\mu$
JES	NN Output Shape & Acceptance	All MC
ISR & FSR	NN Output Shape & Acceptance	Signal MC
ZH cross-section	0.05	ZH MC
EM energy scale	0.015	All MC

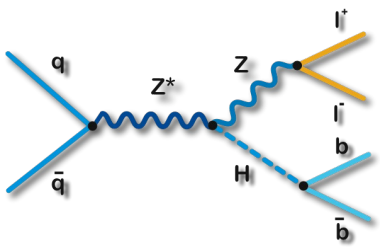
Expected and Observed 95% CL Upper Limits for Individual Channels @ $M_H = 115\,\mathrm{GeV}/c^2$

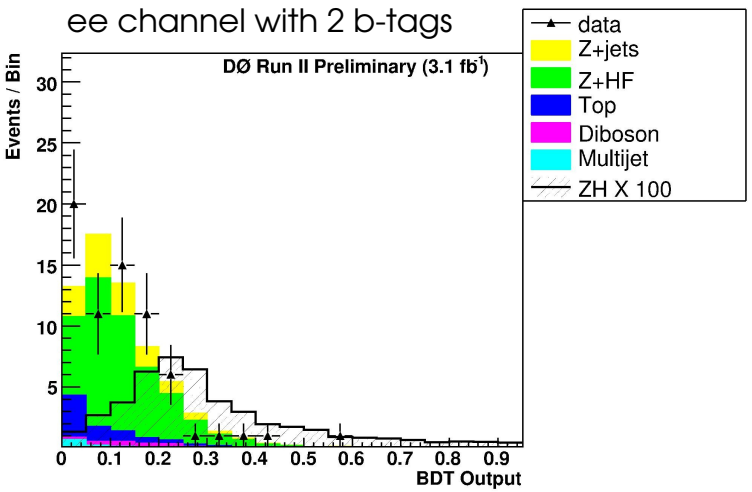
Channel	Data	Background	$S/\sqrt{B}$	Expected$^{+1\sigma}_{-1\sigma}$	Observed
Double Tag High S/B	23	29.3 ± 7.0	0.13	$12.1\ ^{+5.7}_{-5.5}$	11.3
L+JP Tag High S/B	56	52.8 ± 10.5	0.09	$15.98\ ^{+6.95}_{-7.6}$	10.6
Single Tag High S/B	406	366.1 ± 55.9	0.09	$15.5\ ^{+7.1}_{-7.98}$	16.9
Double Tag Low S/B	12	8.7 ± 1.7	0.04	$49.2\ ^{+18.95}_{-19.9}$	58.2
L+JP Tag Low S/B	14	14.3 ± 2.4	0.03	$50.6\ ^{+21.6}_{-21.99}$	71.1
Single Tag Low S/B	116	116.8 ± 17.0	0.02	$41.6\ ^{+19.99}_{-20.04}$	38.5
Combined				$6.8\ ^{+3.22}_{-2.04}$	5.91

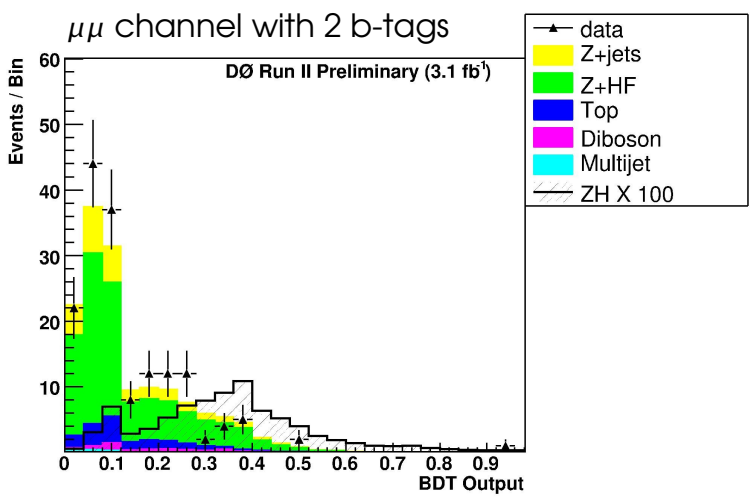
$ZH \rightarrow \ell^+\ell^- b\bar{b}$

4.2 fb^{-1}

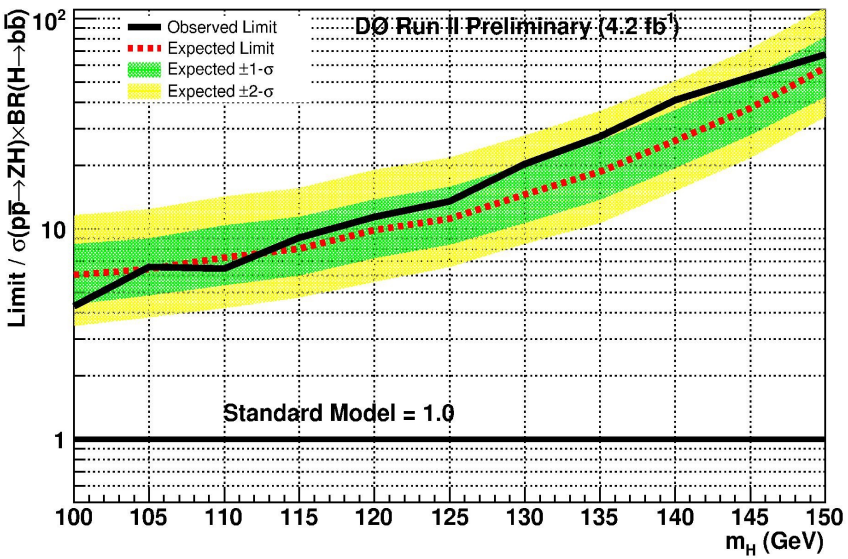
- Event selection: 2 leptons [ℓ=e,μ] + 2 jets.
- Analysis technique:
  - looser electron and muon categories;
  - 1 tight b-tagged jet or 2 loose b-tagged jets (NN b-tagging);
  - kinematic fit of the Z boson and jets;
  - BDT to discriminate signal from bkgs.







channel	$\mu\mu$	ee
tt	16	9
WW,WZ,ZZ	5	3
Z + bb/cc	99	68
Z + jets	27	22
multijet	2	17
ZH (M_H=115)	0.9	0.7
Tot bkg	149	119
data	161	131

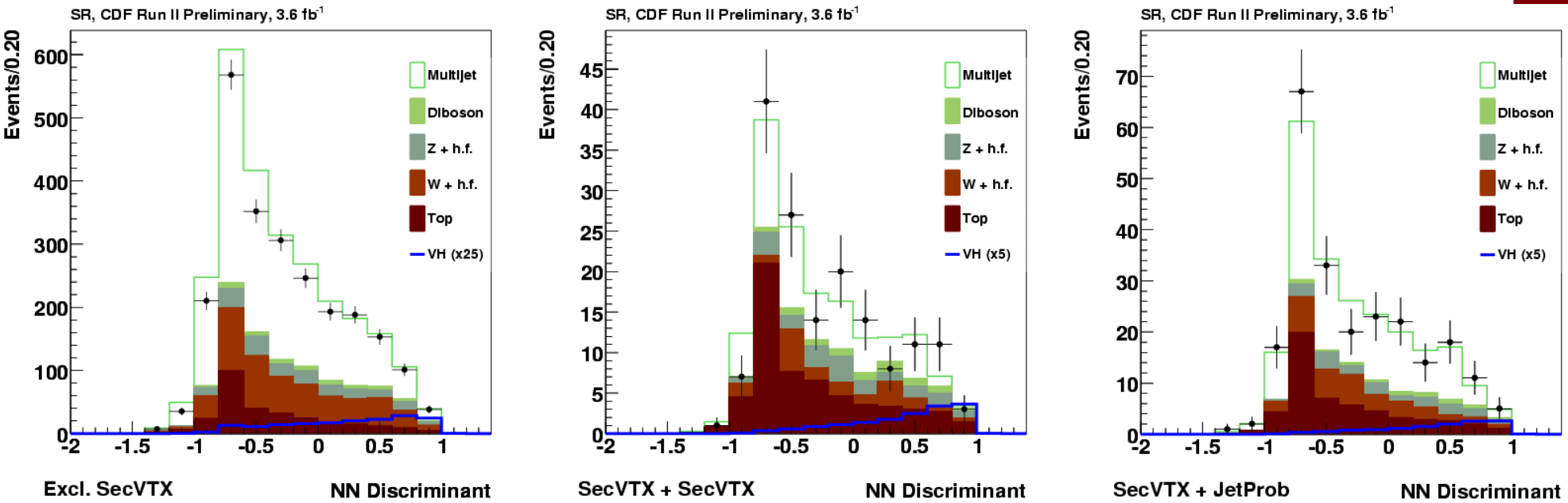


For M_H = 115 GeV/c^2:
- expected limit = 8.0 $\times\ \sigma_{SM}$
- observed limit = 9.1 $\times\ \sigma_{SM}$

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H71/

$ZH \to \nu\nu b\bar{b}$ and $WH \to (\ell)\nu b\bar{b}$

3.6 fb^{-1}

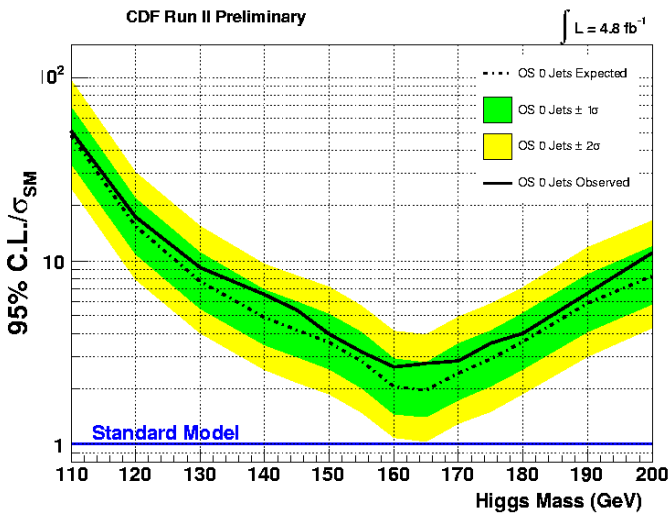


CDF Run II Preliminary, 3.6 fb^{-1}

Process	Excl. ST	ST+ST	ST+JP
QCD + Mistags	1593 ± 63	55 ± 9	120 ± 14
Single Top	73 ± 13	14 ± 3	11 ± 2
Top Pair	209 ± 25	45 ± 7	42 ± 5
Diboson	60 ± 11	8 ± 2	7 ± 2
W+H.F.	499 ± 216	18 ± 10	33 ± 15
Z+H.F.	180 ± 77	18 ± 8	18 ± 8
Exp. Background	2476 ± 300	166 ± 22	259 ± 28
Observed	2397	157	233
$ZH \to \nu\nu bb$ ($MH = 115$ GeV)	3.5	1.6	1.3
$WH \to (l)\nu bb$ ($MH = 115$ GeV)	3.1	1.4	1.2
$ZH \to (ll)bb$ ($MH = 115$ GeV)	0.1	0.1	0.1
Exp. Signal	6.7	3.1	2.6

$H \to WW^* \to \ell\nu\ell\nu$

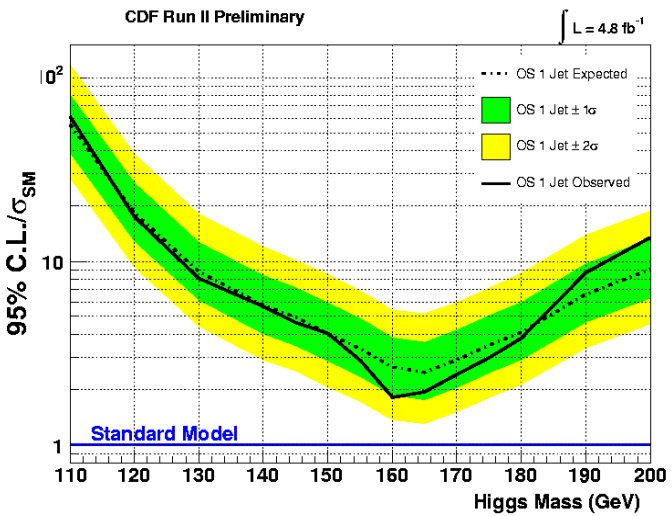
OS + 0 jet



CDF Run II Preliminary $\int \mathcal{L} = 4.8$ fb^{-1}			
$M_H = 165$ GeV/c^2			
$t\bar{t}$	1.99	$\pm$	0.31
DY	128	$\pm$	30
WW	447	$\pm$	48
WZ	19.7	$\pm$	2.7
ZZ	29.9	$\pm$	4.1
W+jets	154	$\pm$	37
$W\gamma$	112	$\pm$	19
Total Background	893	$\pm$	79
$gg \to H$	12.6	$\pm$	1.7
WH	0.00	$\pm$	0.00
ZH	0.00	$\pm$	0.00
VBF	0.00	$\pm$	0.00
Total Signal	12.6	$\pm$	1.7
Data	950		

OS 0 Jets

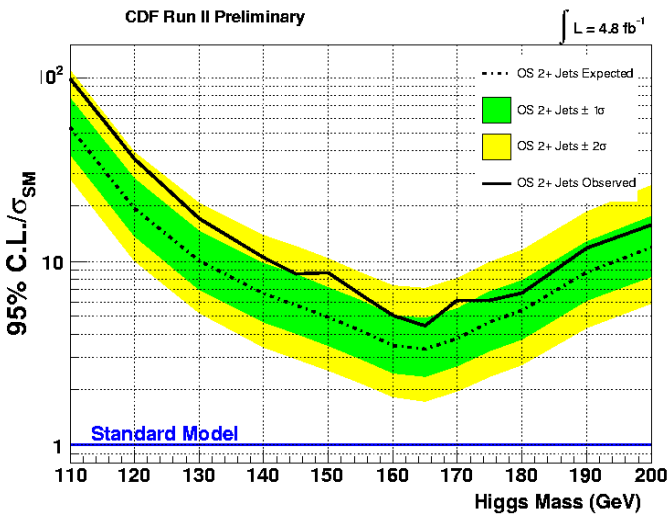
OS + 1 jet



CDF Run II Preliminary $\int \mathcal{L} = 4.8$ fb^{-1}			
$M_H = 165$ GeV/c^2			
$t\bar{t}$	48.4	$\pm$	7.6
DY	133	$\pm$	42
WW	121	$\pm$	13
WZ	20.0	$\pm$	2.7
ZZ	8.0	$\pm$	1.1
W+jets	59	$\pm$	15
$W\gamma$	16.2	$\pm$	3.6
Total Background	406	$\pm$	52
$gg \to H$	6.4	$\pm$	1.7
WH	0.87	$\pm$	0.11
ZH	0.339	$\pm$	0.044
VBF	0.565	$\pm$	0.090
Total Signal	8.2	$\pm$	1.7
Data	393		

OS 1 Jet

OS + >2 jets

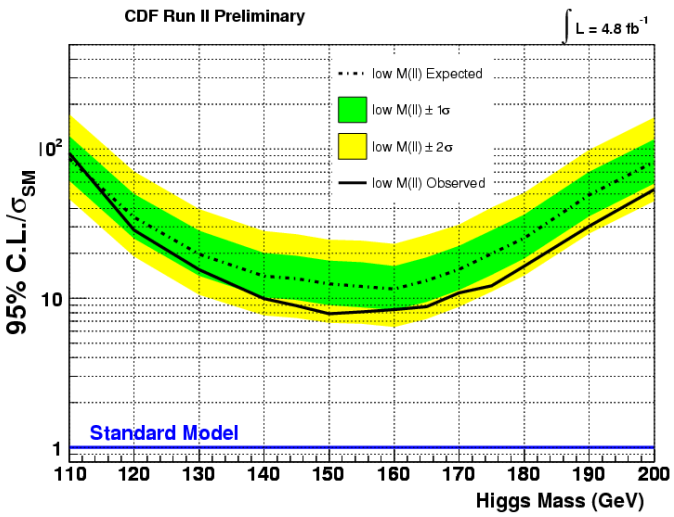


CDF Run II Preliminary $\int \mathcal{L} = 4.8$ fb^{-1}			
$M_H = 165$ GeV/c^2			
$t\bar{t}$	145	$\pm$	24
DY	51	$\pm$	17
WW	25.6	$\pm$	5.8
WZ	5.30	$\pm$	0.73
ZZ	2.36	$\pm$	0.32
W+jets	21.9	$\pm$	5.9
$W\gamma$	2.72	$\pm$	0.67
Total Background	254	$\pm$	33
$gg \to H$	2.5	$\pm$	1.7
WH	1.90	$\pm$	0.25
ZH	0.99	$\pm$	0.13
VBF	1.04	$\pm$	0.17
Total Signal	6.4	$\pm$	1.8
Data	224		

OS 2+ Jets

$H \to WW^* \to \ell\nu\ell\nu$

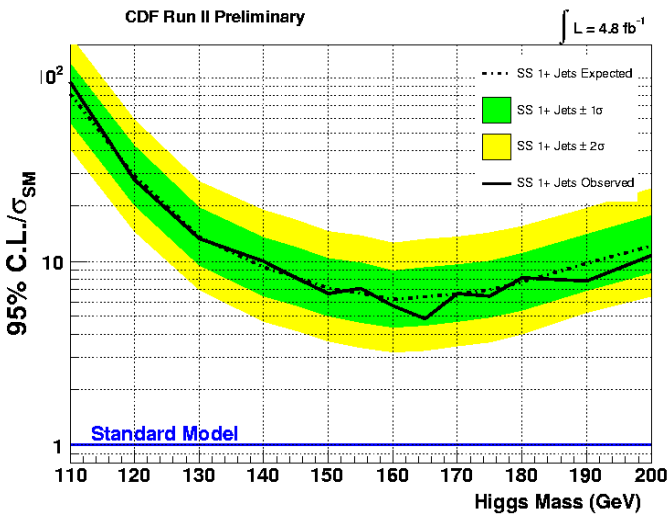
OS low $M_{\ell\ell}$



CDF Run II Preliminary	$\int \mathcal{L} = 4.8$ fb^{-1}		
$M_H = 165$ GeV/c^2			
$t\bar{t}$	0.330	$\pm$	0.052
DY	3.56	$\pm$	0.85
WW	10.9	$\pm$	1.3
WZ	0.284	$\pm$	0.041
ZZ	0.107	$\pm$	0.015
W+jets	9.9	$\pm$	2.4
$W\gamma$	55.9	$\pm$	6.7
Total Background	80.9	$\pm$	7.3
$gg \to H$	0.75	$\pm$	0.12
Total Signal	0.75	$\pm$	0.12
Data	85		

OS low M(ll)

SS + >1 jet

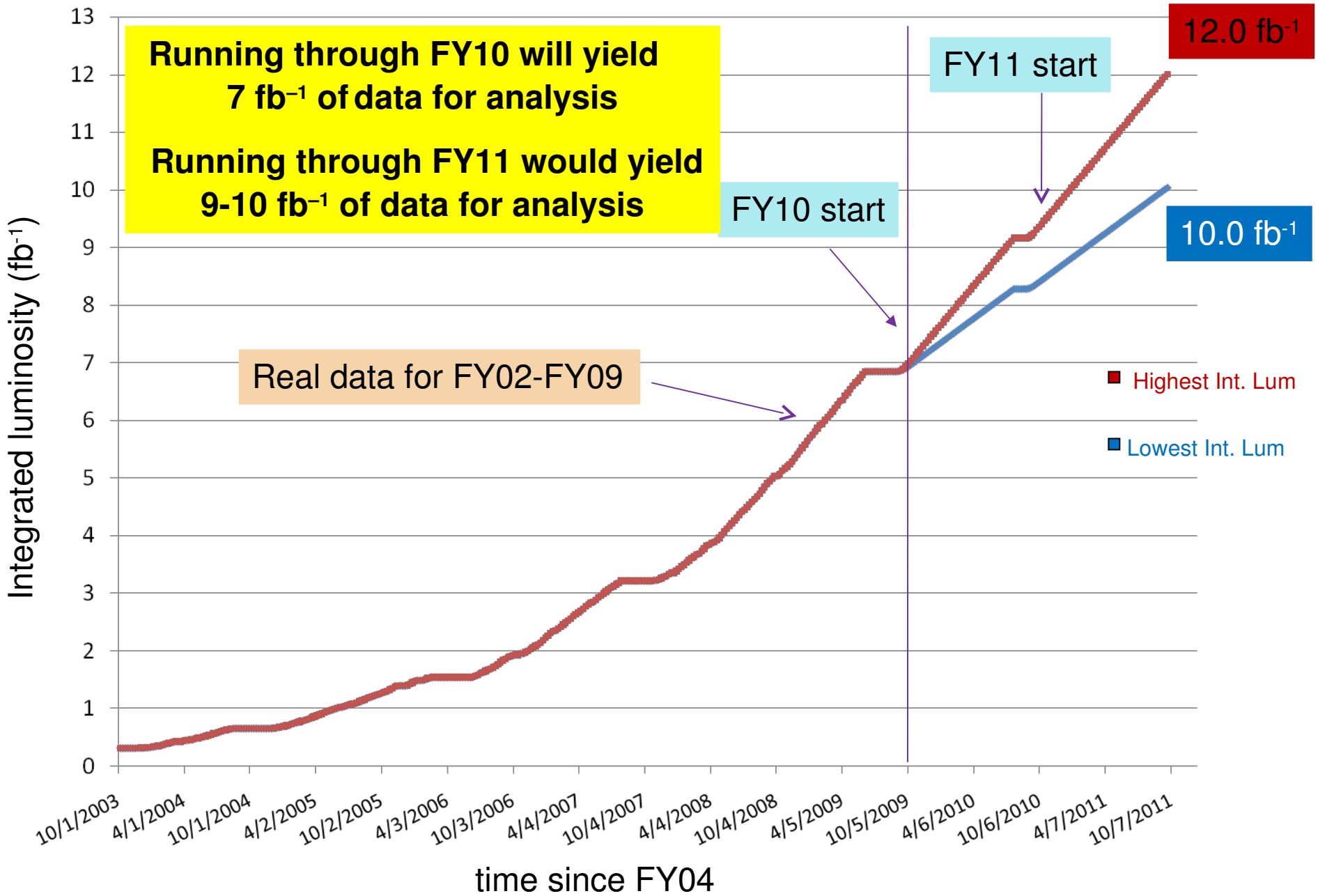


CDF Run II Preliminary	$\int \mathcal{L} = 4.8$ fb^{-1}		
$M_H = 165$ GeV/c^2			
$t\bar{t}$	0.242	$\pm$	0.068
DY	26.7	$\pm$	8.1
WW	0.039	$\pm$	0.010
WZ	9.5	$\pm$	1.3
ZZ	1.98	$\pm$	0.27
W+jets	34	$\pm$	10
$W\gamma$	4.34	$\pm$	0.99
Total Background	76	$\pm$	13
WH	1.61	$\pm$	0.21
ZH	0.261	$\pm$	0.034
Total Signal	1.87	$\pm$	0.24
Data	81		

SS 1+ Jets

$H \to WW^* \to \ell\nu\ell\nu$

- An example of systematics for the OS + 0 jet channel:

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet(s)	$gg \to H$
Cross Section								
Scale								7.0
PDF Model								7.7
Total	*6.0*	*6.0*	*6.0*	10.0	5.0			10.4
Acceptance								
Scale (leptons)								2.5
Scale (jets)								4.6
PDF Model (leptons)	1.9	2.7	2.7	2.1	4.1			1.5
PDF Model (jets)								0.9
Higher-order Diagrams	*5.0*	*10.0*	*10.0*	10.0		11.0		
Missing Et Modeling					21.0			
$W\gamma$ Scaling						12.0		
Jet Fake Rates (Low/High S/B)							21.5/27.7	
Jet Modeling	-1.0					*-4.0*		
MC Run Dependence	2.8							
Lepton ID Efficiencies	2.0	1.7	2.0	2.0	1.9			1.9
Trigger Efficiencies	2.1	2.1	2.1	2.0	3.4			3.3
Luminosity	5.9	5.9	5.9	5.9	5.9			5.9

Luminosity projection curves for Run II