Higgs Searches at the Tevatron

Jianming Qian
University of Michigan

On behalf of CDF and DØ Collaboration

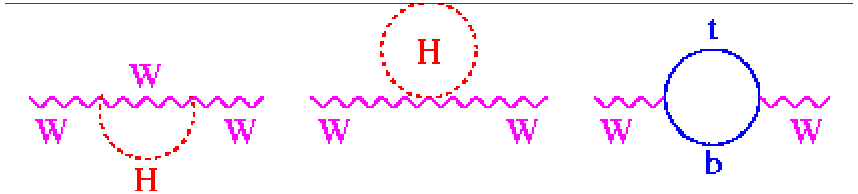
~~Physics at LHC - 2008~~
Physics at Tevatron and LHC - 2008
Split, Croatia

What do we know

Direct searches at LEP:

$m_H > 114$ GeV @ 95% CL

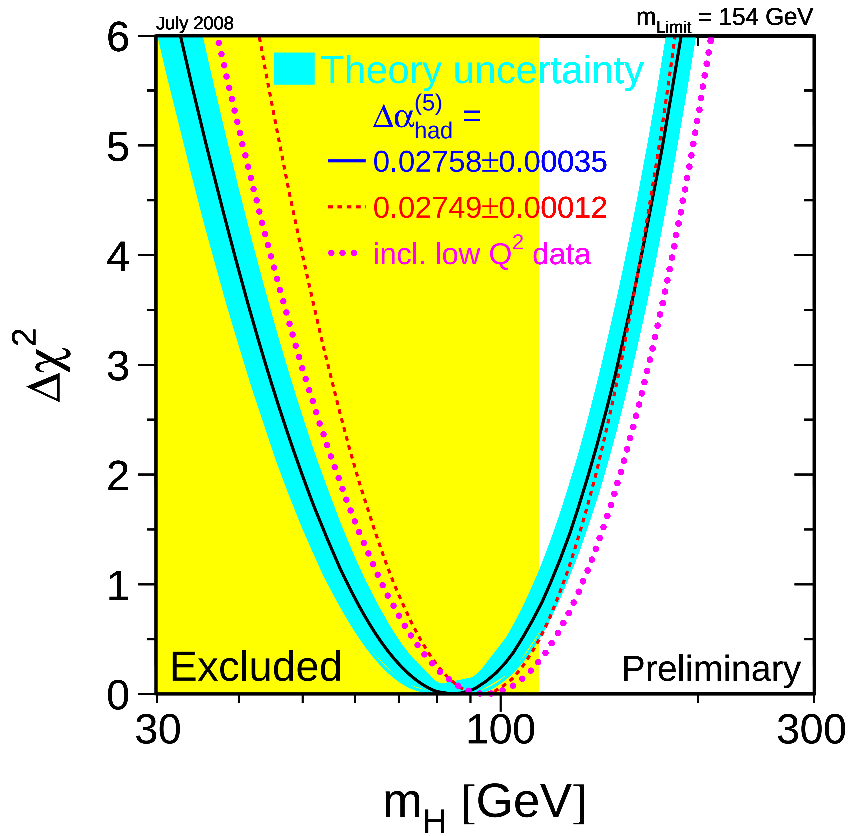
Precision electroweak data are sensitive to Higgs mass



Indirect limit from global fit:

$m_H < 154$ GeV @ 95% CL

(July 2008)



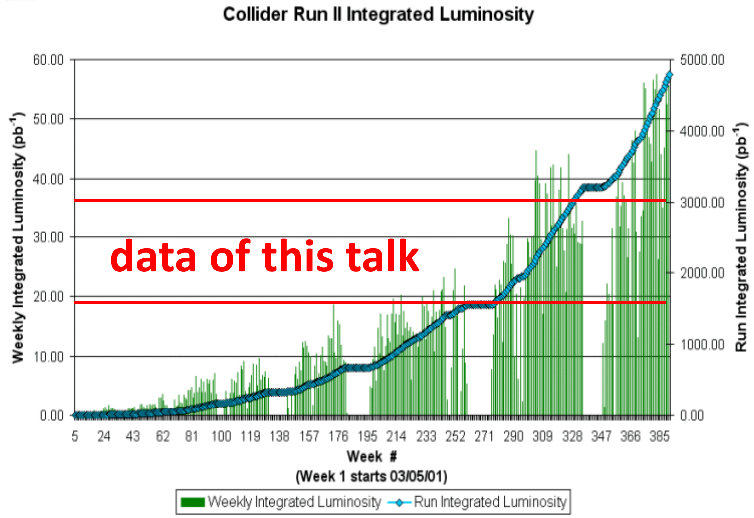
Existing data suggests a low mass standard model Higgs
⇒ good news for the Tevatron…

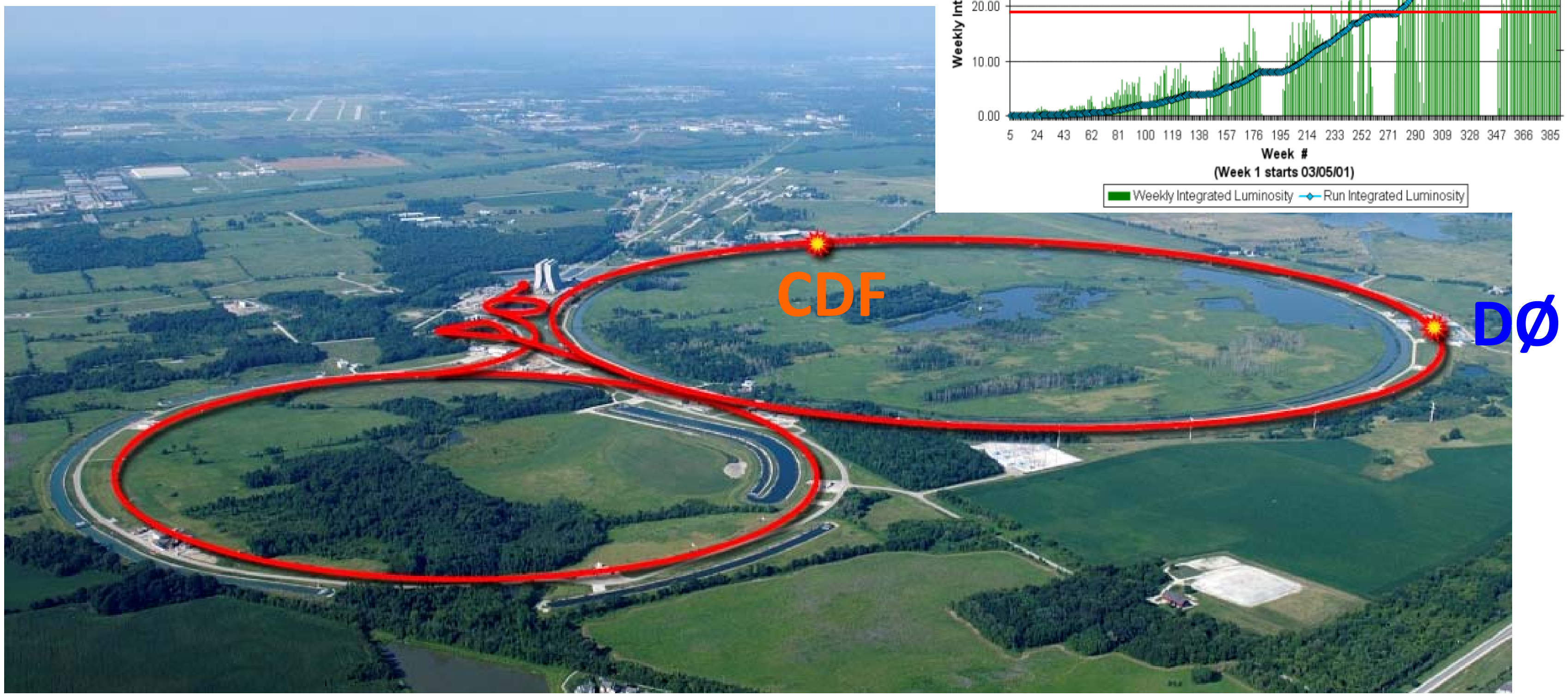
Tevatron Collider

$p\bar{p}$ collider with $\sqrt{s} = 1.96$ TeV

Running well…

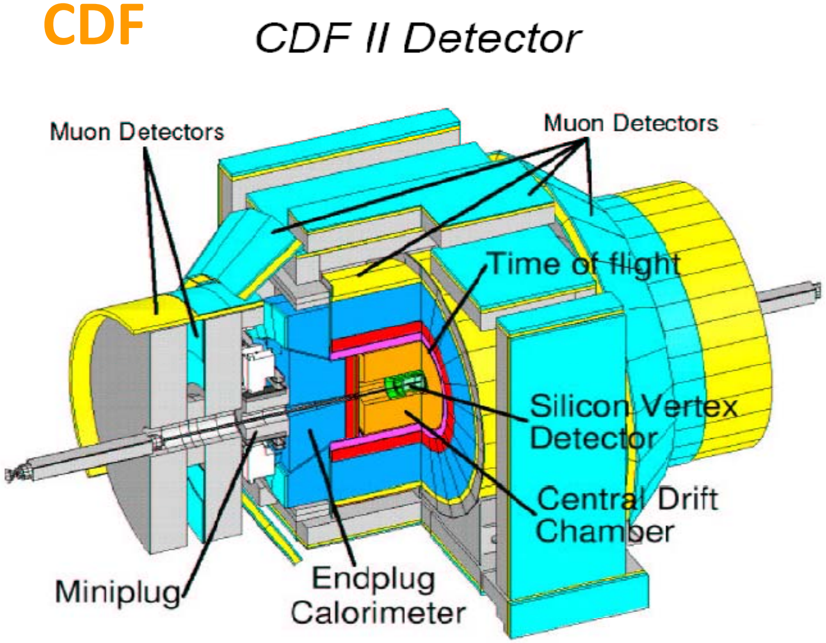
- surpassed design instantaneous luminosity
- delivered over 5 fb^{-1} to each experiment



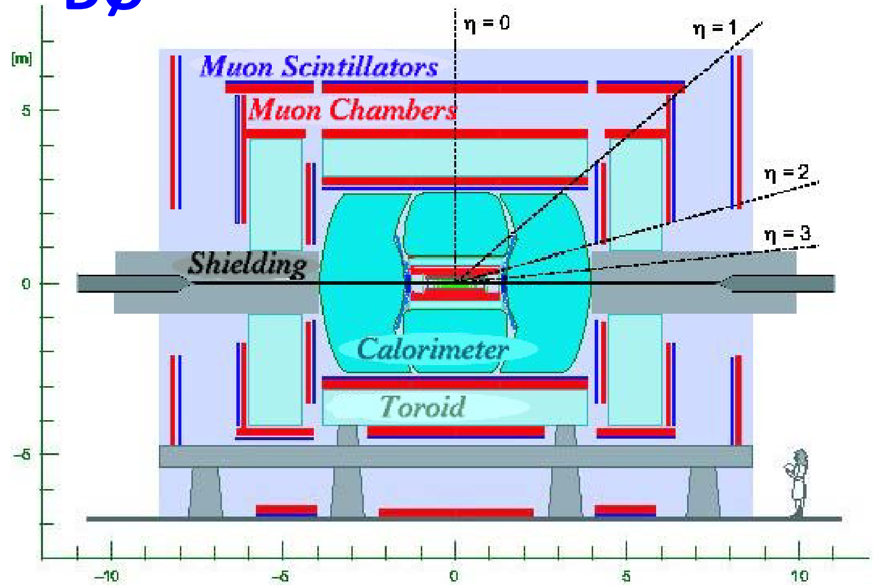


The Detectors

CDF



DØ



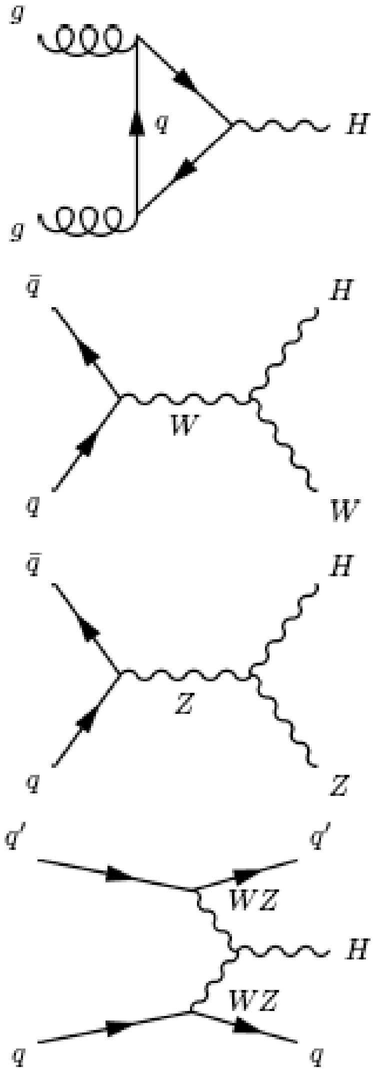
Large tracking volume
Vertex trigger
Large trigger bandwidth
….

Compact tracker,
Large muon coverage
….

Run IIa: 1.3 fb^{-1}, Run IIb: ongoing

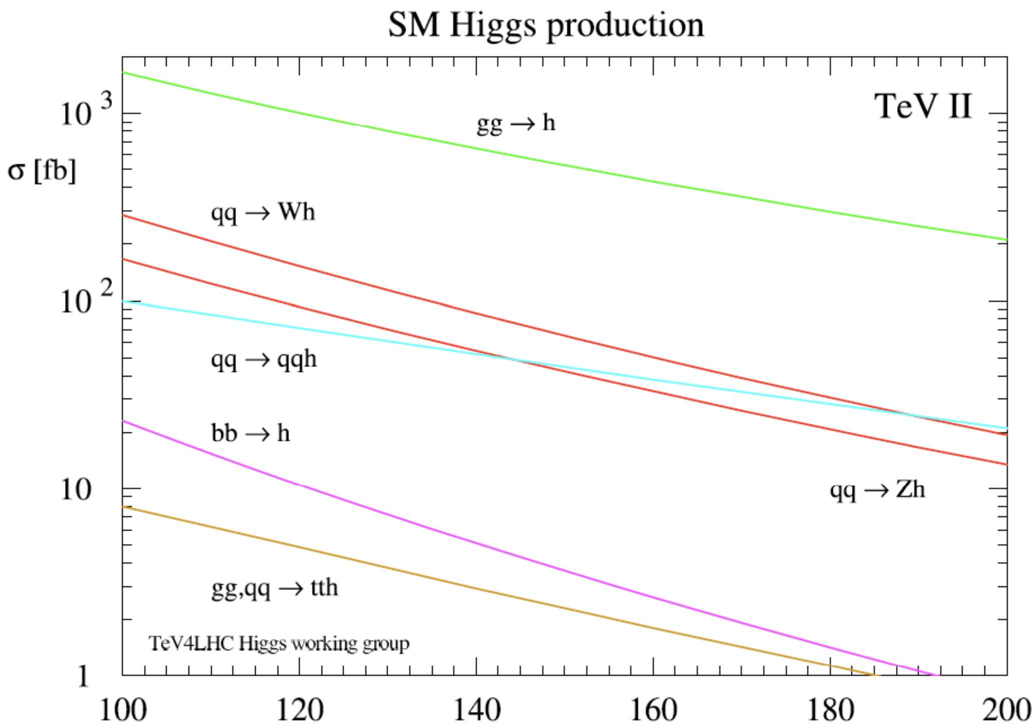
Two “small” detectors, one big dream…

Higgs Production

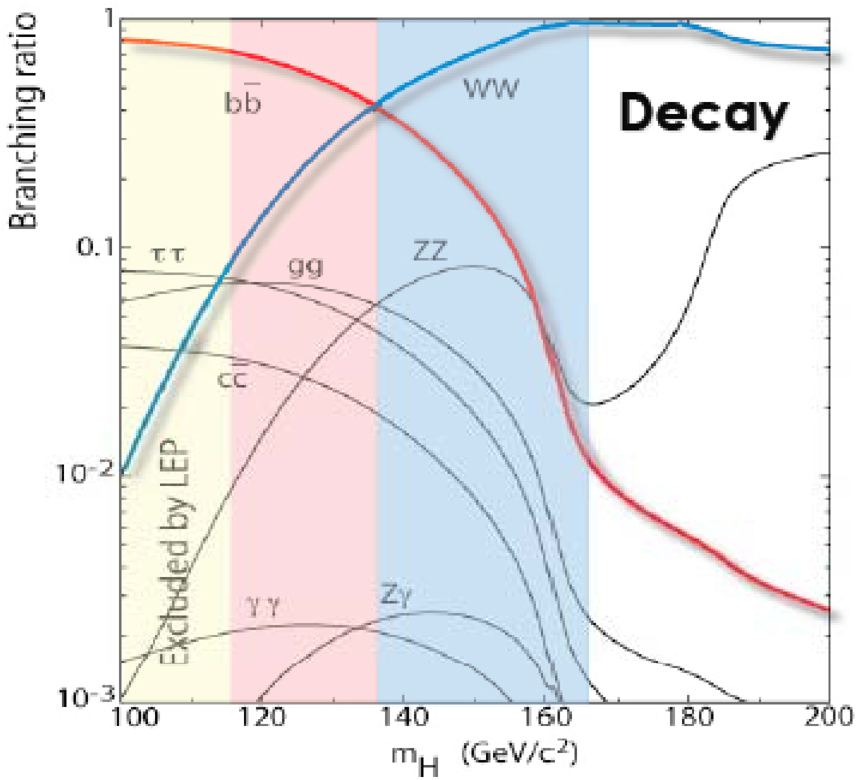


- dominated by gg→H,
- sizeable contributions from WH/ZH
- use all contributions in analyses

$$\sigma\left(p\bar{p} \rightarrow H+X\right) \approx 1\,\text{pb} @ 115\,\text{GeV}$$



Higgs Decay



to anything one can think of, but dominantly to …

- low mass (< ~135 GeV)

  $H \to b\bar{b}$

- high mass (> ~135 GeV)

  $H \to WW^*$

for the mass region of interest at Tevatron

$Br(H \to b\bar{b}) = 73\%$ @ M_H=115 GeV

$Br(H \to WW) = 90\%$ @ M_H=160 GeV

Most sensitive searches

low mass

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

high mass

$(gg \to)H \to WW^* \to \ell\ell$

Search Strategy

We know everything about Higgs… or do we ?

We seem to know more about its mass, but unsure whether it exists!

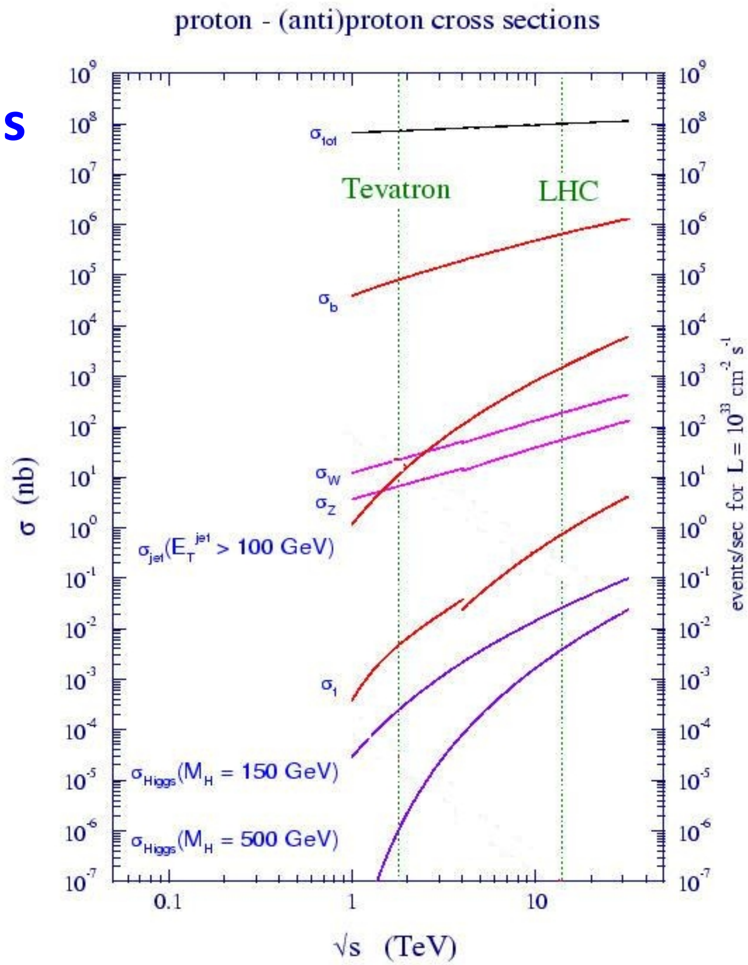
We have knowns and we have unknowns

- **take advantage of the knowns**

  huge backgrounds, extensive application of advanced analysis techniques to find phase space regions with good signal-background separation

  - **Neural Network (NN),**
  - **Boosted Decision Tree (BDT),**
  - **Matrix Element (ME)**
    - **often as an input to NN or BDT**

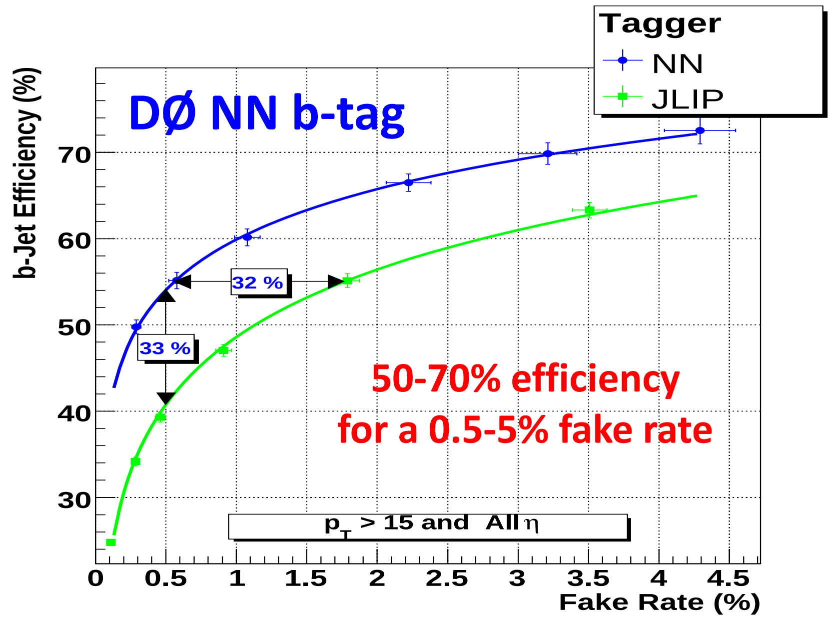
- **and cover the unknowns…**

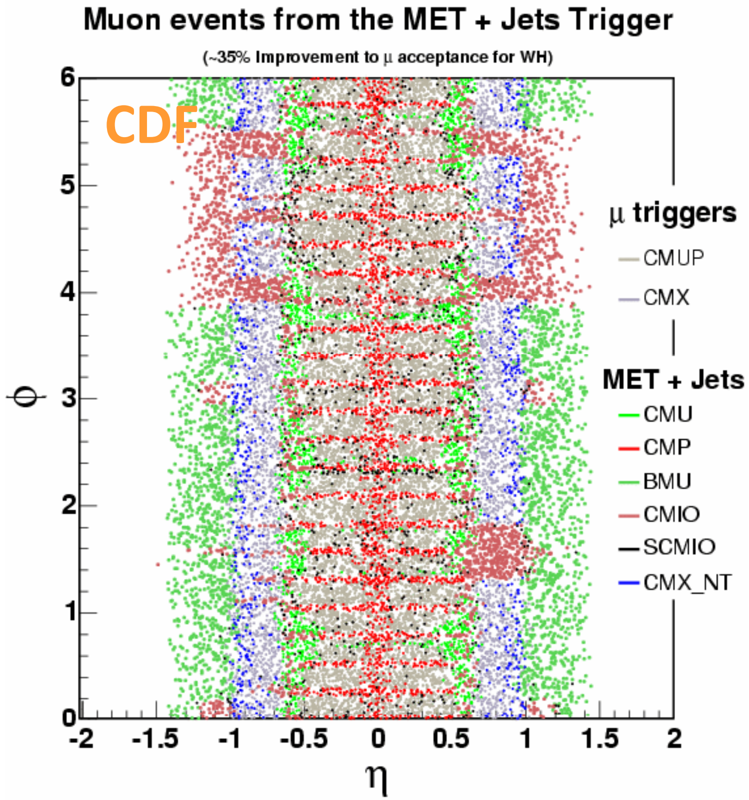


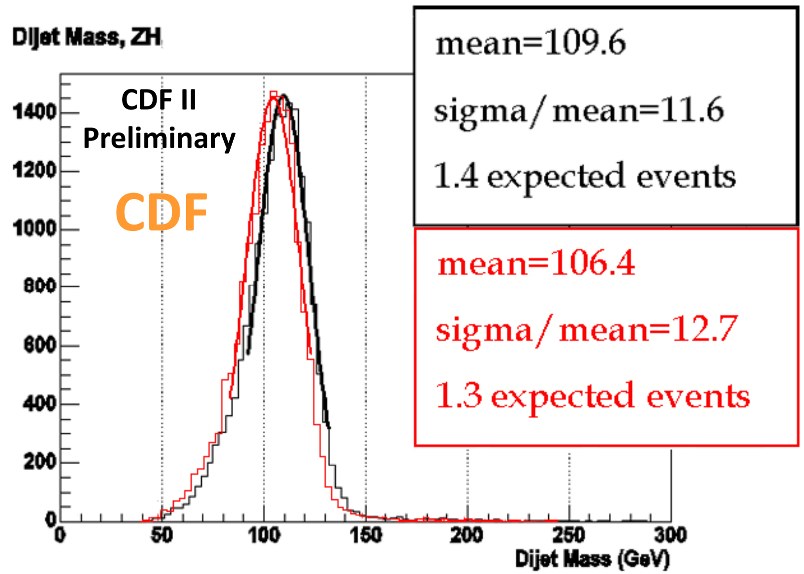
Some Key Issues

For most analyses:

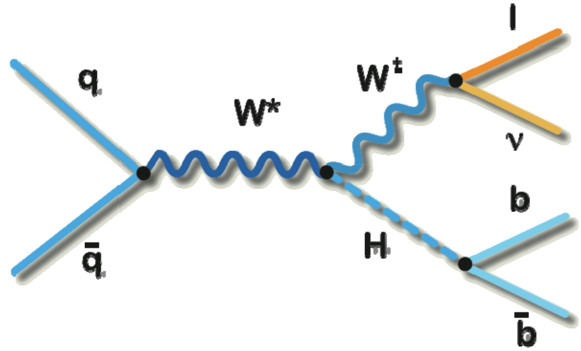
- event selection efficiency
- b-tagging performance
- dijet mass resolution







$WH \to l\nu bb$



$$\sigma\left(WH \to \ell\nu b\bar{b}\right) \approx 30\text{ fb}$$
$$\left(\ell = e,\ \mu;\ \mathrm{M_H}=115\text{ GeV}\right)$$

Main backgrounds:

Wbb, Wcc, Wjj, $t\bar{t}$, multijets...

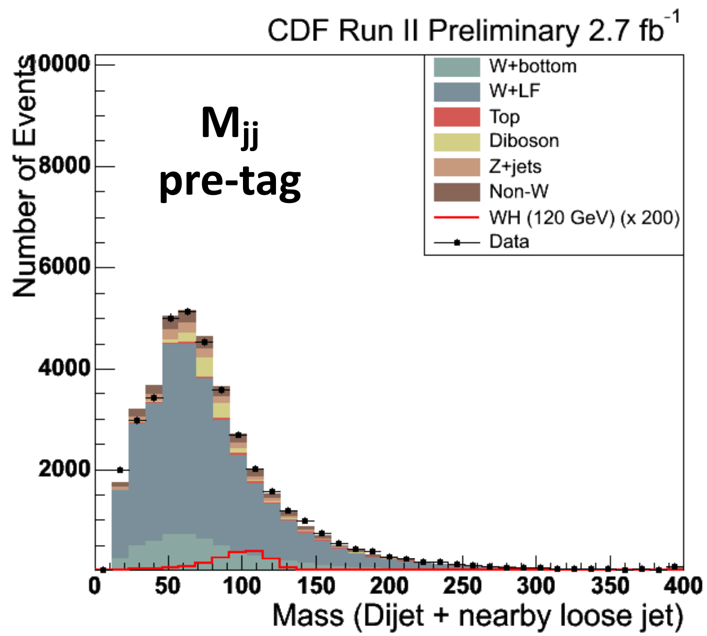
Data Modeling (DØ):

- Pythia for signal simulation
- Alpgen for W/Z+jets with MLM matching
- K-factor from MCFM for relative normalization
- pre-tagged data for validation and overall normalization

Event selection (CDF):

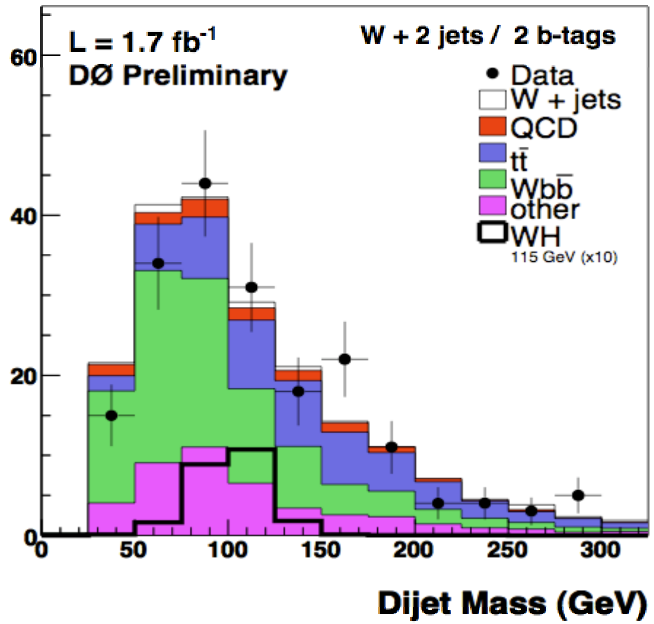
- one lepton with pT>20 GeV;
- missing Et > 20 GeV;
- two jets with pT>20 GeV;
- at least one b-tagged jet

large statistics pre-tagged sample as a control sample



WH→lνbb

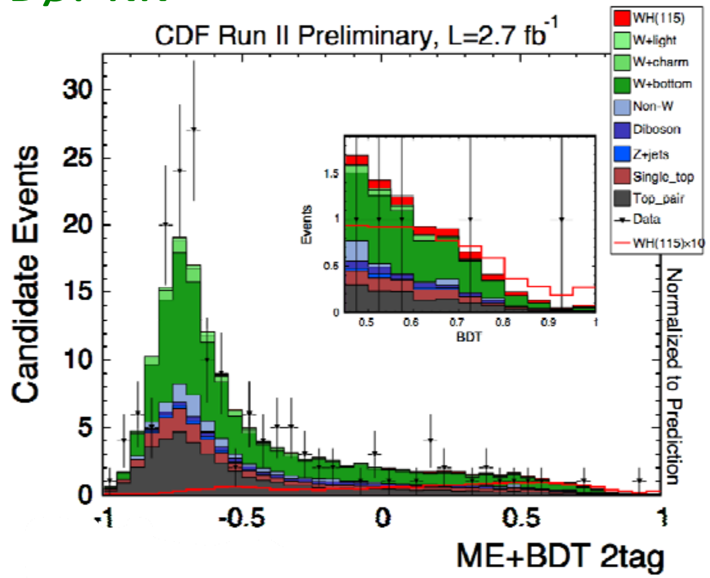
M_{bb} is the most sensitive variable



advanced techniques for further signal and background separation

CDF: NN and BDT with ME input

DØ: NN



Event yields (CDF)

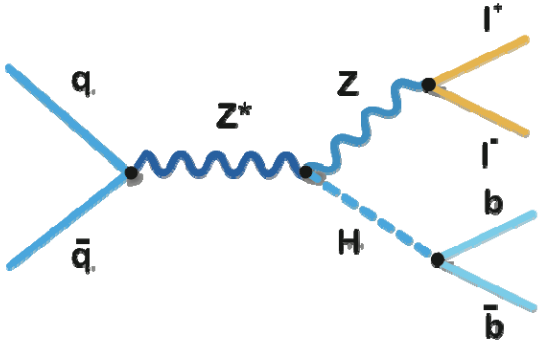
	Ndata	Nbkgd	Nsig
1-tag	1998	2013±324	6.3±0.5
2-tag	156	148±26	2.0±0.2

Selection efficiency ~ 10%

95% CL Limit/SM at M_H=115 GeV

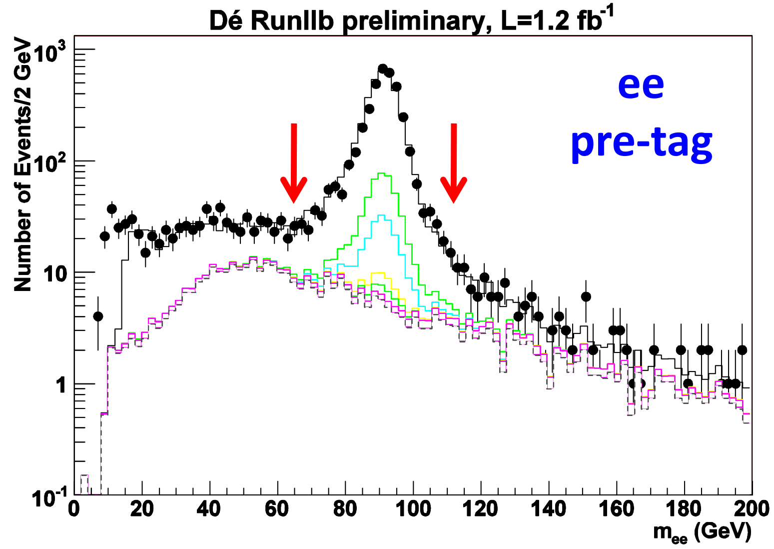
Analysis	Lumi (fb^{-1})	Exp.	Obs.
CDF BDT+ME	2.7	5.6	5.7
CDF NN	2.7	5.8	5.0
DØ	1.7	8.5	9.3

ZH→llbb



$$\sigma\left(ZH \rightarrow \ell\ell b\bar{b}\right) \approx 5 \text{ fb}$$

The cleanest final state, unfortunately the rate is really low.

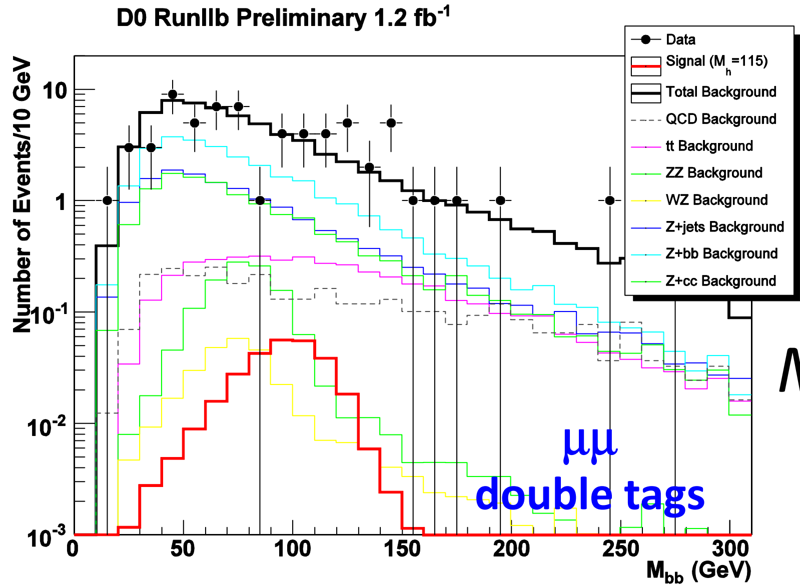


M_{ee}

DØ analysis:

- two leptons (consistent with from Z decays) plus two well-separated jets
- at least one b-tagged jet,
- uses NN and BDT for the ee and μμ channels respectively

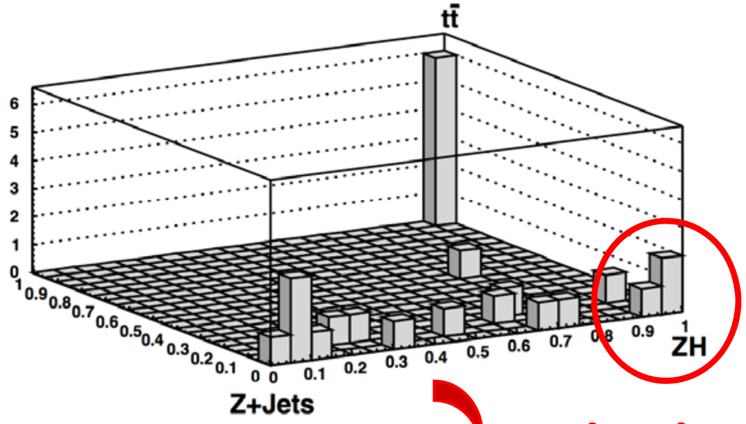
selection efficiency ~ 15%



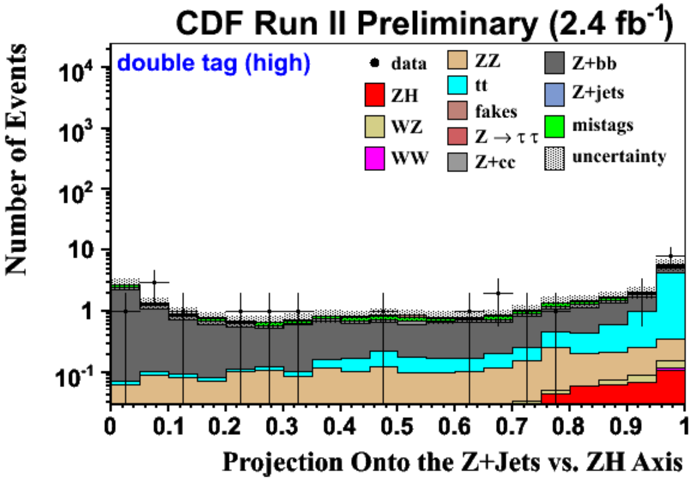
M_{jj}

$ZH \to llbb$

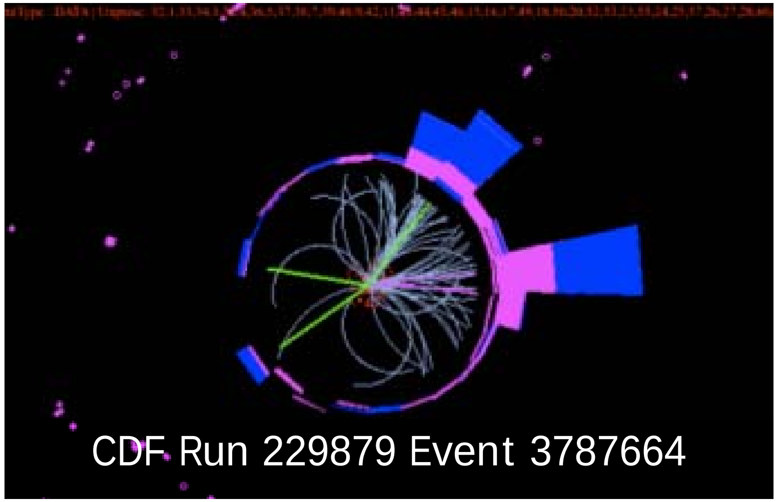
CDF uses a 2-D NN output to distinguish two main backgrounds (Z+jets, ttbar)



projection



A $ZH \to \ell\ell b\bar{b}$ candidate

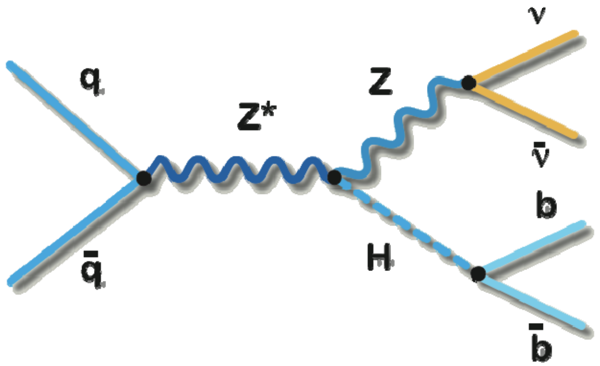


$M_{\mu\mu}$=93.5 GeV, M_{jj}=109.2 GeV

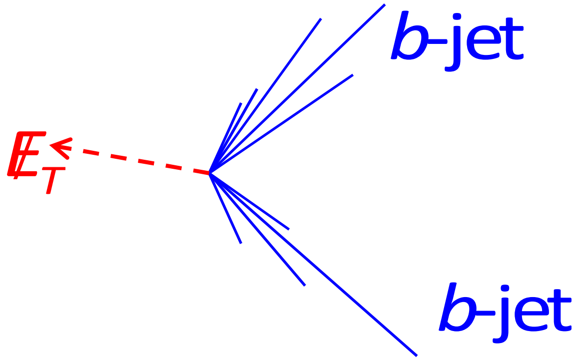
95% CL limit/SM, M_H=115 GeV

	Lumi (fb^{-1})	Nsig	Exp.	Obs.
CDF	2.4	1.8	11.8	11.6
DØ	2.3	2.0	12.3	11.0

ZH→ννbb



$$\sigma\left(ZH \to \nu\nu b\bar{b}\right) \approx 15\text{ fb}$$



No leptons, trigger on jets plus missing Et

Main backgrounds

- **multijets, W/Z+jets, ttbar, …**

Example selection (DØ)

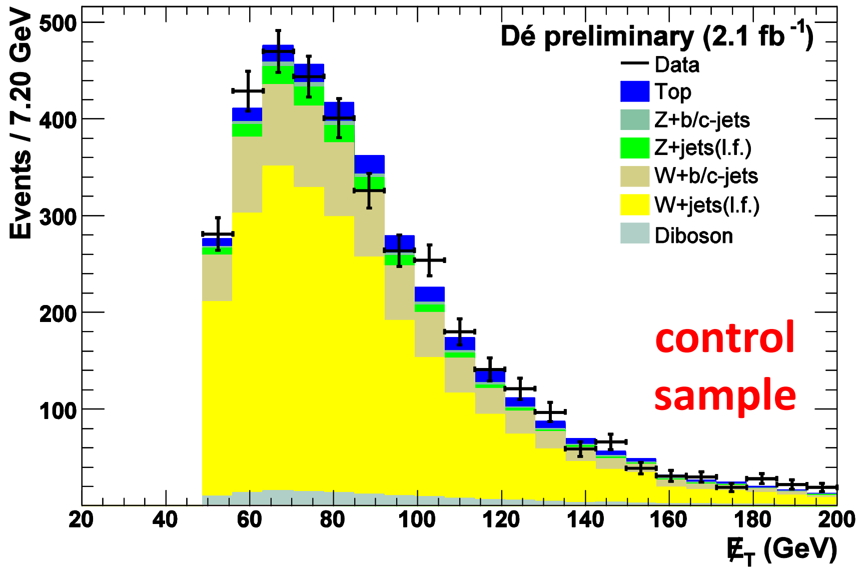
- **missing Et > 50 GeV**
- **2 or 3 jets with Et > 20 GeV**
- **topological cut to reduce multijets**
- **two b-tagged jets**

Efficiencies:

$ZH \to \nu\nu b\bar{b}$: ~ 7%

$WH \to \ell\nu b\bar{b}$: ~ 3%

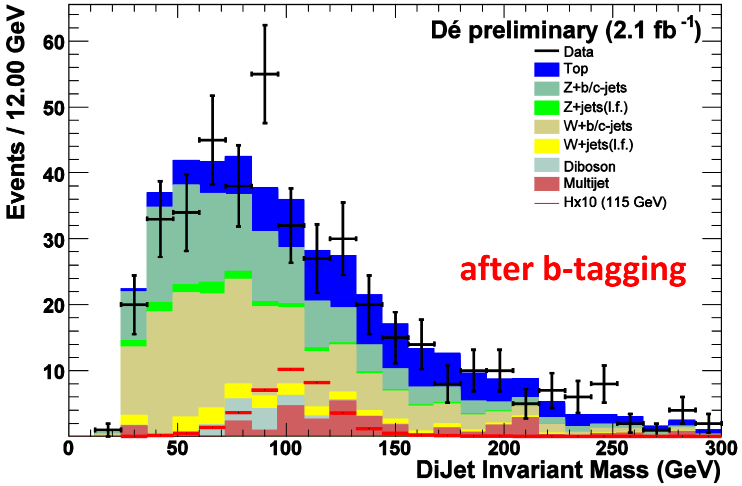
⇒ 50% contribution from each

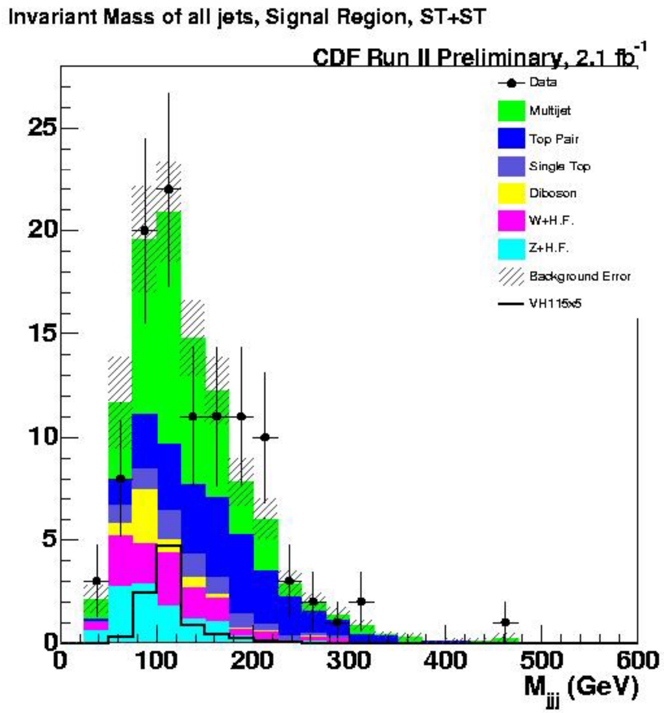


ZH→ννbb

Signal-background separation

NN for CDF and BDT for DØ





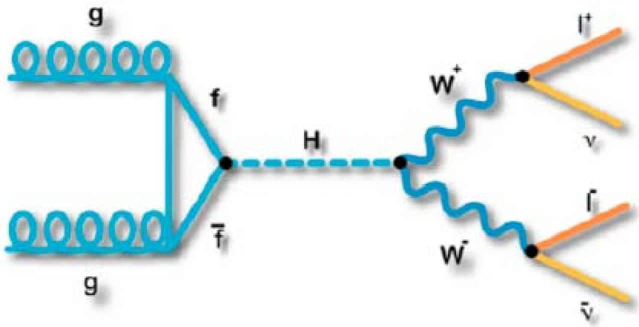
95% CL limit/SM for M_H=115 GeV

Analysis	Lum (fb^{-1})	ZH/WH	Nbkgd	Ndata	Exp.	Obs.
CDF NN	2.1	3.9/3.4	1780*	1696	6.3	7.9
DØ BDT	2.1	2.1/1.6	443	439	8.4	7.5

The analysis is as sensitive as the WH→lνbb analysis!

(* CDF also includes an analysis with exclusive one b-tag)

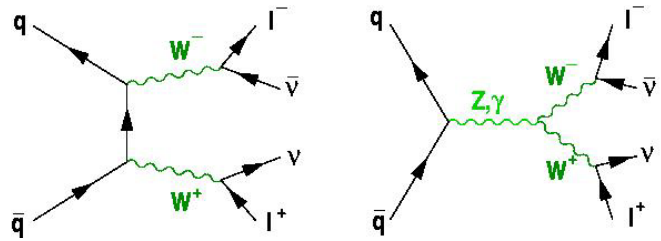
$H \to WW^* \to ll\nu\nu$



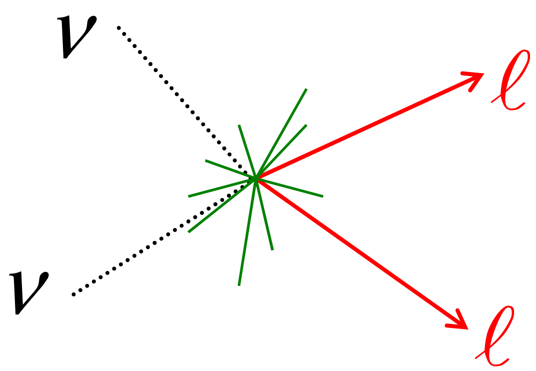
$$\sigma\left(H \to WW^* \to \ell\ell\nu\nu\right) \approx 20\text{ fb}$$

(M_H=170 GeV)

The SM WW is said to be "irreducible"

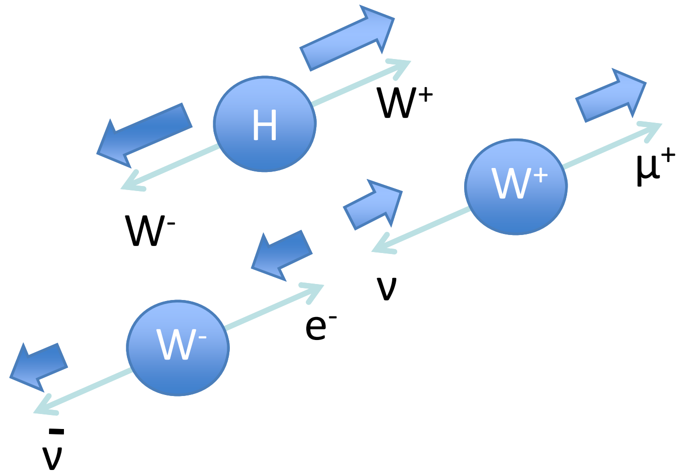


However, WW from the scalar Higgs is expected to have different kinematics



Main background:

WW, W+jets, $t\bar{t}$, Z,…

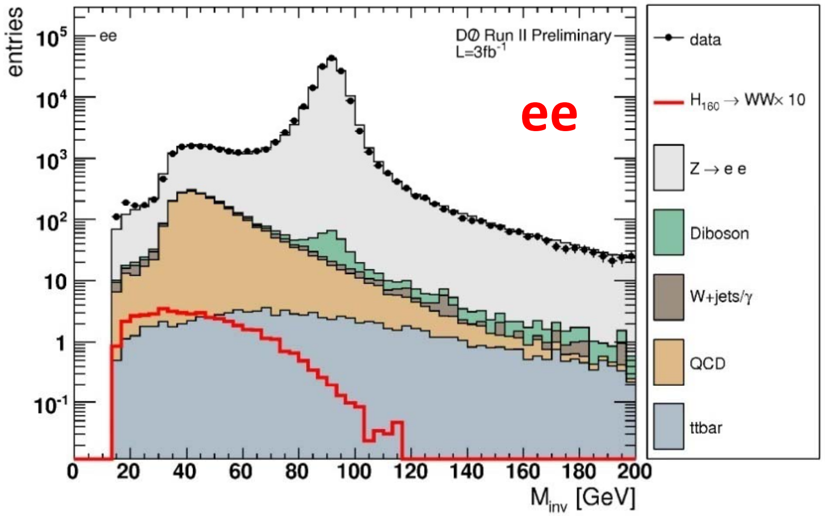


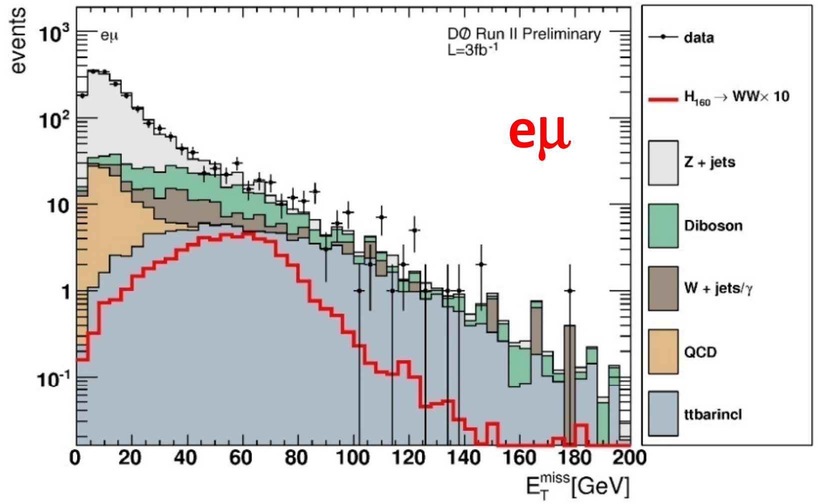
The spin correlation leads to a smaller average opening angle between the two leptons

DØ H→WW*

Event pre-selection:

- two leptons with pT(e)>15 GeV, pT(μ)>10 GeV and M(ll) > 15 GeV





Additional selection:

missing Et>20 GeV,
kinematic requirements (M_T, Δφ, …)

selection efficiency ~ 25%

Three separate NNs trained for every 5 GeV in the signal mass to determine the final sensitivities

Event yield before NN (M_H=160 GeV)

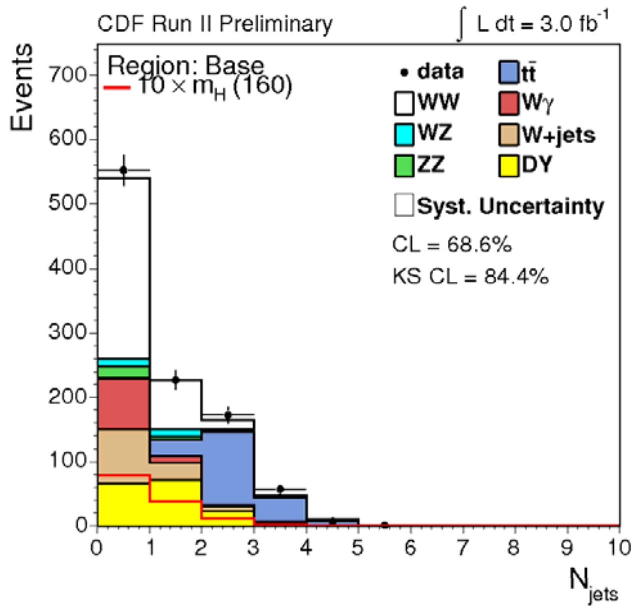
	Nsig	Nbkgd	Ndata
ee	3.5	238±11	236
μμ	4.1	1242±16*	1147
eμ	6.9	234±9	234

(* the large background is mostly due to the low pT(μ) cut)

CDF H→WW*

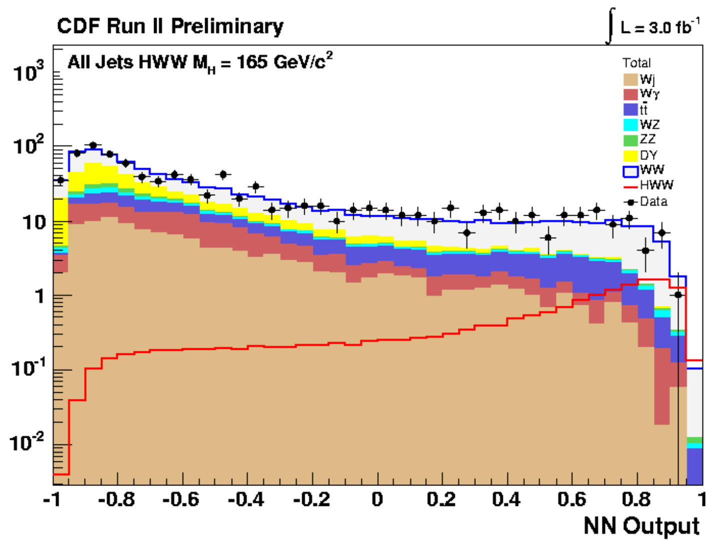
Separate into 0, 1, and 2-jet bins

- backgrounds and signal kinematics are different for each jet bin
- sensitive to additional signal contributions from WH, ZH, and VBF final states in the 2-jet bin



Event yield before NN (M_H=160 GeV)

Jet bin	Nsig	Nbkgd	Ndata
0	8.4±1.3	540±65	552
1	5.2±0.7	226±28	227
2	3.9±0.5	129±20	139

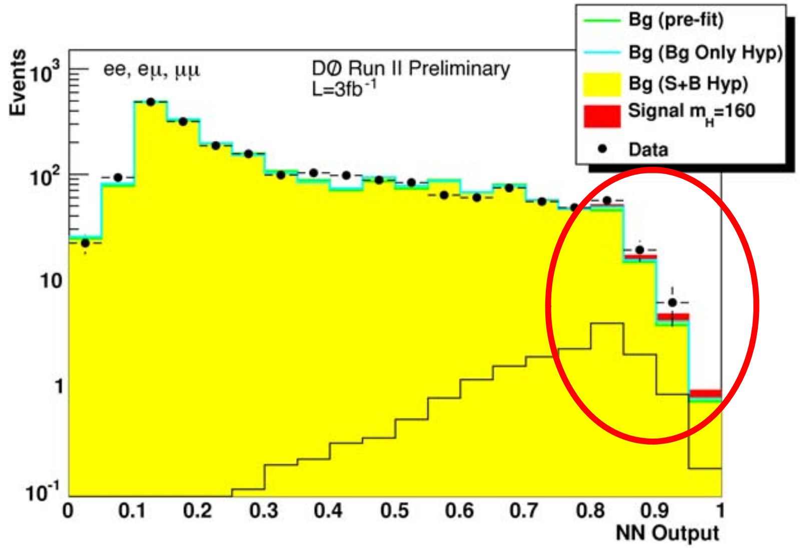


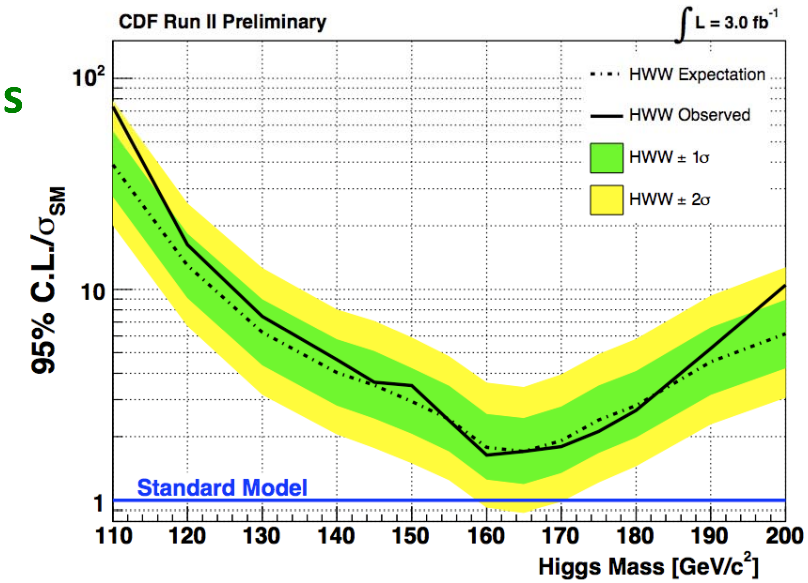
- separate NN for each jet bin
- add ME for the 0-jet bin

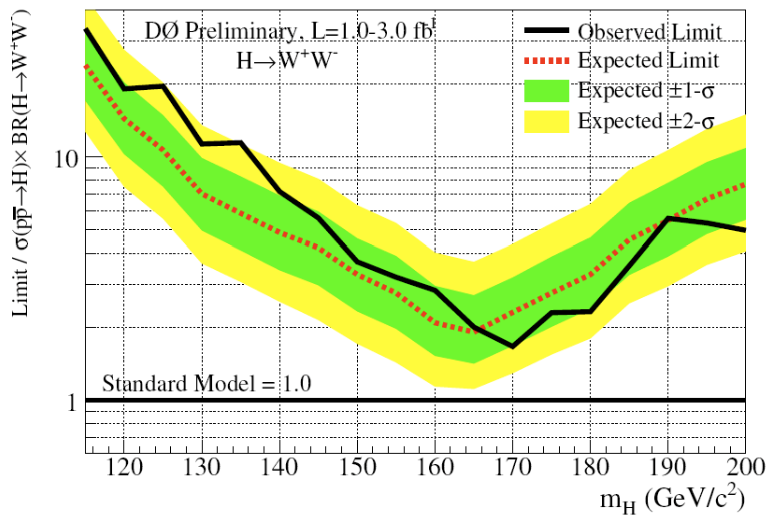
H→WW* Limit

Sensitivity and limit:

- fit NN outputs for each mass hypothesis to determine sensitivity and limit





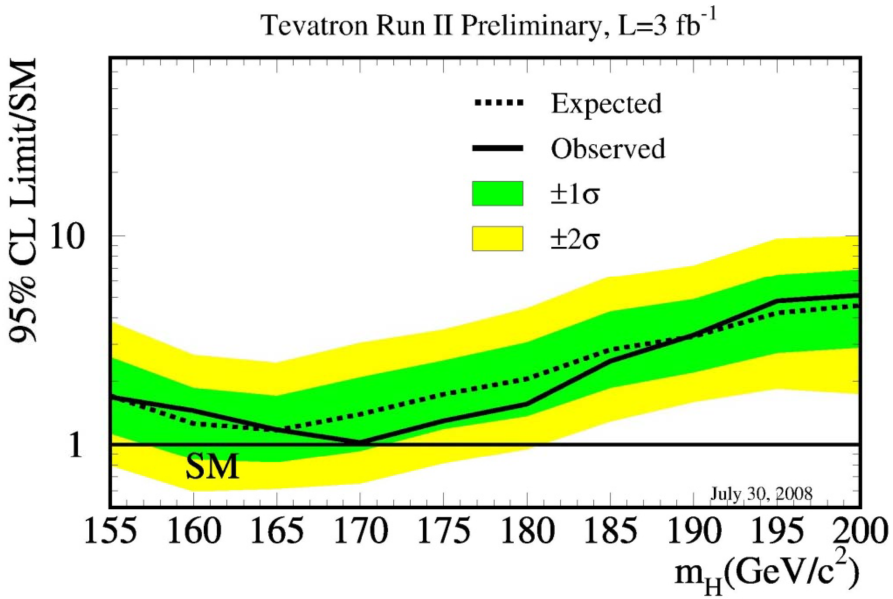


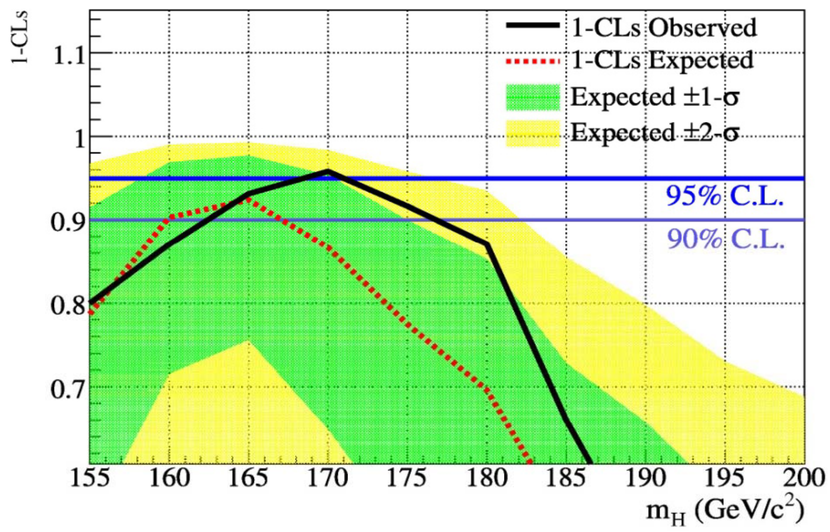
95% CL limit/SM for M_H=165 GeV

	Lumi (fb^{-1})	Nsig	Expected	Observed
CDF	3.0	17.2	1.6	1.6
DØ	3.0	15.6	1.9	2.0

Combined Limit

- **Low mass Tevatron combination for ~ 3 fb^{-1} in progress, expect a limit of ~ 3×SM**
- **High mass combination reaches promising land**





95% CL limit/SM

M_H (GeV)	160	165	170	175	180
Expected	1.3	1.2	1.4	1.7	2.0
Observed	1.4	1.2	1.0	1.3	1.6

Higgs in Supersymmetry

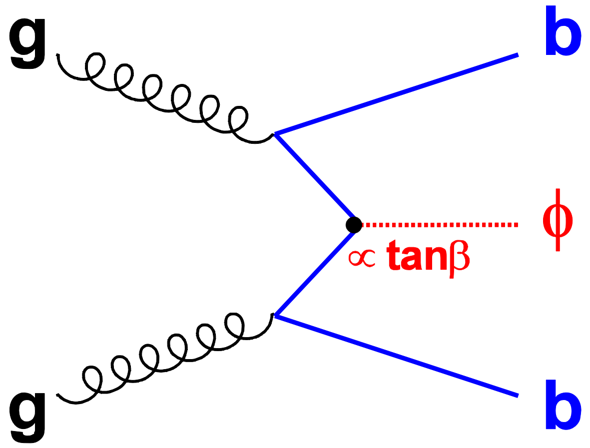
Minimal Supersymmetric Standard Model (MSSM)

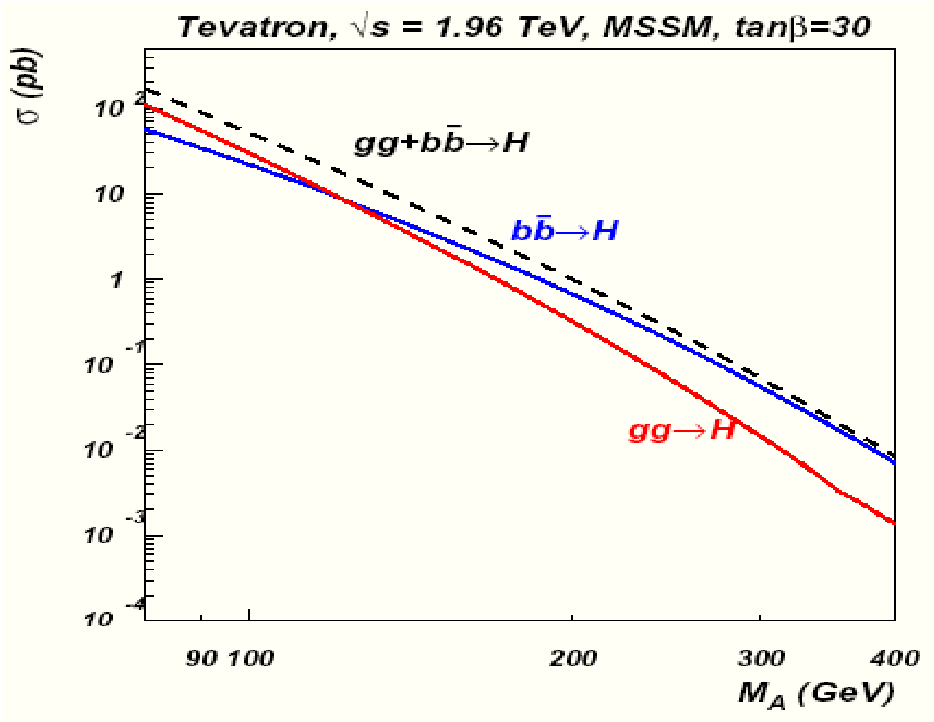
- predicts five Higgs bosons: h, H, A, H^+, H^-
- two of the three neutral Higgs are generally degenerate in mass $\Rightarrow \phi$
- ϕ production cross is proportional to $\tan^2\beta$

$$g_{hbb}^2 + g_{Hbb}^2 + g_{Abb}^2 \approx 2 \times \tan^2\beta \times g_{SM}^2$$

- ϕ decays predominantly to bb and $\tau\tau$ pair

$$\text{For } \tan\beta \sim 40 \; (\approx m_t / m_b)$$
$$Br(\phi \to b\bar{b}) \sim 90\%,$$
$$Br(\phi \to \tau\tau) \sim 10\%$$

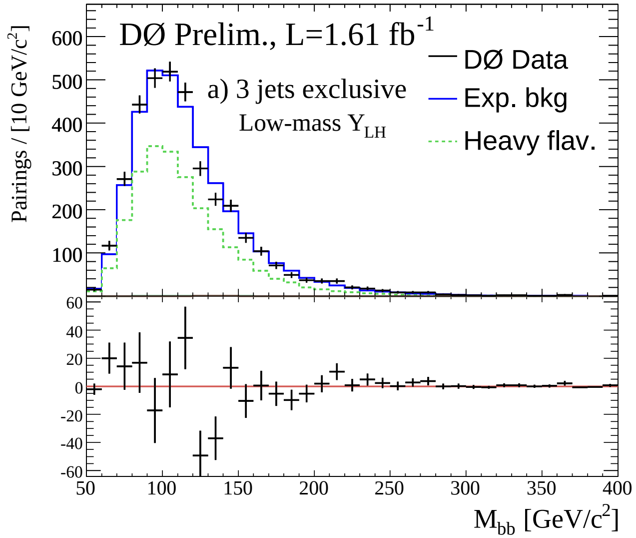


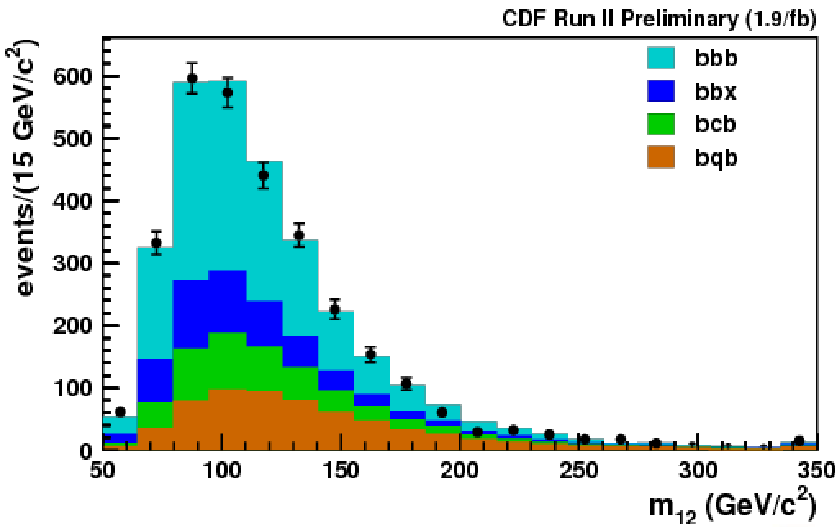


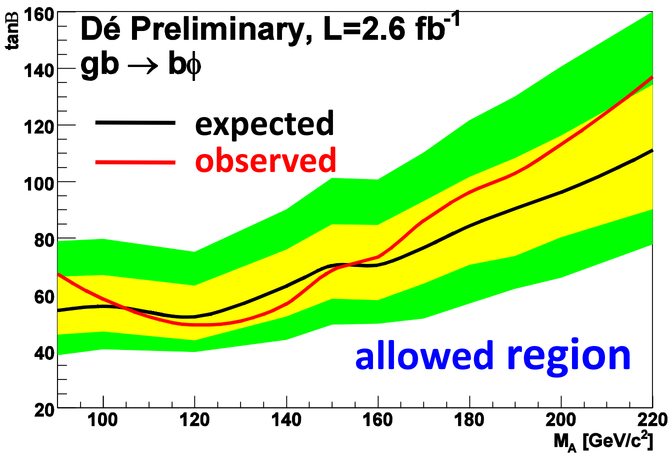
SUSY $\phi \to bb$

Both experiment have searched for $gb \to \phi b \to bbb$ directly

- trigger on multi-jet events
- select events with three b-tagged jets
- look for mass bump of two b-tagged jets
- data-driven background determination
- fit the observed m_{bb} distribution for a potential Higgs signal





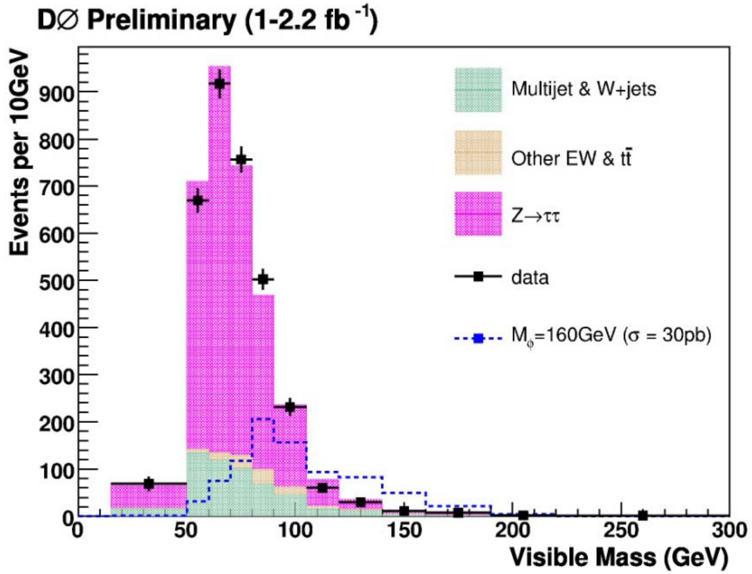


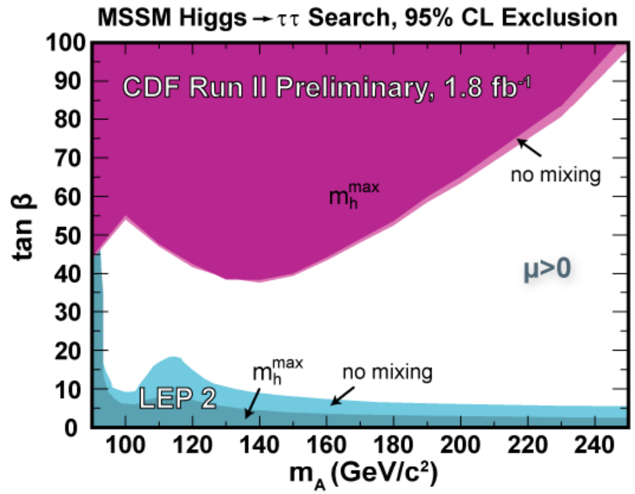
no evidence for $\phi b \to bbb$!

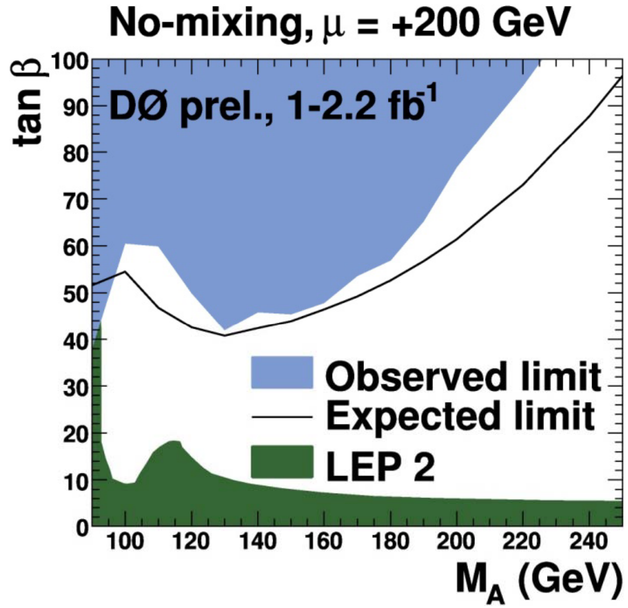
SUSY $\phi\to\tau\tau$

$\phi\to\tau\tau$ is an important search channel at Tevatron

- $\phi\to\tau\tau$ (CDF, DØ) and $b\phi\to b\tau\tau$ (DØ)
- trigger on $e+\tau$ and $\mu+\tau$
- τ identification is the key
  - ~ 60% efficiency with 1% fake rate







nothing in this channel either !

Tevatron combination is in progress.
Expect significant improvement in the limit.

Regrets... Other Searches

- $H \to \gamma\gamma$ (DØ, 2.7 fb^{-1})
  Important low-mass channel at the LHC
  Expected limit: 23×SM, Observed limit: 31×SM @ 115 GeV
- ($H \to \tau\tau$)+2jets (CDF, 2.0 fb^{-1})
  Pick up signals from $gg \to H$, $VH \to qq\tau\tau$, $qq \to qqH \to qq\tau\tau$
  Expected limit: 30×SM, Observed limit: 26×SM @ 115 GeV
- $VH \to qqbb$ (CDF, 2.0 fb^{-1})
  Overwhelm QCD backgrounds.
  Expected limit: 35×SM, Observed limit: 37×SM @ 115 GeV
- $ttH \to ttbb$ (DØ, 2.1 fb^{-1})
  Expected limit: 45×SM, Observed limit: 63×SM @ 115 GeV
- $WH \to WWW^*$ (DØ, 1.1 fb^{-1})
  Expected limit: 1.1 pb, Observed limit: 1.5 pb @ 120 GeV

……

CDF: http://www-cdf.fnal.gov/physics/new/hdg/hdg.html
DØ: http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

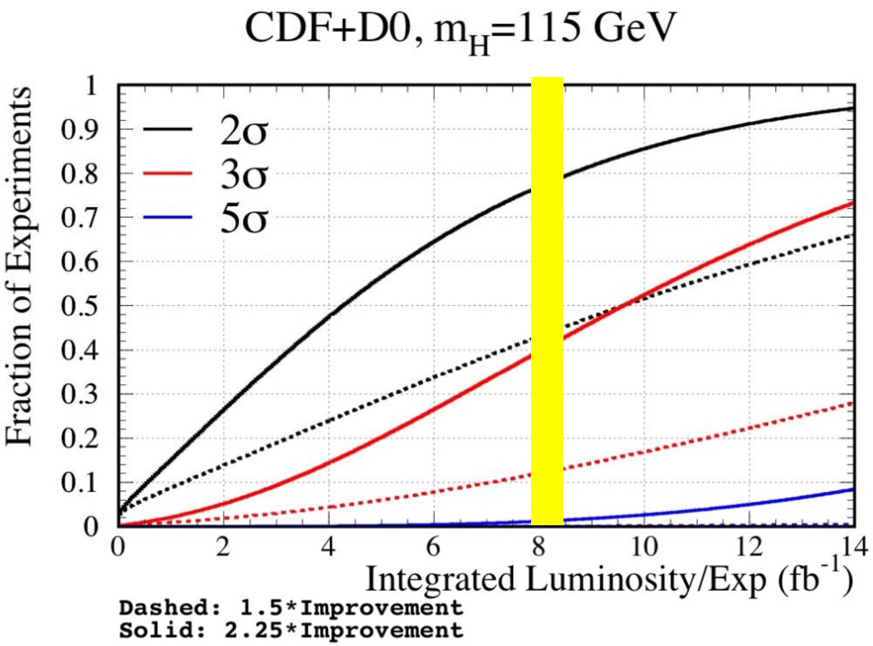
Prospect

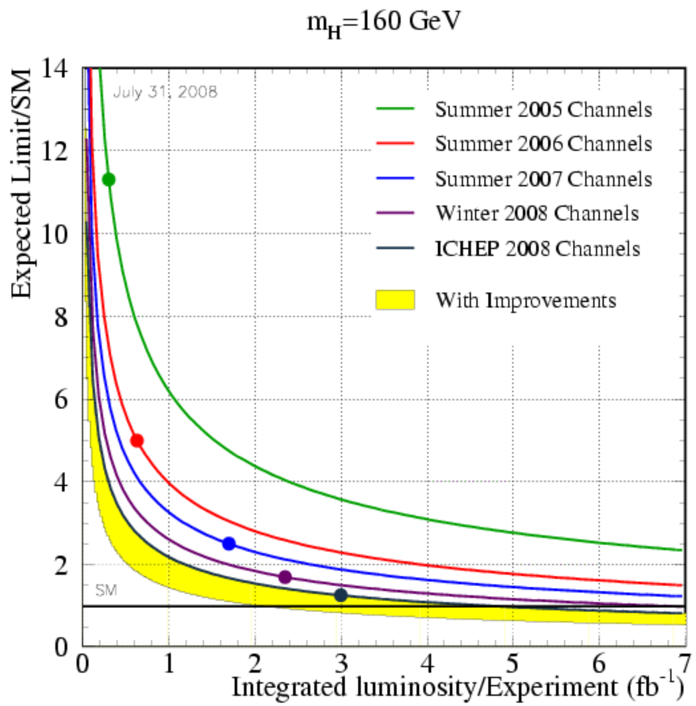
Tevatron Collider

- excellent performance, decision on 2010 running next spring

Experiments continue to push the envelope

- improve lepton acceptance;
- add new search channels;
- new tricks for existing analyses

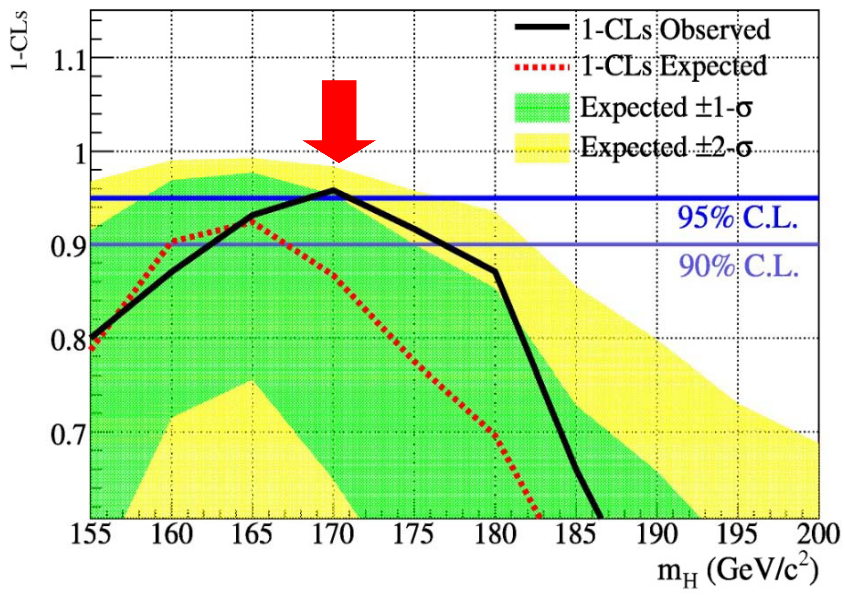




Summary

Both CDF and DØ have a comprehensive Higgs search effort. The sensitivity continues to improve at a rate faster than the data accumulation.

The search has reached a tipping point, expect large exclusion, or better evidences, from Tevatron with the full dataset !



The Tevatron still has a few years going for it …

and the dream is alive !