Higgs searches at the Tevatron

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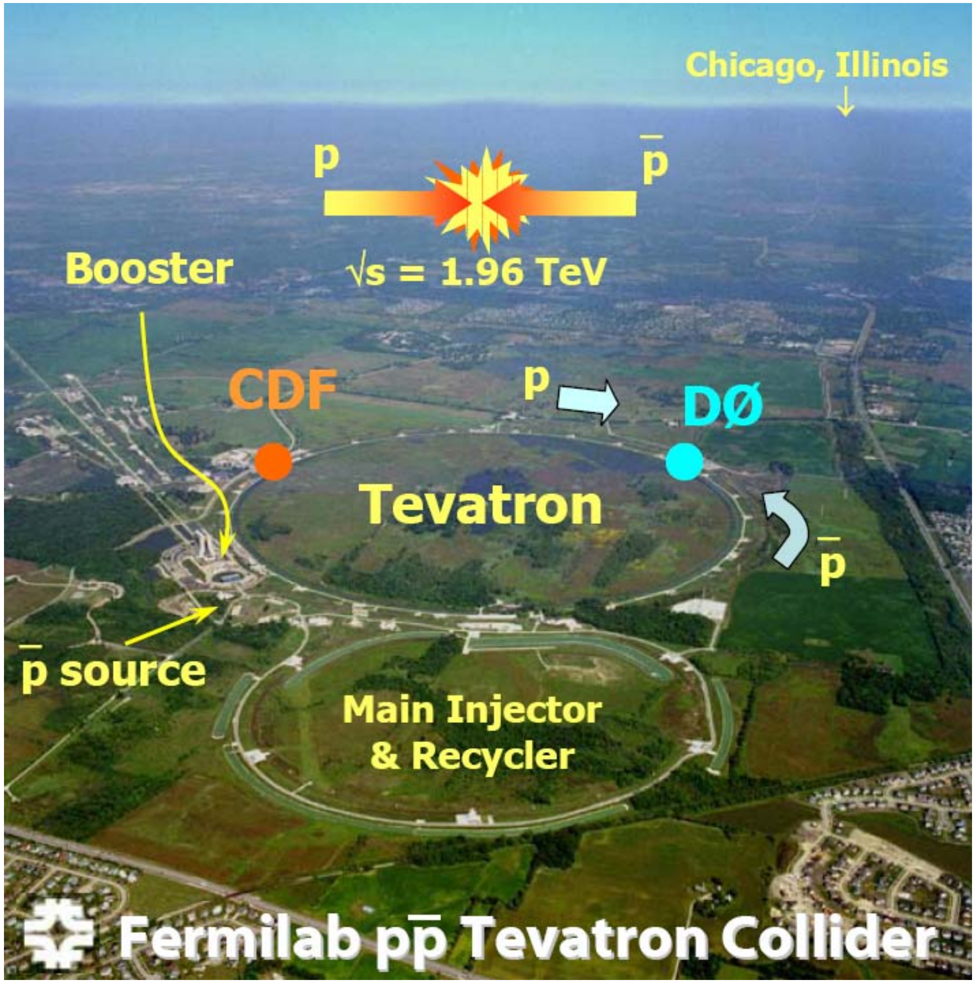
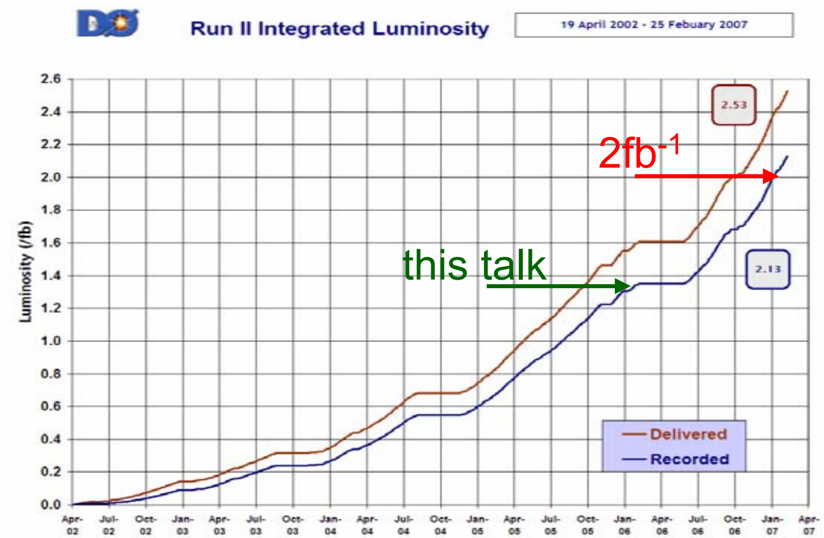
Outline

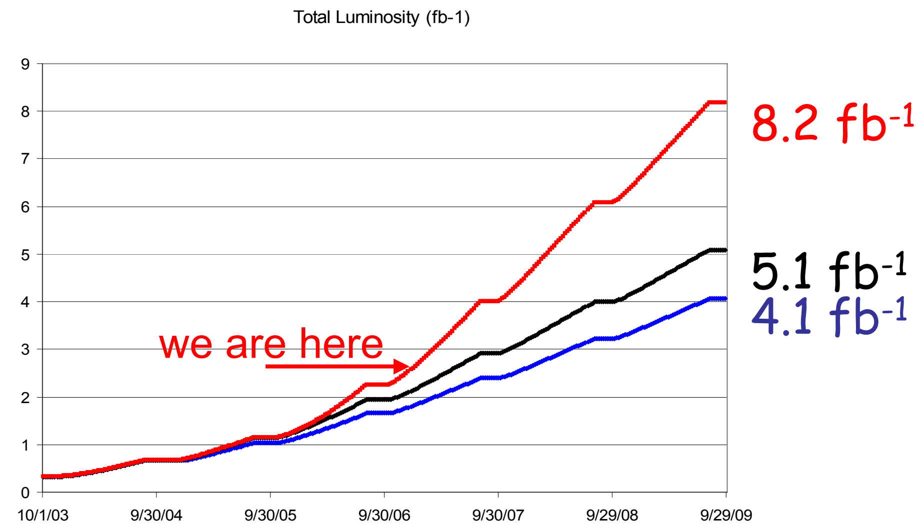
- Introduction
- Low mass SM Higgs
  - $WH \rightarrow l\nu b\bar{b}$
  - $ZH \rightarrow llb\bar{b}$
  - $ZH \rightarrow \nu\nu b\bar{b}$
- High mass SM Higgs
  - $H \rightarrow WW$
- SM limits combination
- Supersymmetric Higgs
  - Higgs $\rightarrow \tau\tau$
- Summary

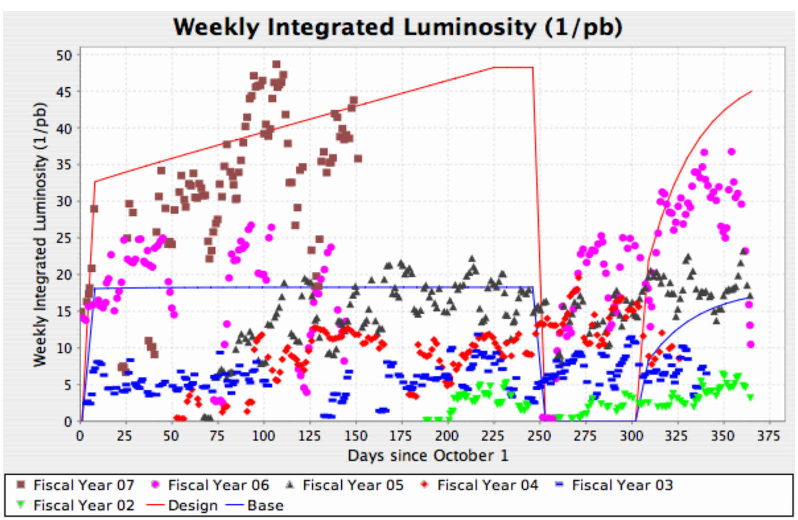


Only results obtained with the first 1fb^{-1} data set are shown

Tevatron performance



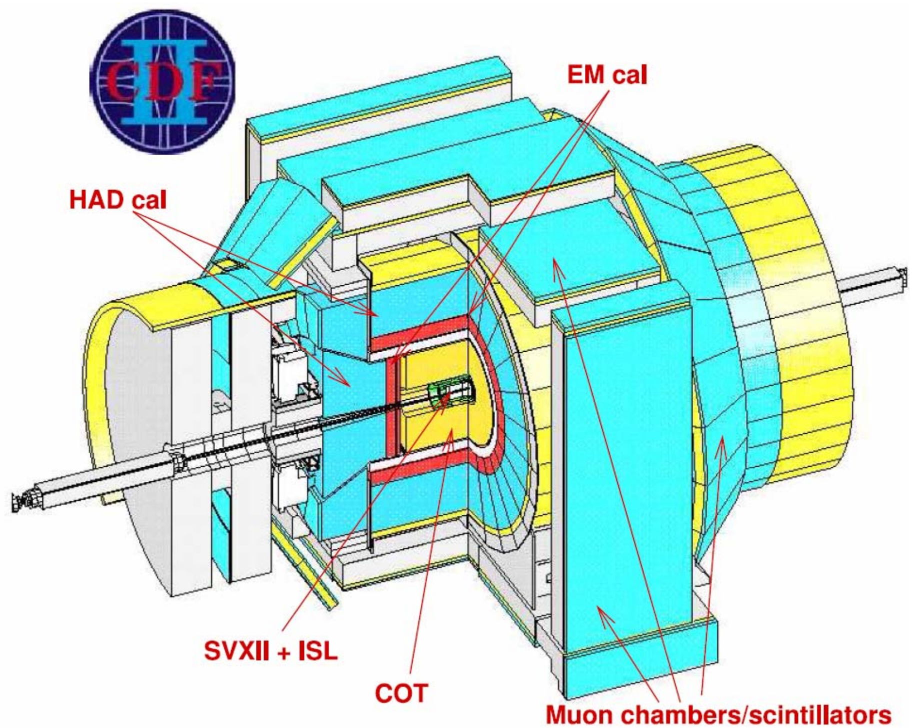


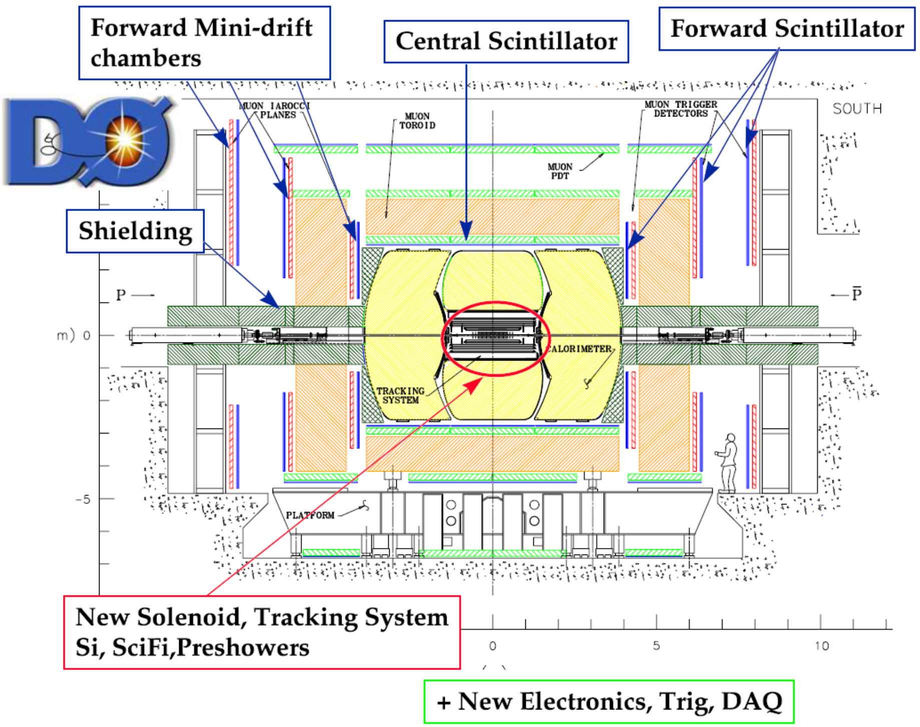


- Each experiment recorded more than $2fb^{-1}$ collision data
- Tevatron is running with peak luminosities of 300E30
- Performance is matching expectations for the design integrated luminosity of $8fb^{-1}$ by 2009

CDF and DØ experiments in RunII

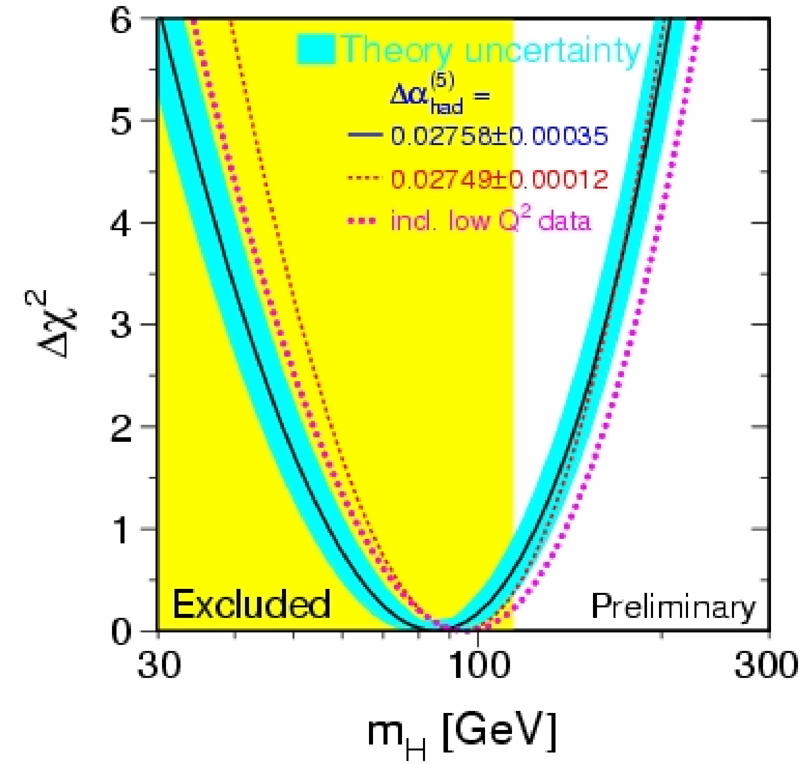
- Both detectors are highly upgraded in RunII
  - New silicon micro-vertex tracker
  - New tracking system
  - Upgraded muon chambers

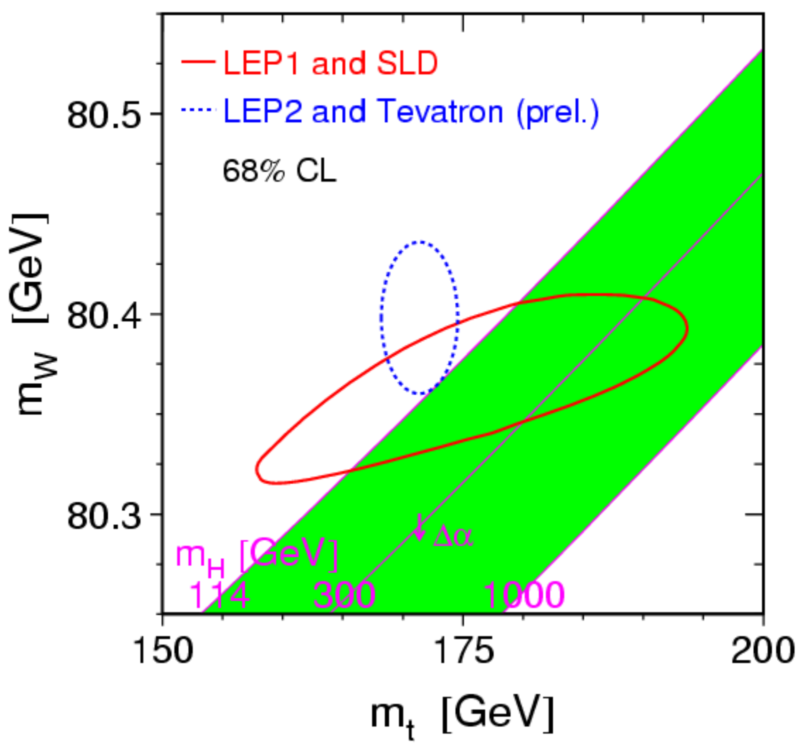




- CDF: new Plug Calorimeters, new TOF
- DØ: new solenoid, new pre-showers, LØ for SMT in RunIIb, new L1Cal trigger

Constrains on the Higgs mass





- Direct searches at LEP2: m_H > 114.4 GeV @95%CL
- m_H < 166 GeV @95%CL (EW fit) (< 199 GeV if LEP2 limit included)
- m_H constrained by radiative corrections to m_W
- New precision measurements of m_W and m_{top} from Tevatron (see talks by O. Stelzer and E. Barberis)

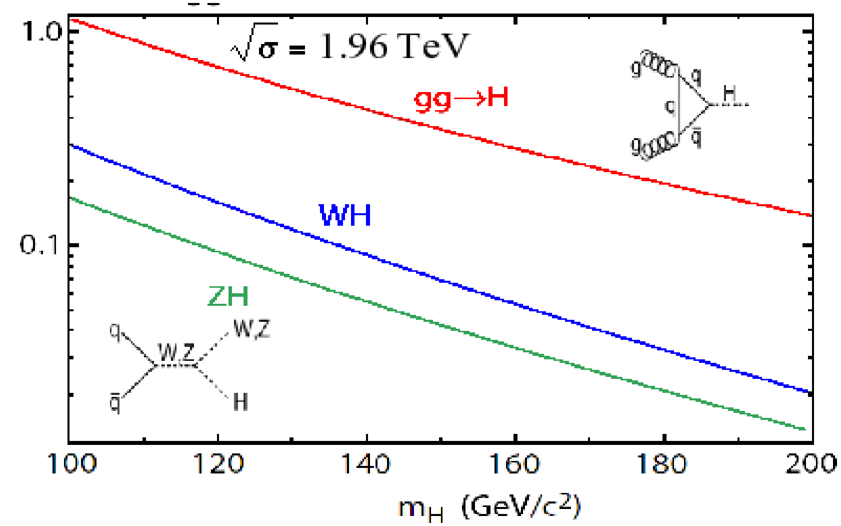
➡ A light SM Higgs boson is favored!

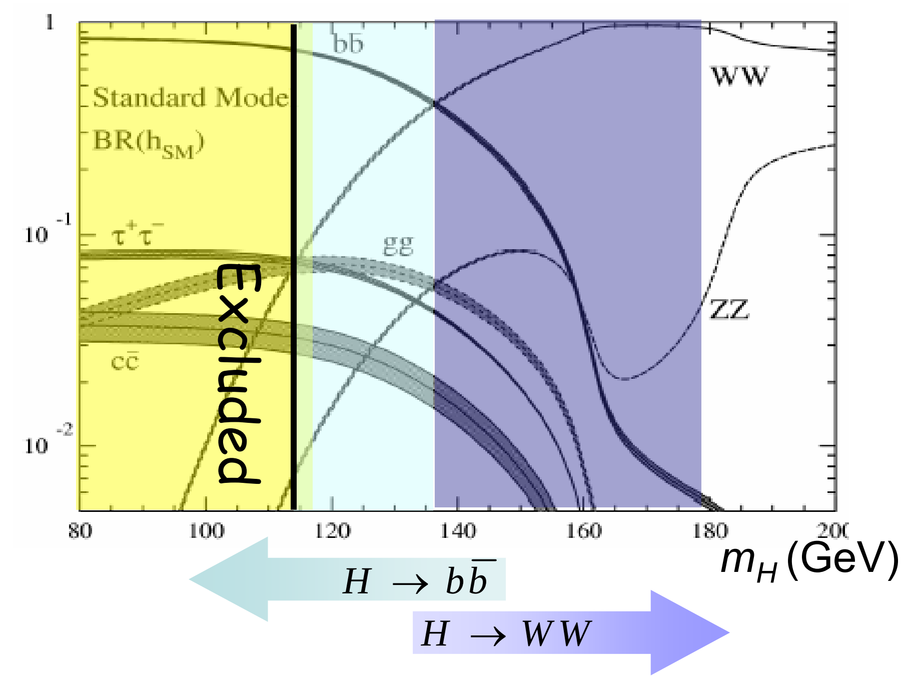
SM Higgs production and decay

- Production cross sections are small:
  0.1-1 pb depending on m_H
  1 in 10^{12} $p\bar{p}$ events is a Higgs

Search strategy at the Tevatron:

- m_H < 135 GeV
  - Associated production WH and ZH with H→bb decay
  - Main backgrounds are: Wbb, Zbb, W/Zjj, top, di-boson, QCD
  - gg →H →bb overwhelmed by multijet (QCD) background
- m_H > 135 GeV
  - gg →H production with decay to WW
  - The main background is: WW



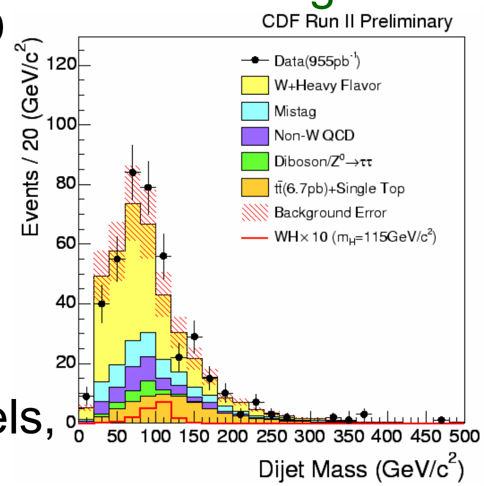


$WH \rightarrow l\nu b\bar{b},\ l = e, \mu$

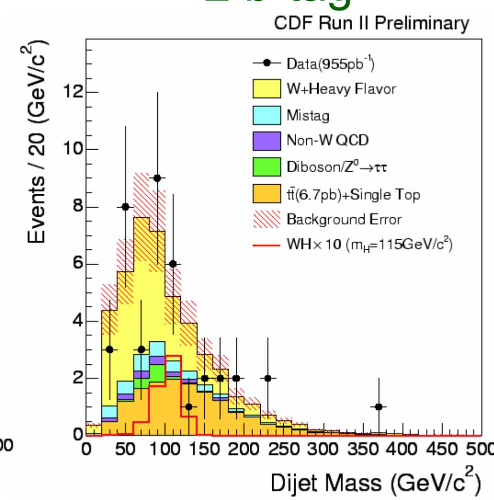
- CDF/DØ cut based analyses
- Backgrounds: Wbb, top, di-boson,QCD
- Selection:
  - isolated e or μ with p_T > 20 GeV
  - missing E_T > 20 GeV
  - jets > 15 GeV (CDF), > 20 GeV (DØ)
- CDF/DØ: independently analyzed one "tight" b-tag and 2 "loose" b-tag channels, later combined
- Cross section limits are derived from the invariant mass distributions and later combined
- 95% *CL* upper limits (pb) for m_H=115 GeV (SM expected: 0.13 pb)
  - CDF: 3.4 (2.2) observed (expected)
  - DØ: 1.3 (1.1) observed (expected)

➡ $\sigma_{excl} / \sigma_{SM} \sim 8.8$ (expected, best measurement)

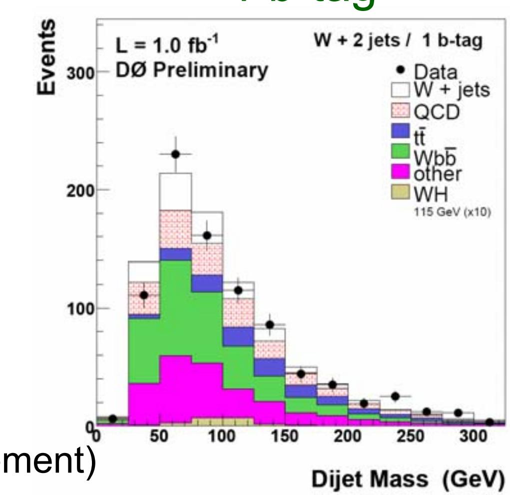
1 b-tag



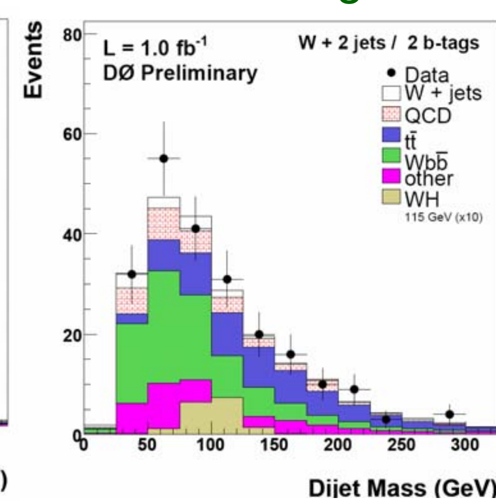
≥2 b-tag



1 b-tag



2 b-tag



$WH \to l\nu b\bar{b},\ l = e, \mu$

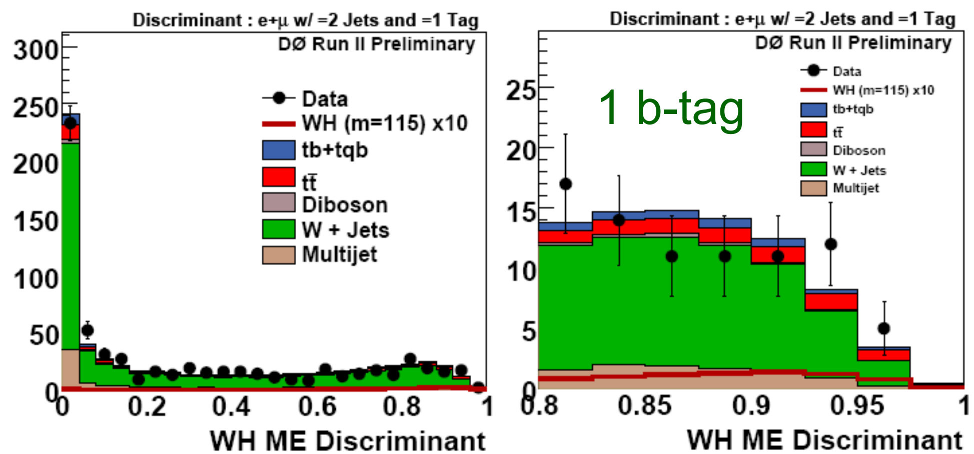
- Matrix element technique: use LO ME to compute the event probability densities for signal and background

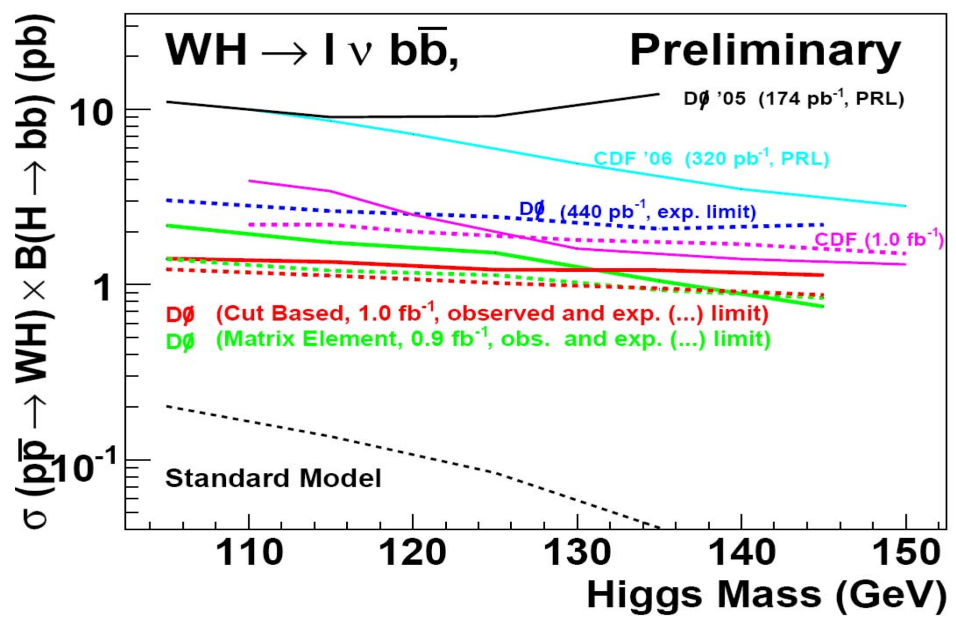
$$D(\vec{x}) = \frac{P_{WH}(\vec{x})}{P_{WH}(\vec{x}) + \sum_i c_i P_{Bi}(\vec{x})}$$

(see talk by T.Gadford)

- Selection criteria based on single top search (will be optimized in the future)
- Cross section limits are derived from the per-channel discriminant distributions
- 95% *CL* upper limit for m_H=115 GeV is 1.7 (1.2) pb observed (expect.)
- Similar ratio to SM as cut-based analysis (~9)

Matrix element analysis

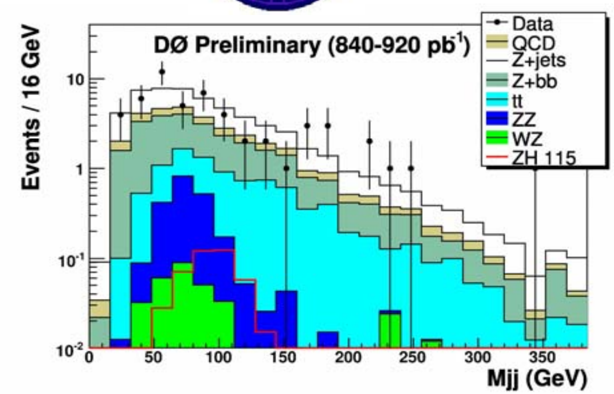


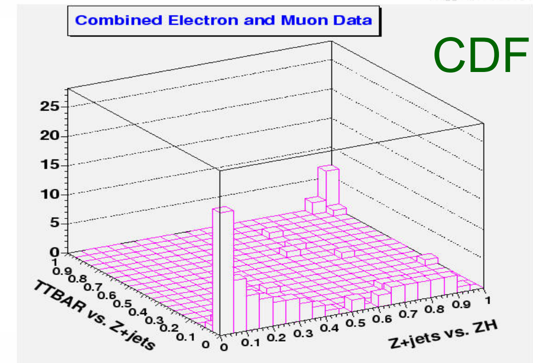


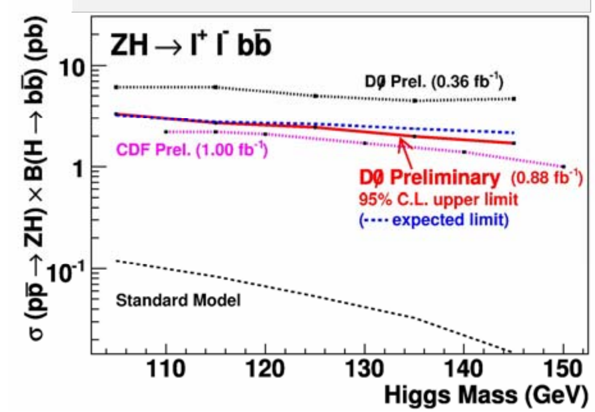
$ZH \to llb\bar{b}, \quad l = e, \mu$

- Dominant backgrounds: Z+jets (Zbb irreducible), top, WZ, ZZ, QCD multijet
- Selection:
  - jets > 15 GeV (DØ), > 25(15) GeV (CDF)
  - ee or μμ with m_{ll}~M_Z, opposite charge and isolated from jets
- DØ: require at least two b-tagged jets. Cross section limit derived from dijet invariant mass distribution within a search window
- CDF: 1 b-tagged jet. 2-D Neural Network to discriminate against the two largest backgrounds ($t\bar{t}$ vs. ZH and Z+jets vs. ZH)
  Limits are derived from the neural network distribution
- 95% *CL* upper limits (pb) for m_H=115 GeV (SM expected: 0.08 pb)
  - DØ: 2.7 (2.8) observed (expected)
  - CDF: 2.2 (1.9) observed (expected)

➡ $\sigma_{excl} / \sigma_{SM} \sim 24$ (expected, best measurement)

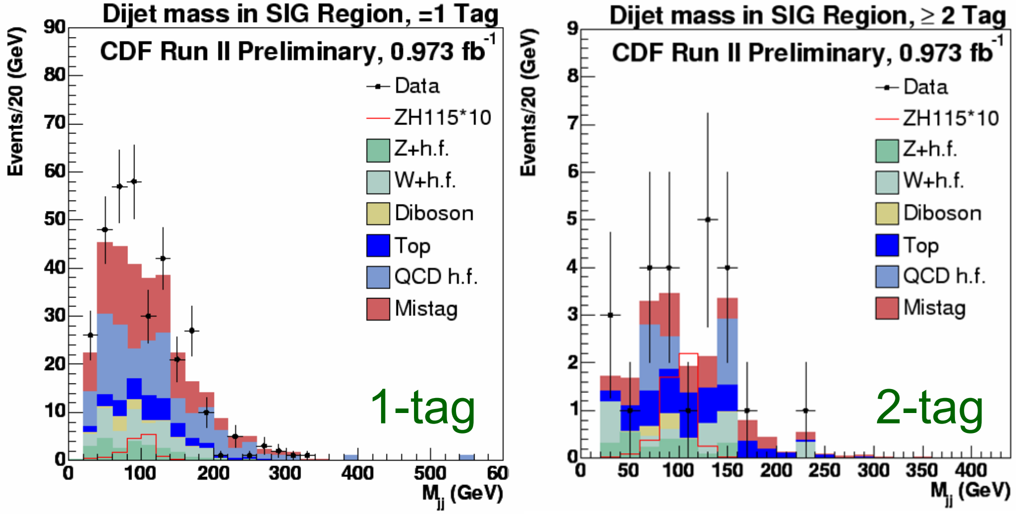






$ZH \rightarrow \nu\nu b\bar{b},\ \ WH \rightarrow (l^{\pm})\nu b\bar{b}$

- Challenging at hadron colliders due to the absence of visible leptons and only two jets in the final state
- Backgrounds:
  - Physics: Z/W+jets, di-boson, top
  - Instrumental: mismeasured $\not{E}_T$ together with QCD jets
- Separate analysis for 1 and 2 b-tag sample
- Estimate instrumental background:
  - processes with real taggable objects (QCD h.f. di-jets) are simulated
  - light flavor jet background is from mistags and is estimated from data (from negative tags)
  - the QCD h.f. contributions is then normalized in a control region



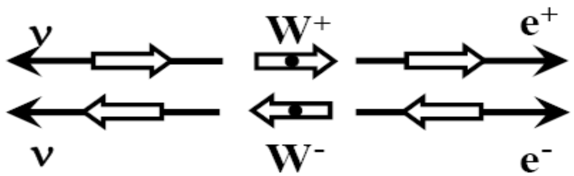
- Final selection:
  - jets: > 60(20) GeV, |η|<1.1(2.4)
  - large missing E_T > 75 GeV
  - No isolated e or μ
  - $\not{E}_T$ not aligned in ϕ with jets
- 95% *CL* upper limit for m_H=115 GeV

ZH,WH each: $\sigma_{excl} / \sigma_{SM} \sim 28, 34$

➡ combined: $\sigma_{excl} / \sigma_{SM} \sim 15$ (expected)

$H \to WW^{(*)} \to l^+ l^- \nu\bar{\nu}, \quad l = e, \mu$

- Channel sensitive at higher Higgs masses
- Main background: WW production
- Search strategy:
  - 2 high p_T isolated, opposite sign leptons
  - require missing E_T and veto on jets or jets p_T
  - *WW* comes from spin 0 Higgs: leptons prefer to point in the same direction

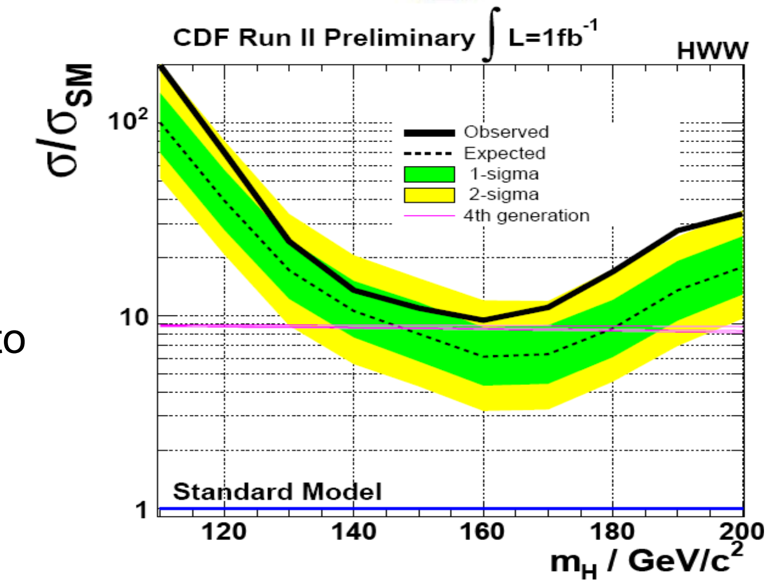


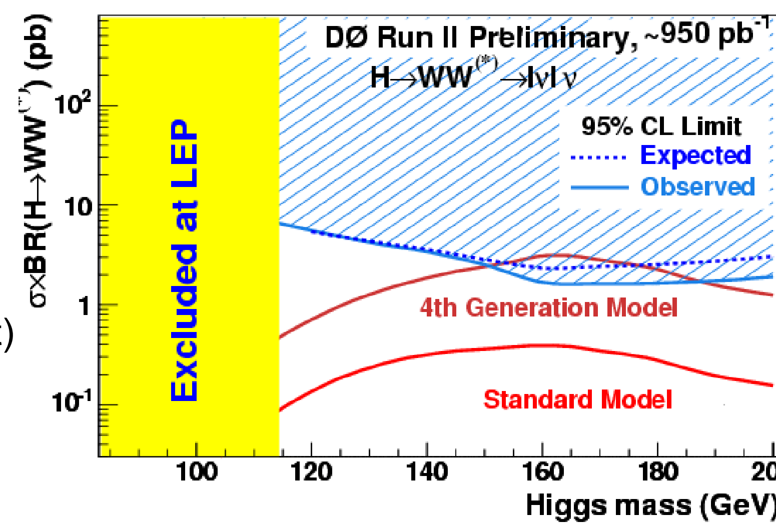
  - di-lepton opening angle $\Delta\phi_{ll}$ to discriminate against dominant WW background
  - cross section limit derived from $\Delta\phi_{ll}$ distribution
- Sensitivity at $m_H \sim 160$ GeV:

  ➡ $\sigma_{excl} / \sigma_{SM} \sim 5$ (DØ)

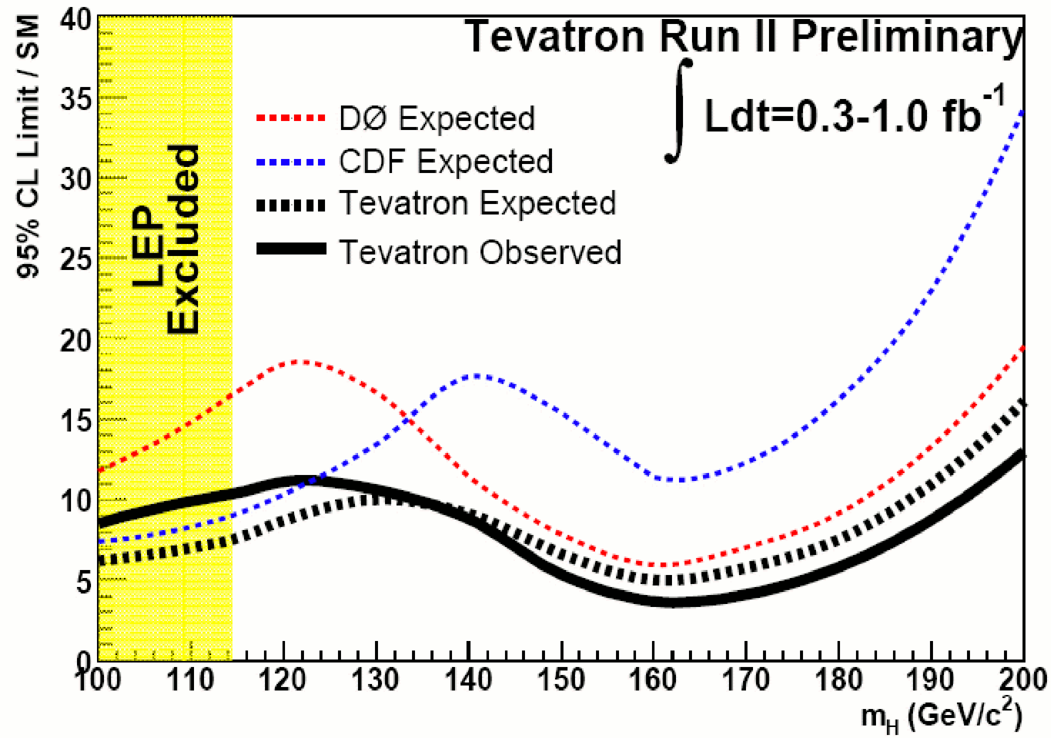
  (expected, best measurement)

- 4^{th} generation model already excluded for $m_H = 150 - 185$ GeV





Combined SM Higgs limits



- First Tevatron (CDF/DØ) combination limit released in the summer
- The expected combined limits are a factor 7.5 at m_H=115 GeV and a factor 4 at m_H=160 GeV away from the SM
  - this does not include CDF's new 1fb^{-1} high mass result yet
  - and it does not include any of DØ's new 1fb^{-1} low mass result yet
- Expect further significant improvements when all the 1fb^{-1}results will be included!

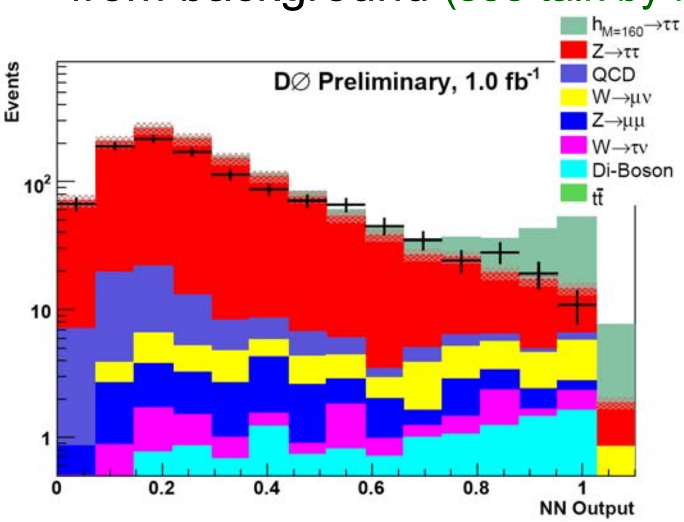
Higgs bosons in the MSSM

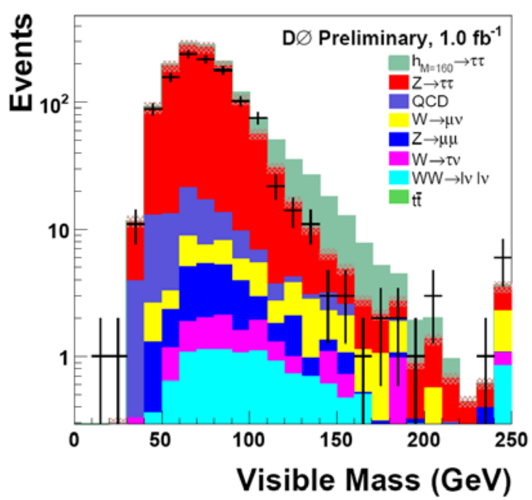
- In the MSSM there are two Higgs doublet fields
  - H_u (H_d) couple to up- (down-) type fermions
  - The ratio of their VEV's
    $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$
  - 5 Higgs particles after the EWSB
    h, H, A, H^+, H^-
  - h has to be light:
    $m_h <\sim 130 - 140$ GeV

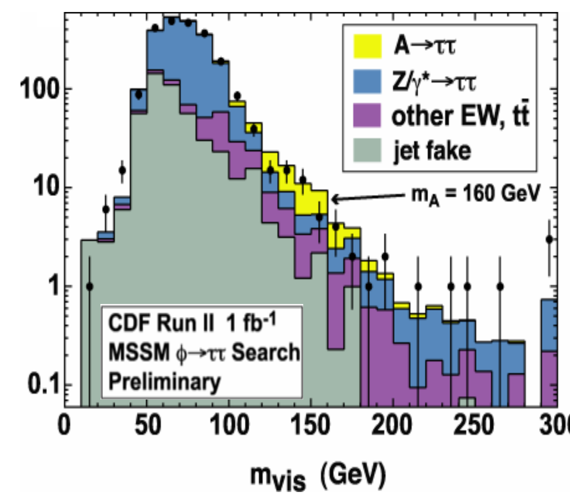
- At large tan β the coupling of A and h to down-type fermions, e.g. *b*-quark, is enhanced wrt. the SM
- The production amplitude at tree level is proportional to tan β, thus the production cross section rise as $\tan^2\beta$
- In addition h/H and A (commonly denoted by φ) are nearly degenerate in mass → further increase of the cross section

Neutral MSSM Higgs $\rightarrow \tau_l \tau_{had}$

- Main backgrounds: $Z\rightarrow\tau\tau$ (irreducible), W+jets, Z $\rightarrow$ee,$\mu\mu$, multijet, di-boson
- DØ (μ channel only): Selection:
  - only one isolated μ separated from the hadronic τ with opposite sign
  - set of NNs to discriminate τ from jets
  - cut on M_W(visible) < 20 GeV removes most of the remaining W boson backgr.
- Optimized NNs to separate signal from background (see talk by M.Owen)
- CDF (e, μ, e+μ channels): Selection:
  - isolated e or μ separated from the hadronic τ with opposite sign
  - variable-size cone algorithm for τ discrimination
  - jet background suppressed by requiring: $|p_t^l| + |p_t^{had}| + |\not{E}_T| > 55$ GeV
  - remove most of the W background by a requirement on the relative directions of the visible τ decay products and $\not{E}_T$

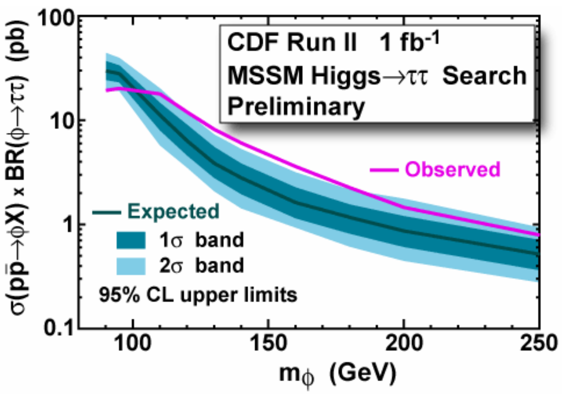


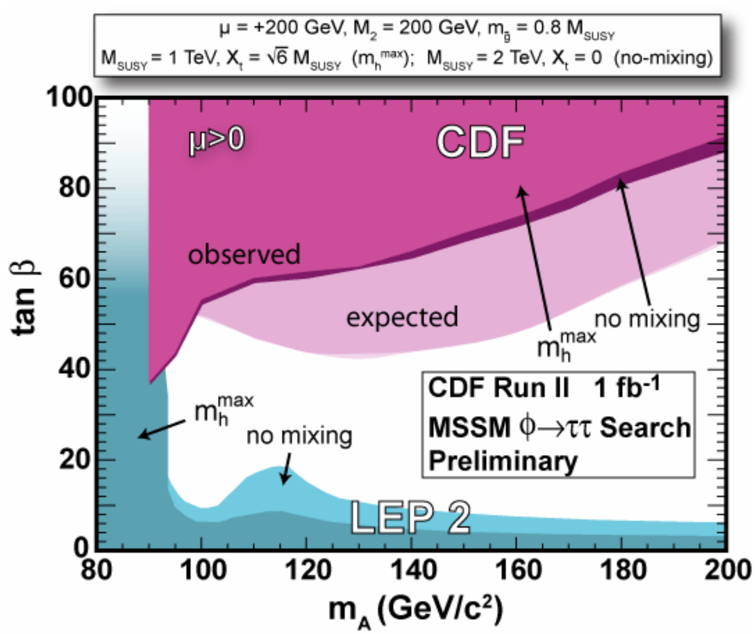


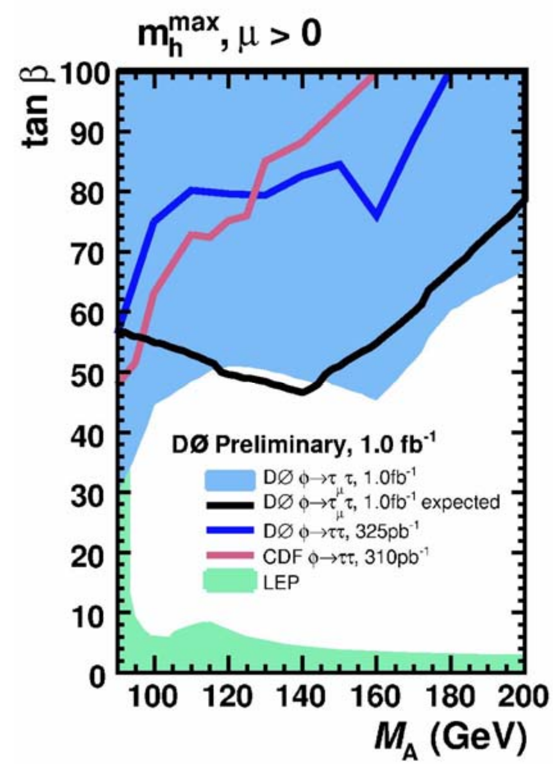


Neutral MSSM Higgs $\rightarrow \tau_l \tau_{had}$

- DØ: the output of the NNs for the different tau types is used in the limit calculation
- CDF: cross section limits are derived from the visible mass distribution. Observed limits weaker than the expectations due to some excess of events in the data sample, but significance ≤ 2σ
- Both experiments similar results: in the region 90<m_A<200 GeV, tan β values larger than 40-60 are excluded for the no-mixing and the m_h^{max} benchmark scenarios







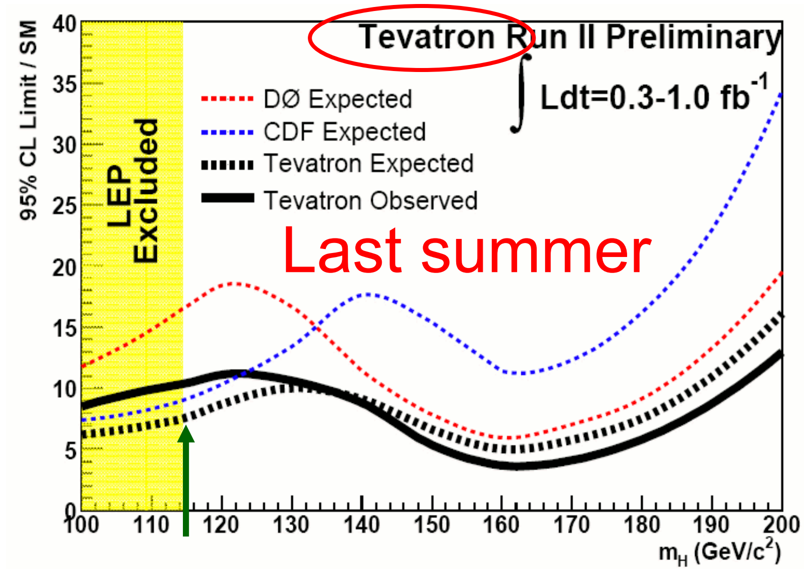
Perspectives

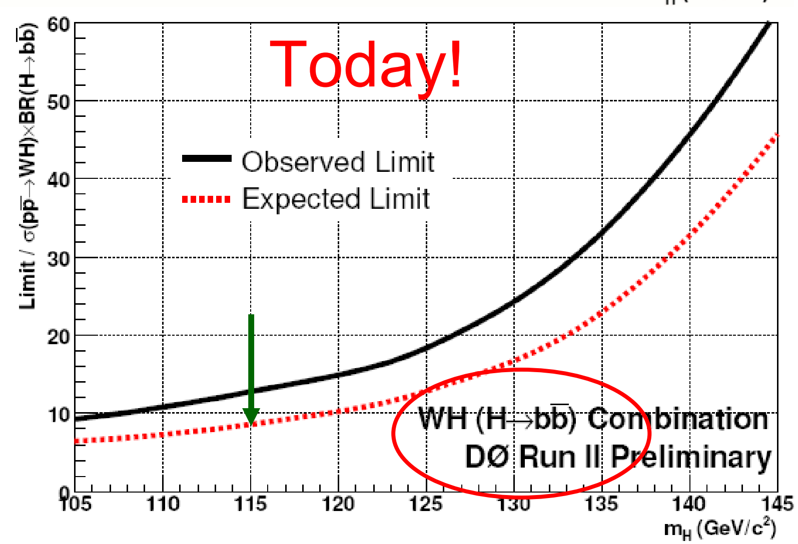
- Today some single channels have cross section limits similar to the combined Tevatron results half a year ago

More sensitivity will be gained by:

- Increase of the luminosity by about a factor 8
- Include more channels (e.g. τ final states)
- Improved di-jet mass resolution, b-tagging and simulation
- Improve analyses, especially the use of multivariate analysis techniques, e.g. NN and Matrix Element analysis, Decision Trees

DØ's evidence for Single Top production and CDF *WZ* observation is an important milestone in the use of these techniques to discriminate very low rate signals in the presence of substantial backgrounds





Summary

- Tevatron and CDF/DØ experiments performing very well
- Already two times more data on tape than used for the presented results
- A wide range of Higgs searches have been performed by both CDF and DØ with up to 1 fb^{-1} RunII data:
  - No deviations from the SM expectations observed
  - No signal observed in the MSSM Higgs search, but already powerful!
- Individual cross section limits now also at the low mass range about one order of magnitude above SM
- First Tevatron combination from Summer ’06
  - Some individual channels result already in similar limits!
- Start using advanced analysis techniques
  - Many analyses use Neural Networks for signal discrimination
  - First Matrix Element Higgs analysis with promising result
- More work needed to reach expected sensitivity but there is a clear roadmap
- A very exiting time ahead!

Fermiophobic Higgs $\rightarrow 3\gamma + X$

- In various extensions of the SM (also MSSM) the coupling of h might be suppressed to Fermions
- Search for the channel:

$$p\bar{p} \rightarrow h_f H^{\pm} \rightarrow h_f h_f W^{\pm} \rightarrow \gamma\gamma\gamma(\gamma) + X$$

- Good photon identification is crucial
- Cuts: 3γ within |η|<1.1
  $E_T^{1,2,3}$ > 30, 20, 15 GeV
- Backgrounds: Jets or electrons misidentified as γ and direct 3γ prod.
- Background is estimated from data with efficiencies ε^{γ}, P(j→γ), P(e→γ)

3γ prod.: $N^{3\gamma} = \frac{N_{\gamma\gamma\gamma}(MC)}{N_{\gamma\gamma}(MC)} N_{\gamma\gamma}(Data) * \rho$

- Cut on $p_T^{3\gamma} > 25$ GeV gives 1.1 events in background and 0 in data
- Upper limit: $\sigma = 25.3\ fb\ (95\%\ CL)$