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Review of Tevatron Higgs Results

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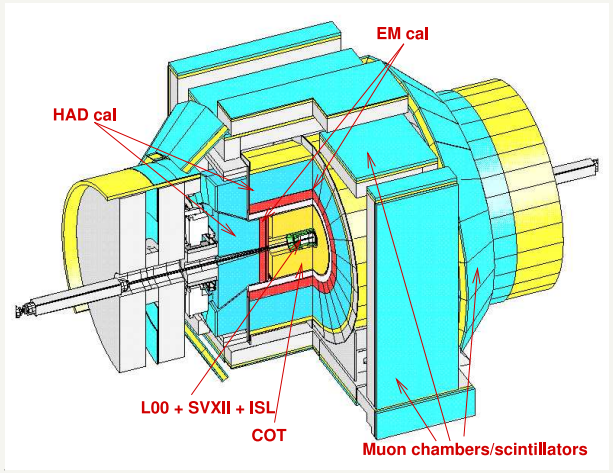
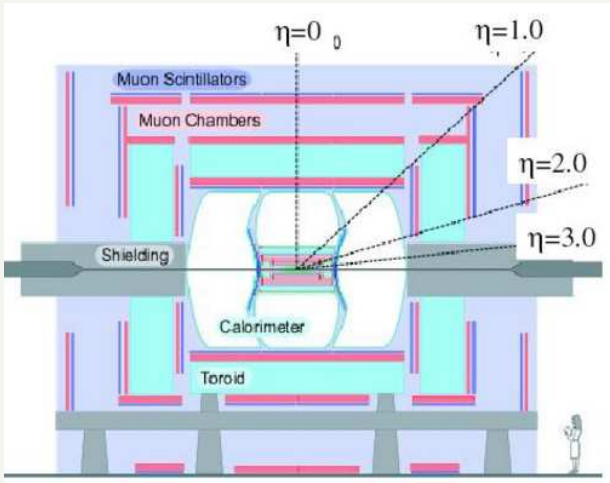


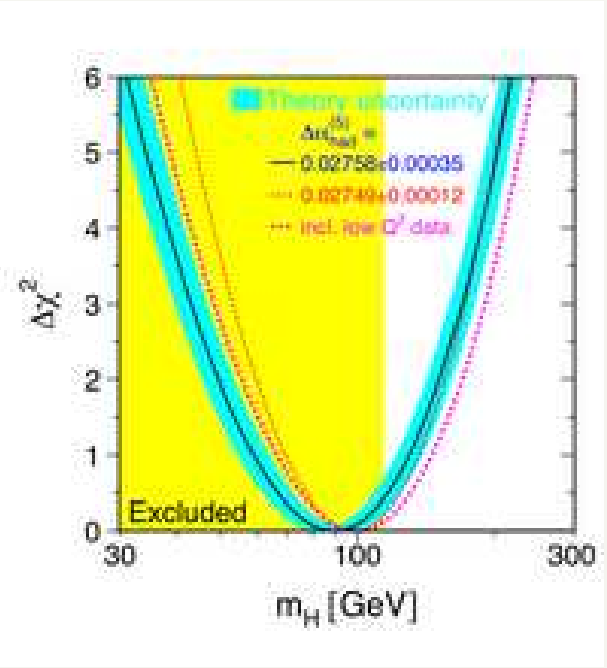


Overview of the talk

- **Search for the SM Higgs**
  - $\Rightarrow$ **Results from WH production (low mass)**
  - $\Rightarrow$ **Results from ZH production (low mass)**
  - $\Rightarrow$ **Results from H production (high mass)**
  - $\Rightarrow$ **Combination of results to improve limits**
  - $\Rightarrow$ **Plans for the future (goals of the Run II)**
- **Search for MSSM Higgses**
  - $\Rightarrow$ **Searches in the b channel**
  - $\Rightarrow$ **Searches in the τ channel**
  - $\Rightarrow$ **Limits and plans**
- **Other Higgs searches: Doubly-charged Higgs**
- **Summary and Outlook**

The Standard Model Higgs

SU(2)$_L$xU(1)$_Y$ is very well tested in collider experiments



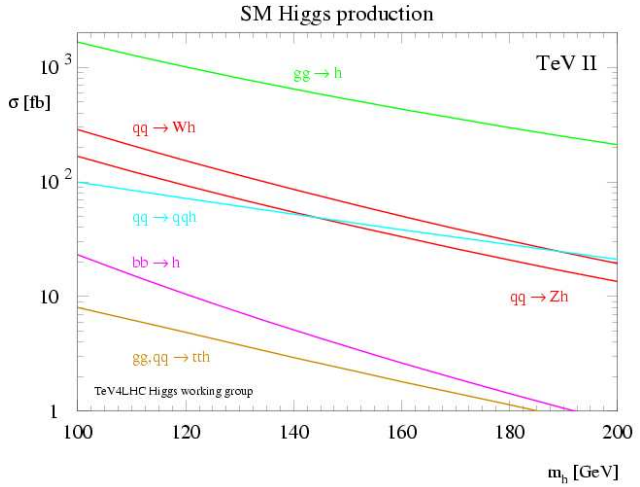
It can only be a description of Nature by adding a mechanism to break the symmetry.

The simplest model is the Standard Model, introducing one complex-doublet field with a expectation value in vacuum.

After EWK symmetry is broken, one degree of freedom is left, giving rise to a scalar field, the Higgs boson.

$\Rightarrow$ **Fits to SM gives a value:** 89^{+42}_{-30} **GeV/**c^2

$\Rightarrow$ **LEP search excludes SM Higgs with** $m_H < 114.4$ **GeV/**c^2



Tevatron searches are challenging due to

- **Small production cross section**
- **Large backgrounds (for low mass region)**

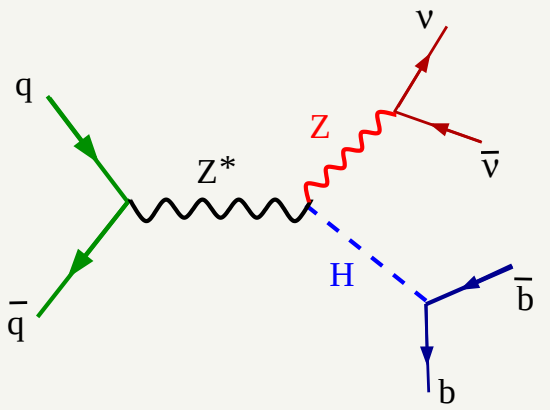
Tevatron and the SM Higgs: Strategy

Considering the branching ratios and production cross section, the strategy is as follows:

- **Low mass ($m_H < 130$ GeV/c^2) decay dominated by $H \rightarrow b\bar{b}$**

  $\Rightarrow$ Impossible to observe in inclusive production

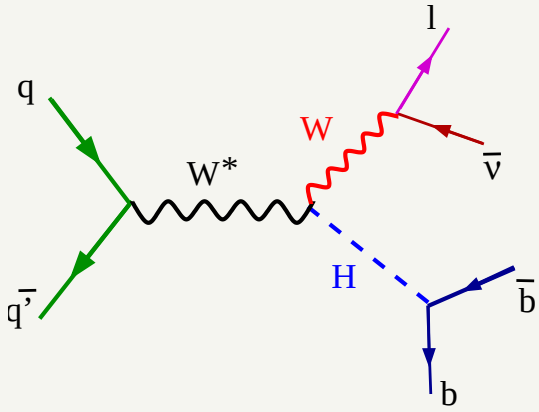
  $\Rightarrow$ Chances in ZH and WH production requiring a b-jet and leptonic decays



- **High mass ($m_H > 160$ GeV/c^2) decay dominated by $H \rightarrow WW$**

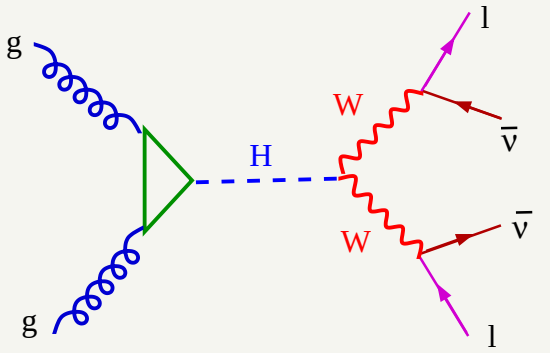
  $\Rightarrow$ Leptons from the Higgs reduce background

  $\Rightarrow$ Inclusive production is dominant channel (although associated production is not negligible, e.g. $WH \rightarrow W(WW)$)



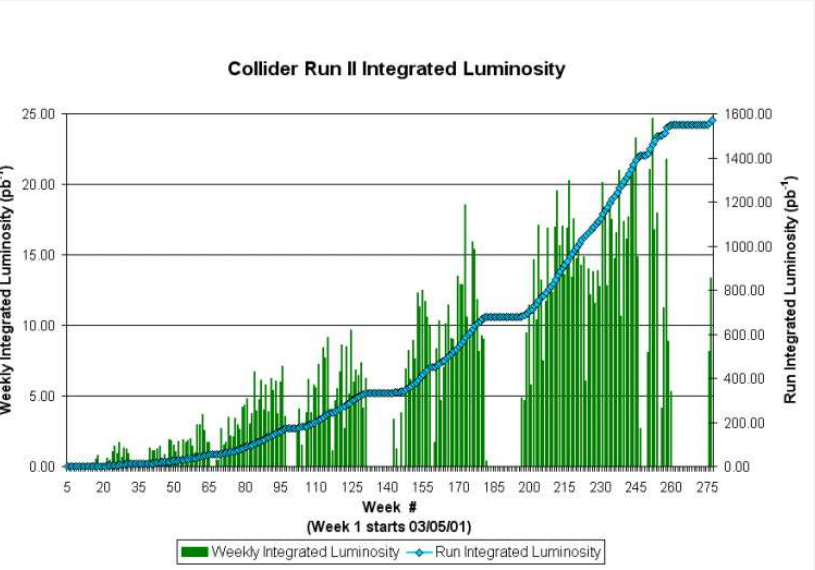
- **Intermediate region**

  $\Rightarrow$ Sensitivity from previous modes

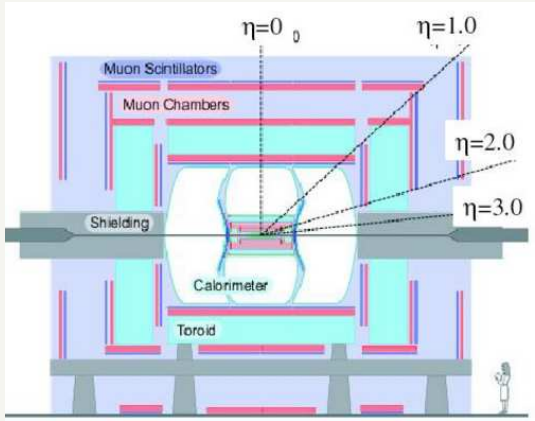


We need good lepton identification, $\not\!\!E_T$ reconstruction and b-jet tagging to perform the search.

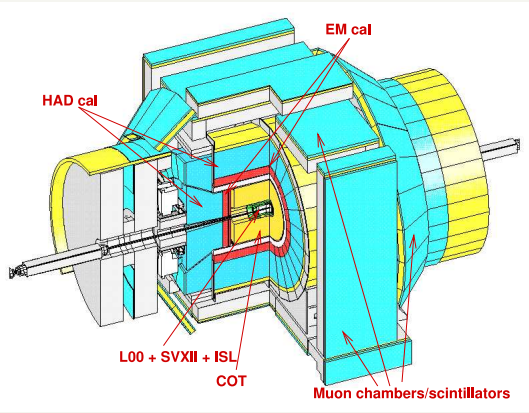
Tevatron and the SM Higgs: Experiments



- CDF and D0 analyze $p\bar{p}$ collisions at Tevatron.
- Already collected more than 1 fb^{-1} of good data
- Just restarted from a 3-month shutdown



- General-purpose detectors, axial and forward-backward symmetric
- Precision tracking (including silicon detectors) and 4π calorimetry.



$\Rightarrow$ Good $\not\!\!E_T$ reconstruction

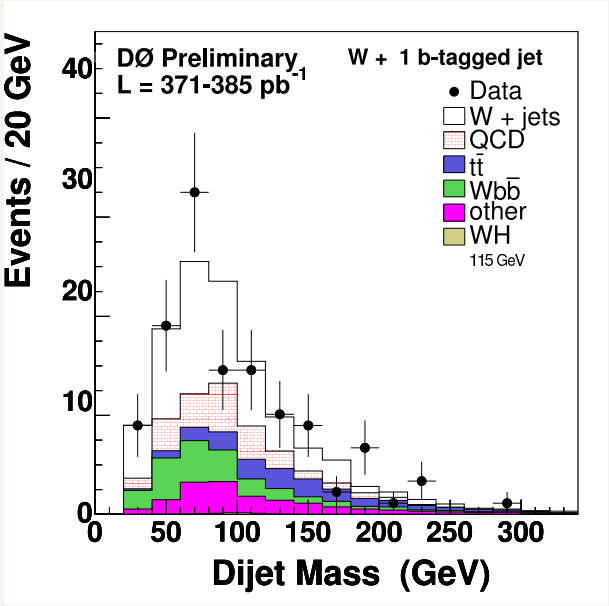
$\Rightarrow$ Good b-tagging performance

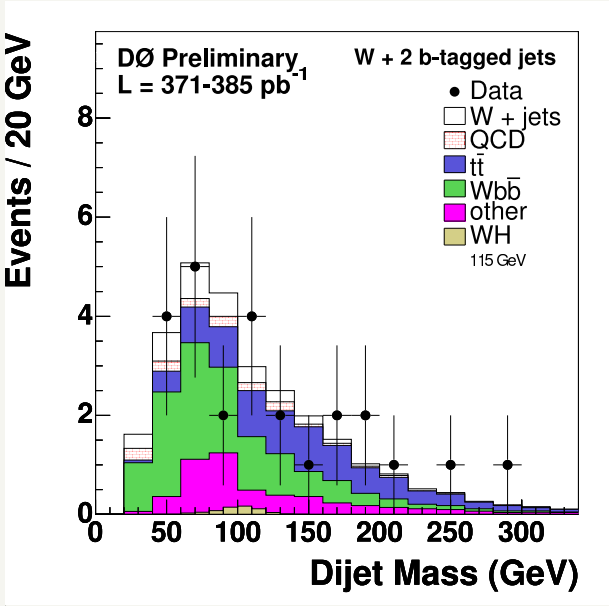
$\Rightarrow$ Good lepton identification (including Muon chambers)

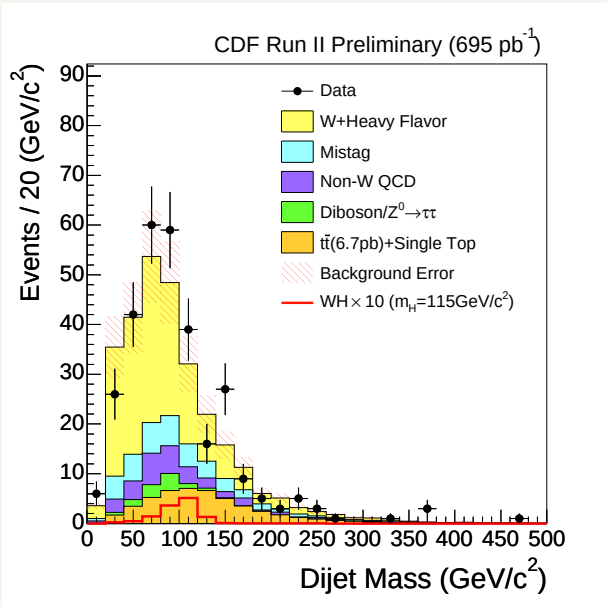
The results shown here do not include all the data already collected.

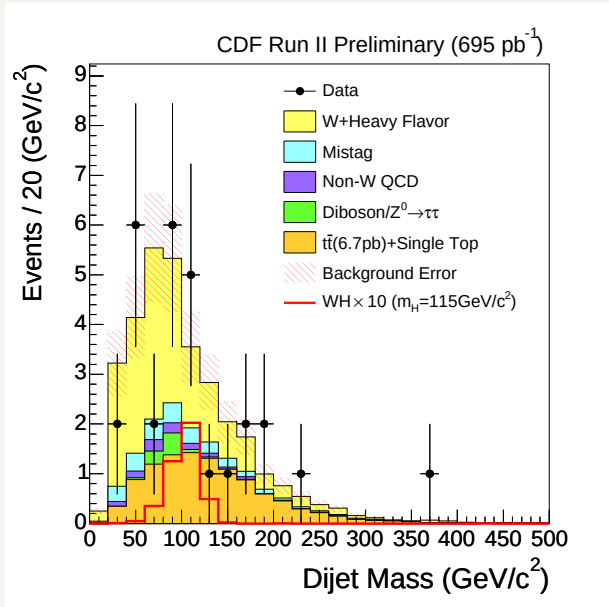
Expecting to have updates soon.

SM Higgs: $WH \rightarrow l\nu b\bar{b}$ (I)









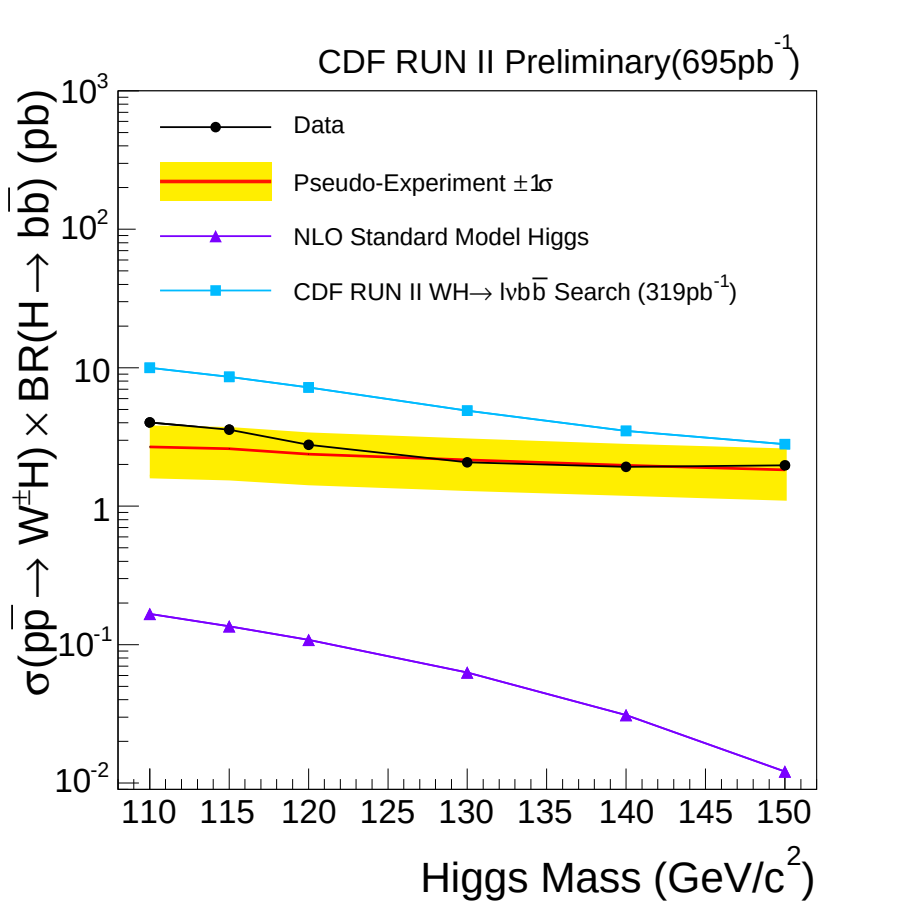
Events are selected with:

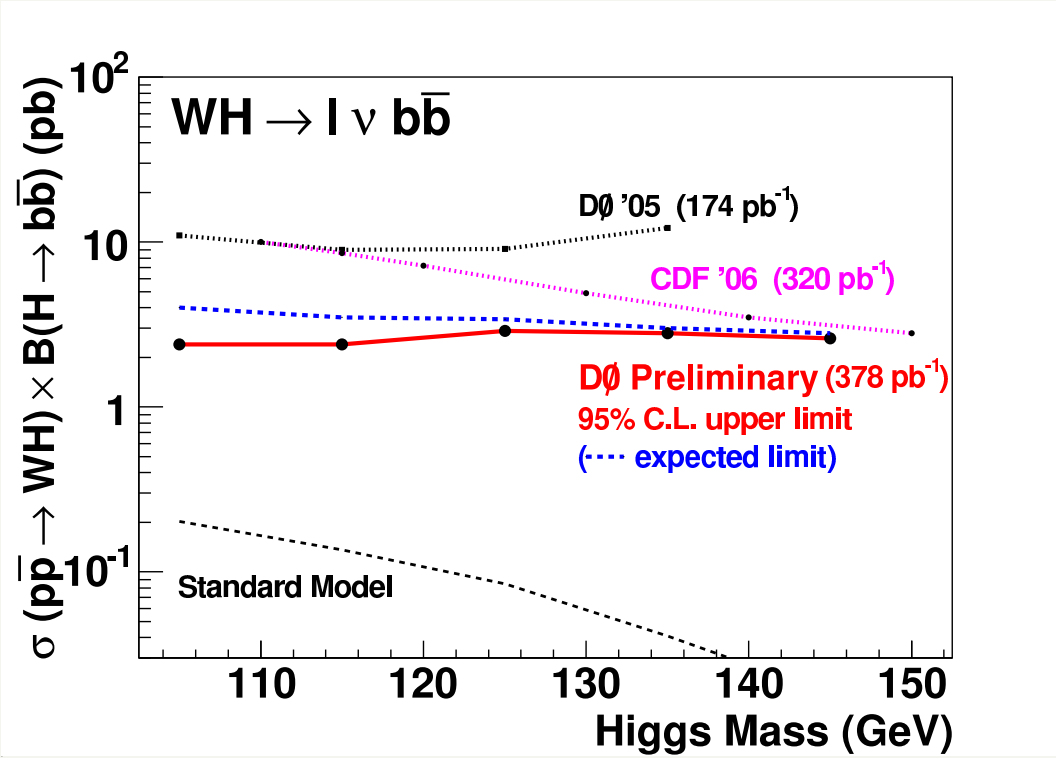
- W selection: one electron or muon and $\not\!\!E_T$
- H selection: two hadronic jets
- At least one jet identified as coming from a b quark
- Separating in exclusive single-tag and inclusive double-tag events.

Invariant mass is the key variable to reduce the final background.

Final limits set by cutting in a mass-window cut (D0) or mass-shape fit (CDF) to optimize the sensitivity.

$WH \rightarrow l\nu b\bar{b}$: Limits





- **Limits still far above to the expected cross section (from the SM)**
- **Large improvement in sensitivity with increasing data, improved analysis techniques.**
- **Experiments are adding the remaining data, already available**

$ZH \rightarrow \nu\bar{\nu}b\bar{b}$ (I)

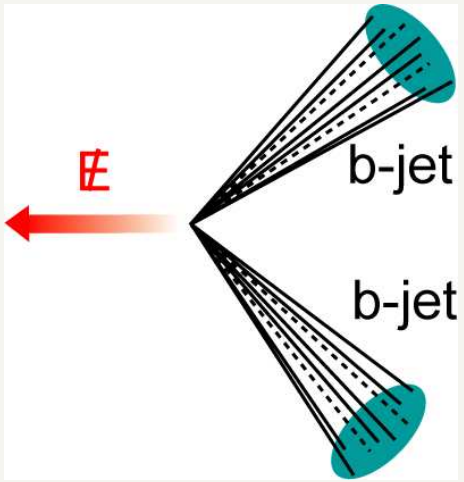
- **Signal is expected to have large $\not\!\!E_T$ and two jets**
- **Selection very similar to both experiments**

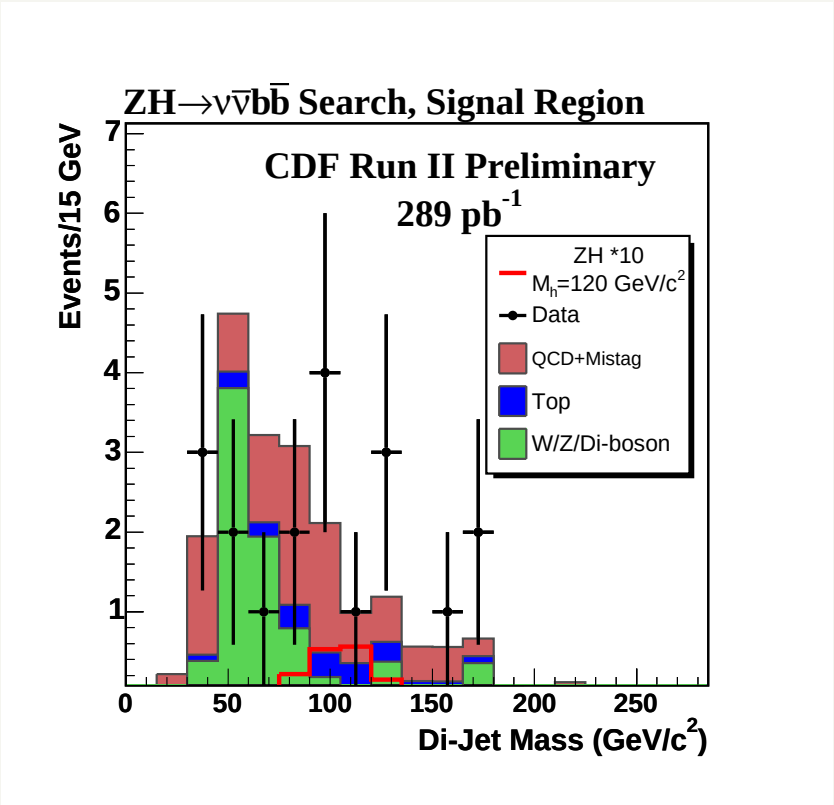
Two jets with $E_T > 60, 25$ GeV (and veto multijet)

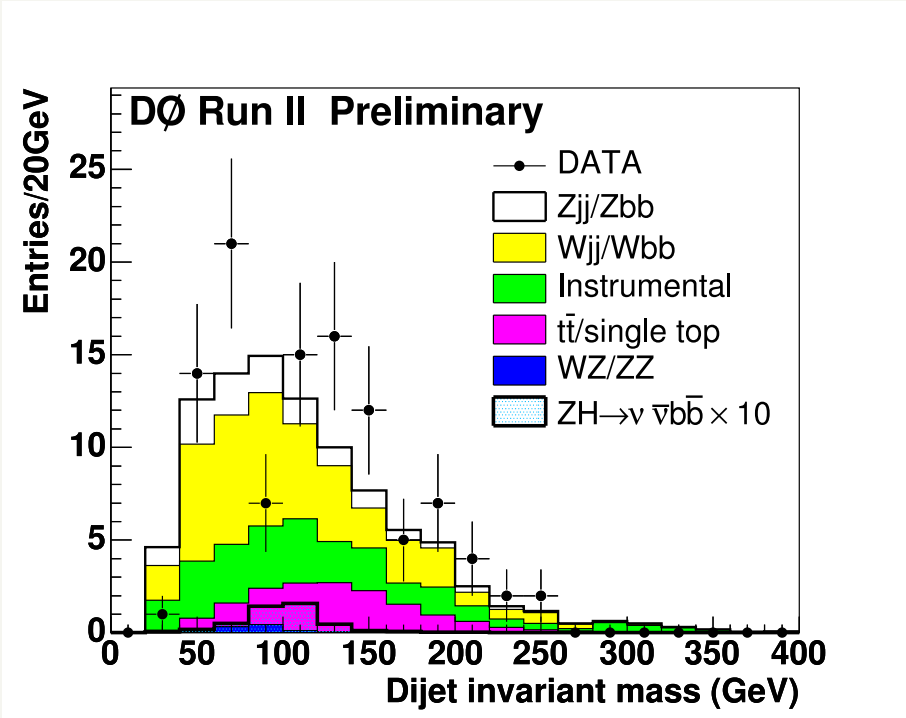
Vetoing leptons (CDF) or isolated tracks (D0)

$\not\!\!E_T > 50$ (D0), 70 (CDF) with cut on jet-direction

D0 splits into single and double tag events



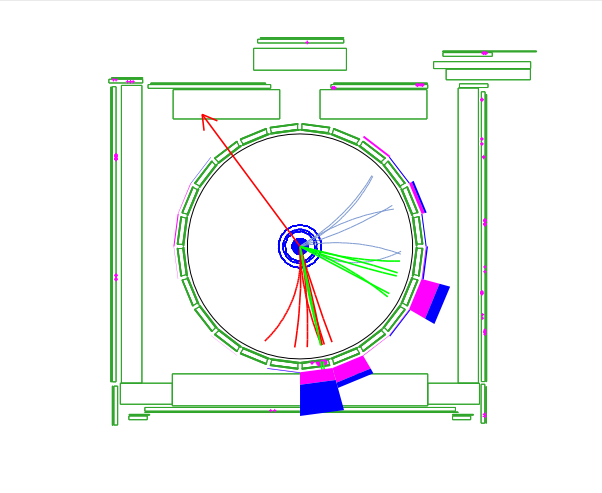


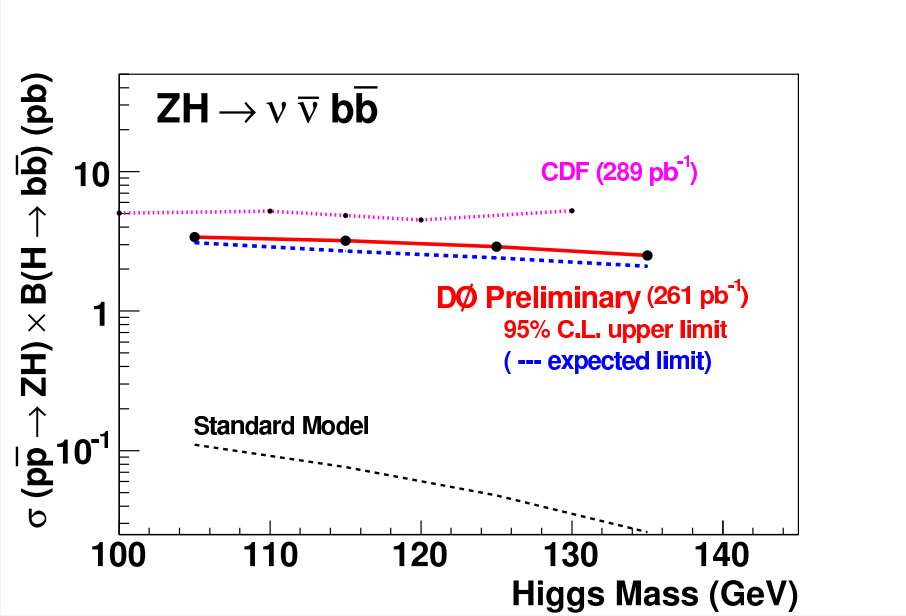


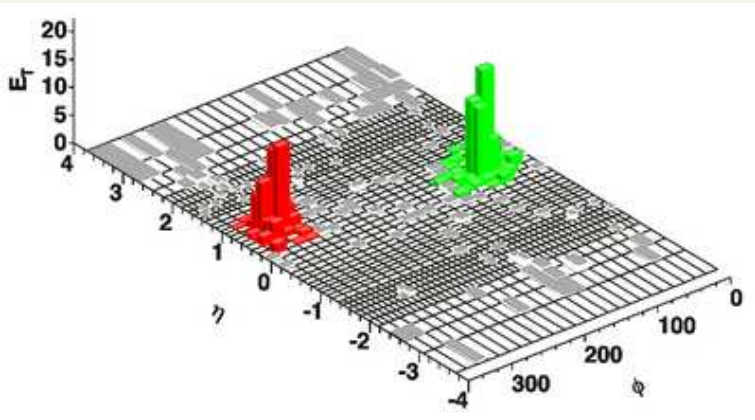
$ZH \rightarrow \nu\bar{\nu}b\bar{b}$: Limits

Some numbers before the dijet-mass cut:

Channel	Expected	Observed
CDF ($\leqslant 1$ b-tag)	19.7 ± 3.5	19
D0 ($= 1$ b-tag)	94.5	106
D0 ($\leqslant 2$ b-tags)	27.0	25







- Limits are clearly improving with time
- Expecting results from $ZH \rightarrow llbb$ soon

Information about this event:

$\not\!\!E_T = 98$ GeV

Dijet mass: 128.6 GeV/c^2

E_T (first jet): 84.7 GeV

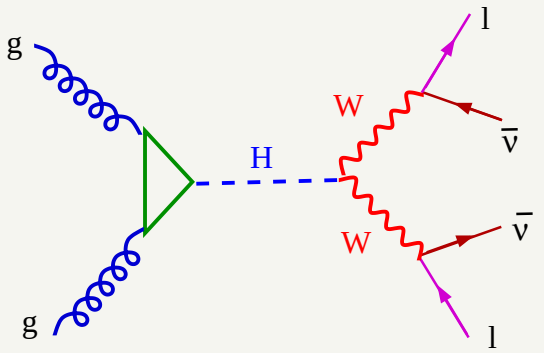
E_T (second jet): 71.9 (b-tagged)

$H \rightarrow WW \rightarrow l\nu l\nu$ (I)

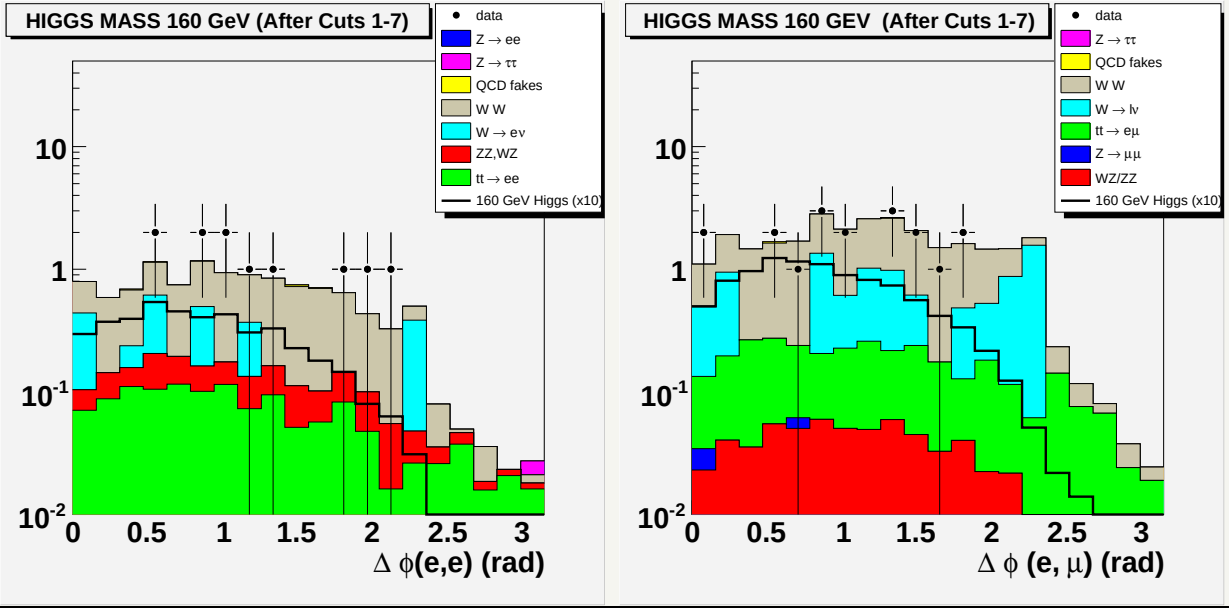
- **Selection cuts:**

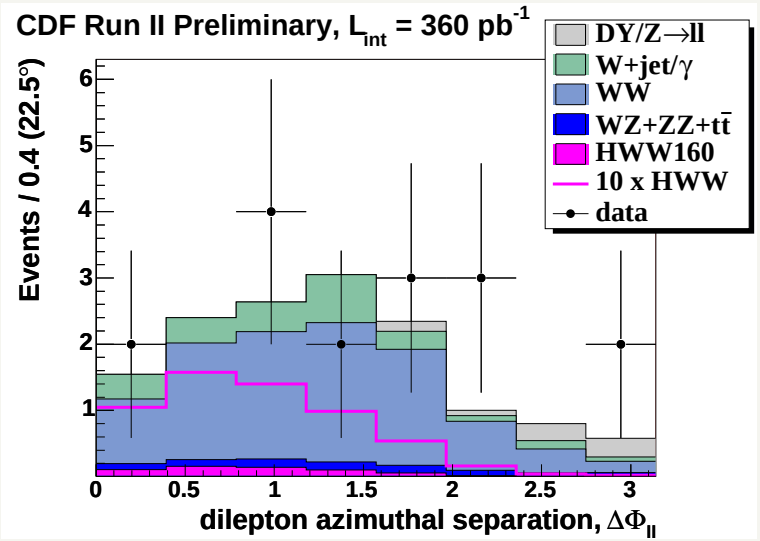
  Two opposite-charged leptons

  $\not\!\!E_T$ in the event

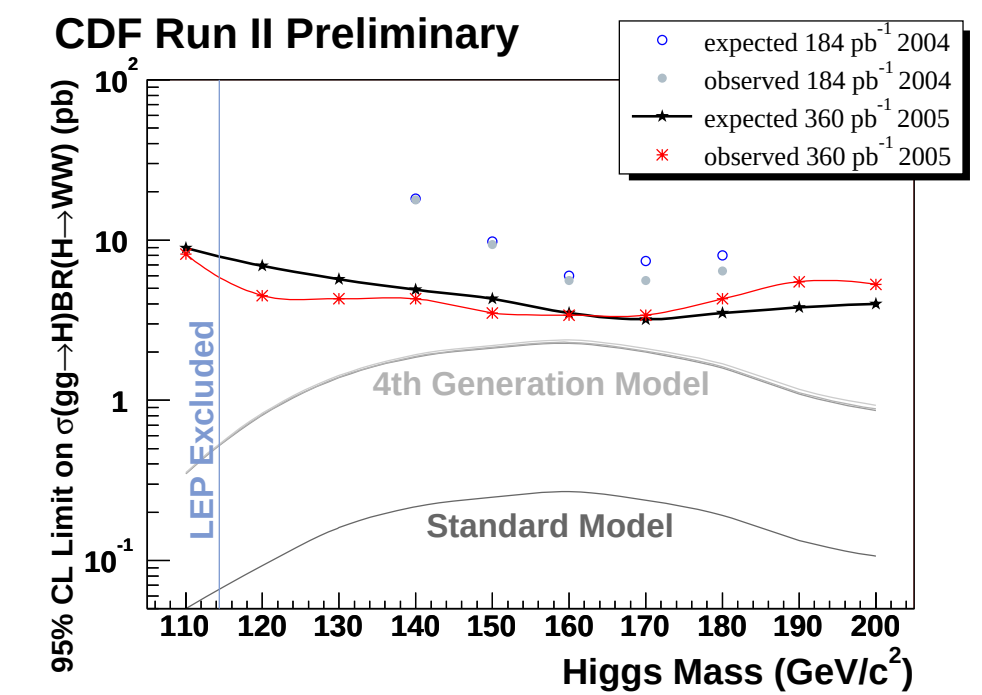


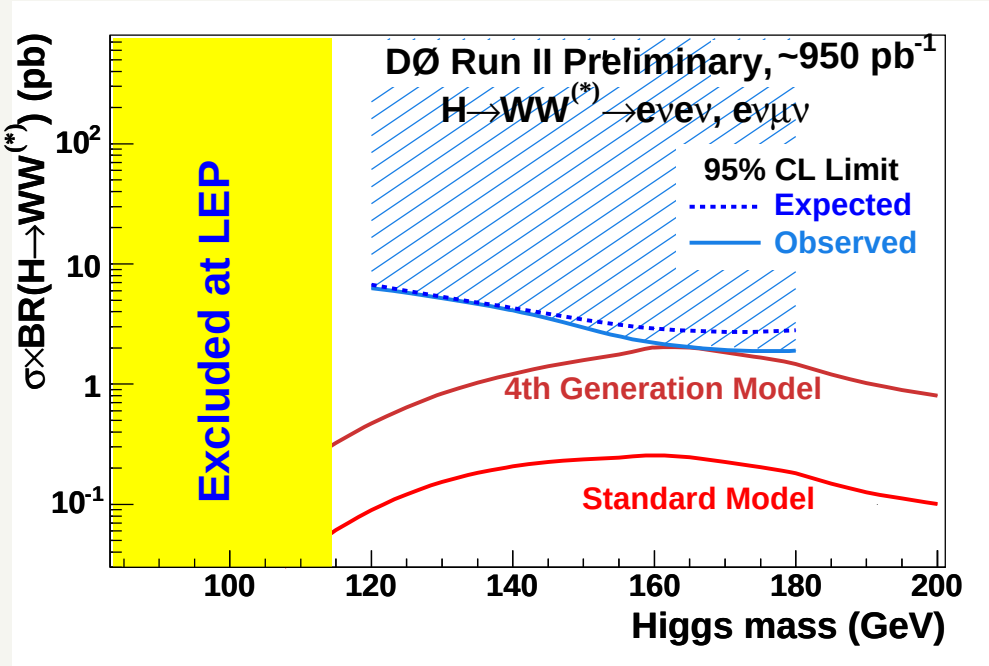
- **Due to the scalar nature of the Higgs Boson, the angular correlation between the W (and the charged leptons) is different than the dominant background (WW production)**
- **The kinematics depend on mass $\Rightarrow$ cuts are mass-dependent**
- **Amount of background depends on the cuts (i.e. on m_H)**





$H \to WW \to l\nu l\nu$: Limits

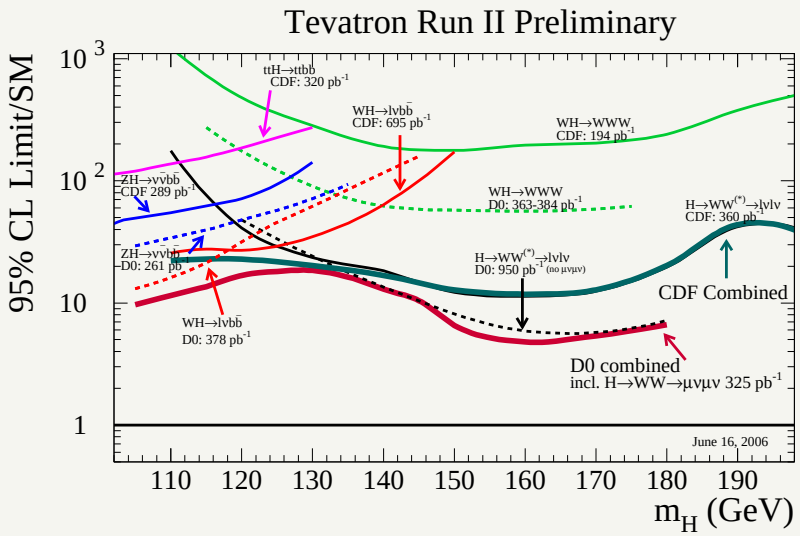


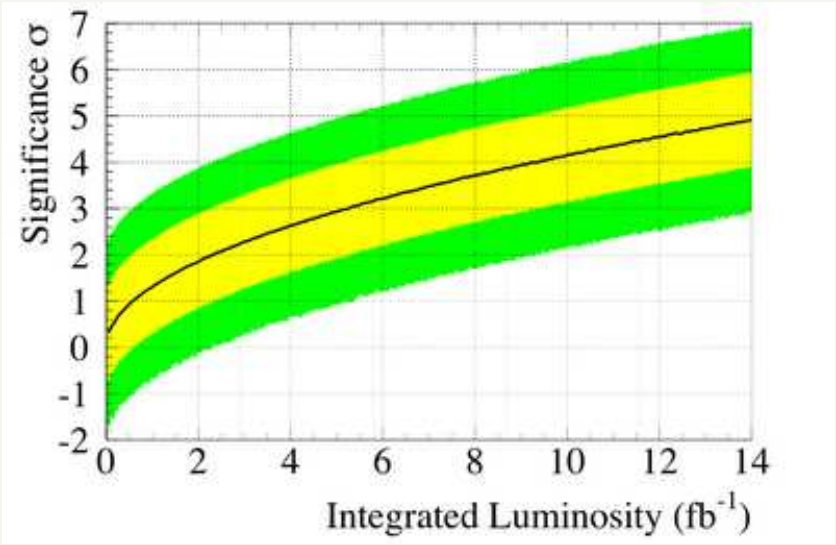


- **Far from the SM predictions, but sensitivity improving quickly**
- **Already excluding models with a 4^{th} generation**

Summary of the SM Higgs at Tevatron

⇒ **Limits and expected significance (with improvements)**





⇒ **Need to work on further improvements, especially**

- **Use of Neural-Networks for selecting events**
- **Dijet mass resolution**
- **Increase lepton accepance**

⇒ **Need to accumulate more Integrated Luminosity (increase of a factor 6-10 for Run II)**

⇒ **Starting to combine in each experiment and plan to combine CDF and D0 results.**

⇒ **Chances of observing the Higgs for low masses (difficult range for LHC)**

The Higgs sector at the MSSM

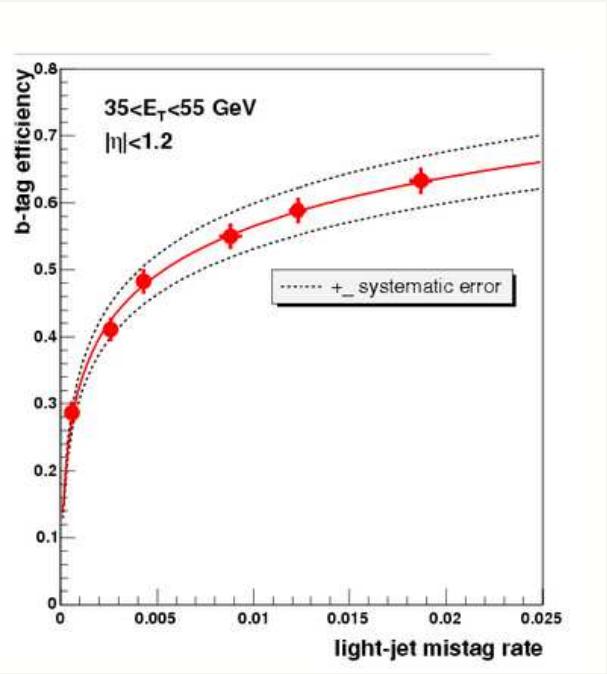
- In the MSSM we expect 5 Higgs bosons: h, H, A and $H^{\pm}$ due to two complex Higgs doublets (to avoid anomalies)
- Prediction: $m_h \leqslant 135$ GeV/c^2
- For the neutral Higgses:
  - $\longrightarrow$ Coupling of down-type fermions to Higgses enhanced for high $\tan\beta$
  - $\longrightarrow$ Preferred Decay into bb (90%) and $\tau\tau$ (10%), almost independent of $\tan\beta$.
  - $\longrightarrow$ b-tagging and tau identification are fundamental tools
- For the charged Higgses (not covered here)
  - $\longrightarrow$ Produced in top decays (most accessible mode at the Tevatron)
  - $\longrightarrow$ Look for differences in the topological final states from SM top production

Strategy to search for the Neutral Higgs (MSSM)

- The strategy is to look for the dominant decay modes
- In the case of $\phi \longrightarrow bb$

  $\longrightarrow$ Production in bbH to reduce background.

  $\longrightarrow$ Multi-tag selection (need of high efficiency in b-tagging)

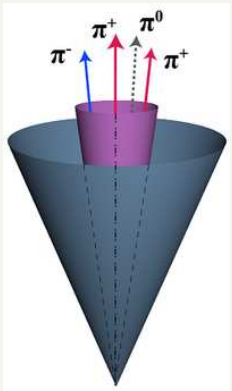


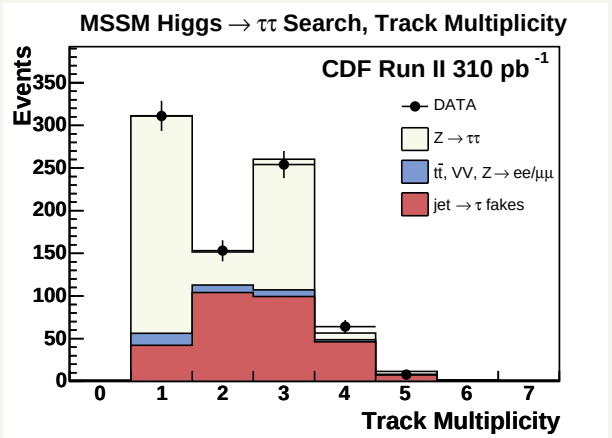
- In the case of $\phi \longrightarrow \tau\tau$

  $\Rightarrow$ **Efficiency:** Need to identify and reconstruct hadronic decays

  $\Rightarrow$ Algorithms are intended for isolated τ which may be used in several analyses to test the SM predictions and in searches.

  $\Rightarrow$ **Purity:** reduction of contamination from hadrons which pass the τ ID selection.





MSSM Higgs in the 4-b channel

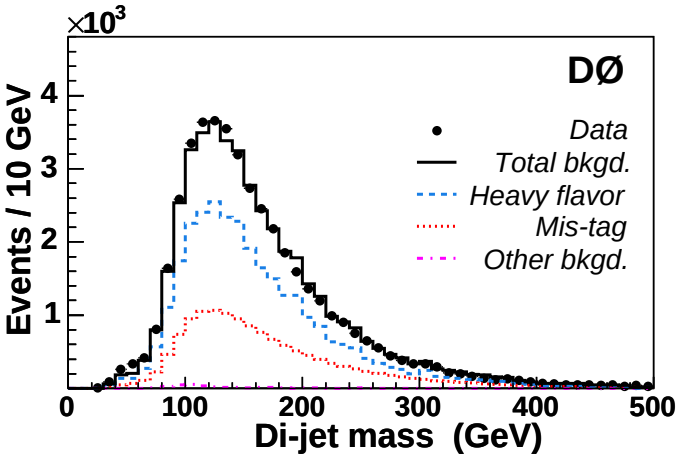
Production of Higgs in association with b-quarks is enhanced in extensions of the SM such as MSSM with large $\tan\beta$.

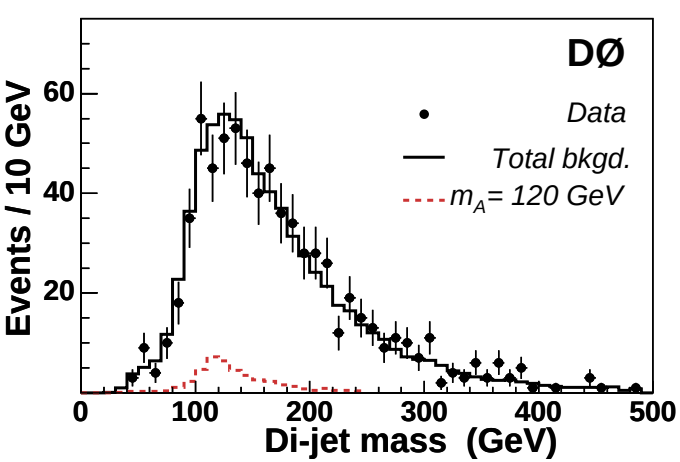
Selecting events with at least two and three b-tagged jets

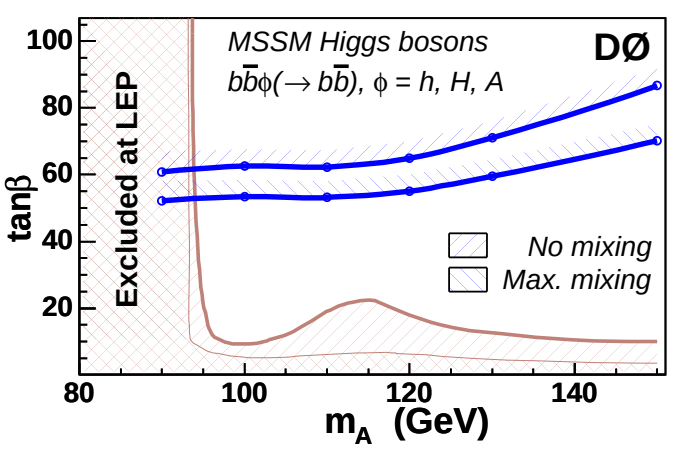
$\Rightarrow$ For the three-tag selection, taking shape from the 2 b-jets and 1 mistag sample.

$\Rightarrow$ Normalization obtained from data (i.e. real three b-jet backgrounds assumed to have the same shape) outside the signal mass window.

No excess observed over the predicted background.







CDF result with 1 fb^{-1} and updates from D0 are in preparation

MSSM Higgs in the tau channel

Although the tau channel has small branching ratio, it is much cleaner and allow observation of inclusive production.

It is also complementary to the 4-b analysis since it has different kind of uncertainties (e.g. different effect of backgrounds and ways to estimate them).

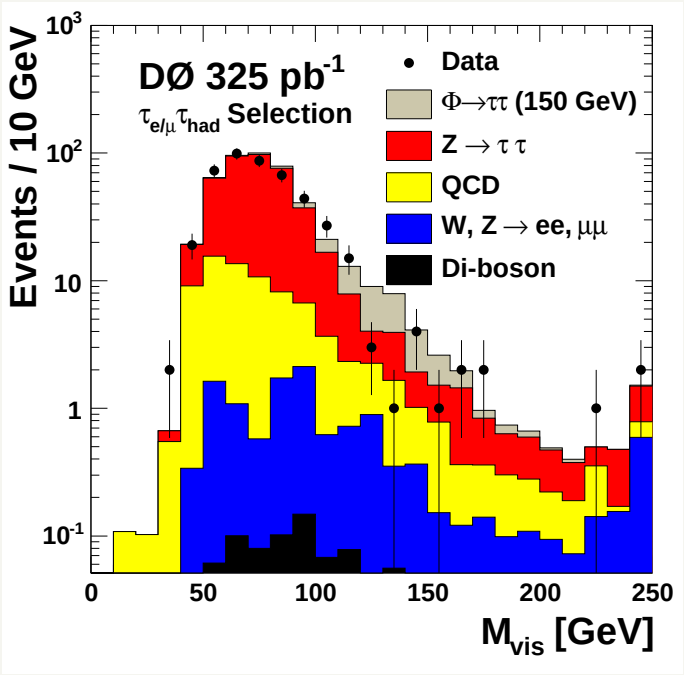
Big effort performed to understand hadronic tau's at Tevatron to avoid missing events in hadronic-tau decays.

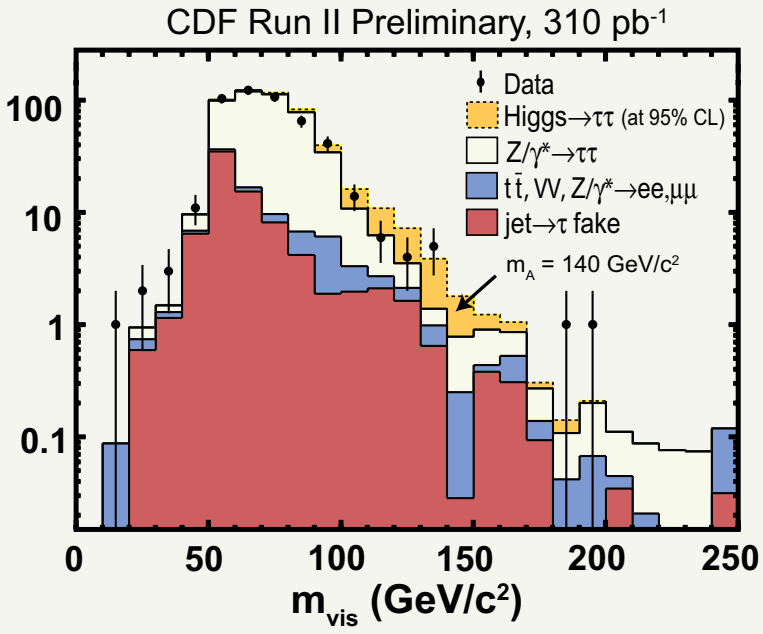
CDF uses $W \rightarrow \tau\nu$ as control sample

$Z \rightarrow \tau\tau$ is cleaner (useful to understand global τ selection) but selected events are potentially signal

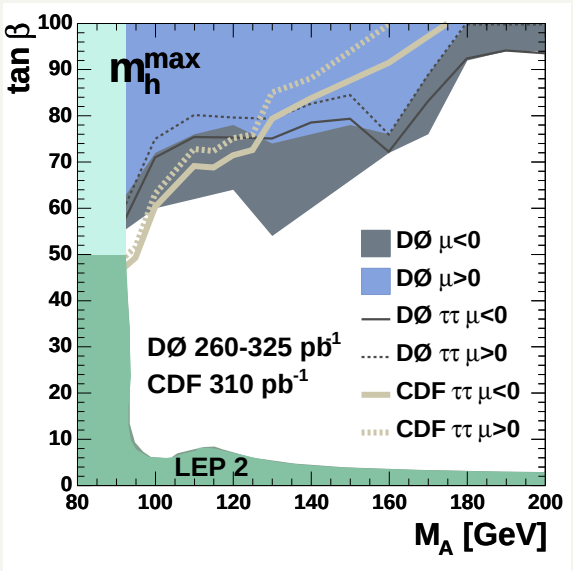
Good agreement with expected background:

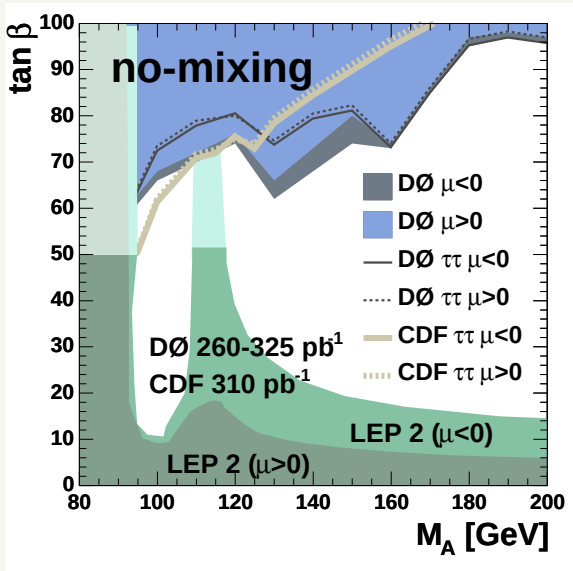
- **τ identification is under control**
- **No Higgs discovery (yet…)**

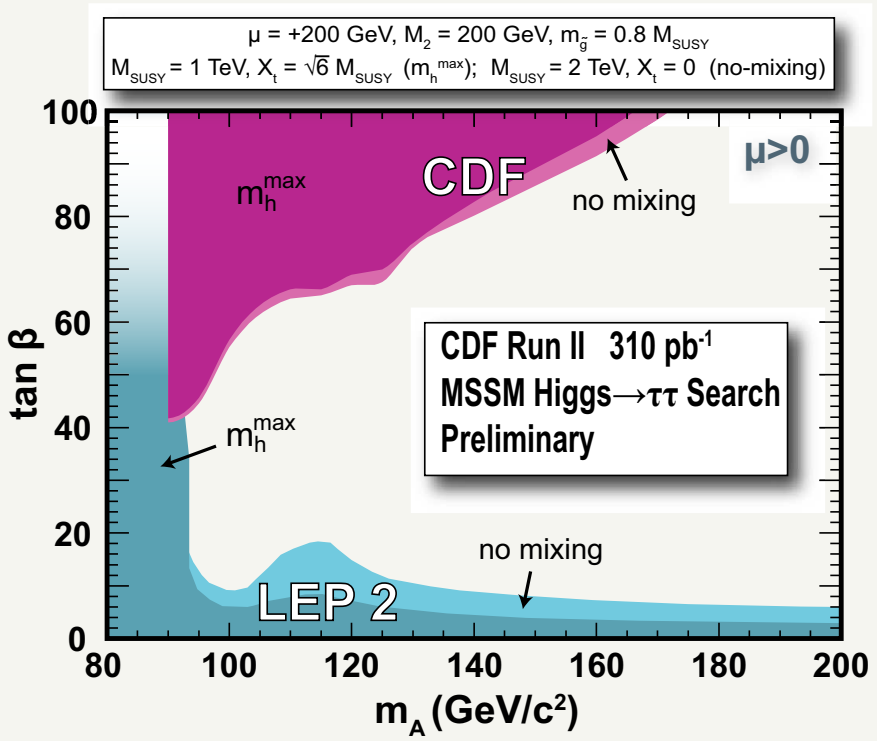




MSSM Higgs in the tau channel: Limits





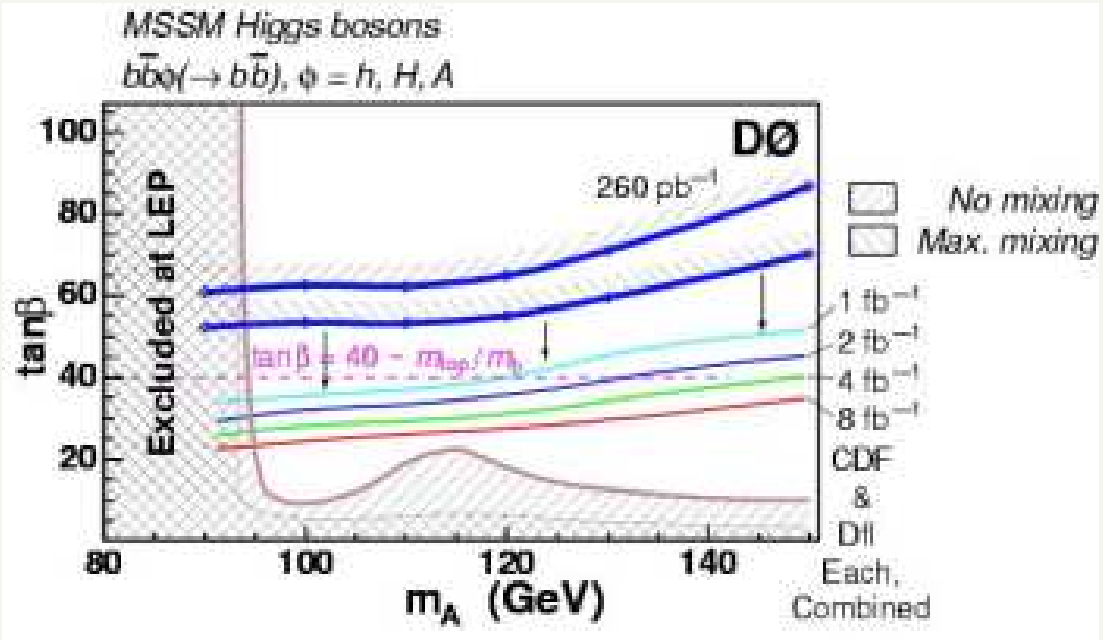


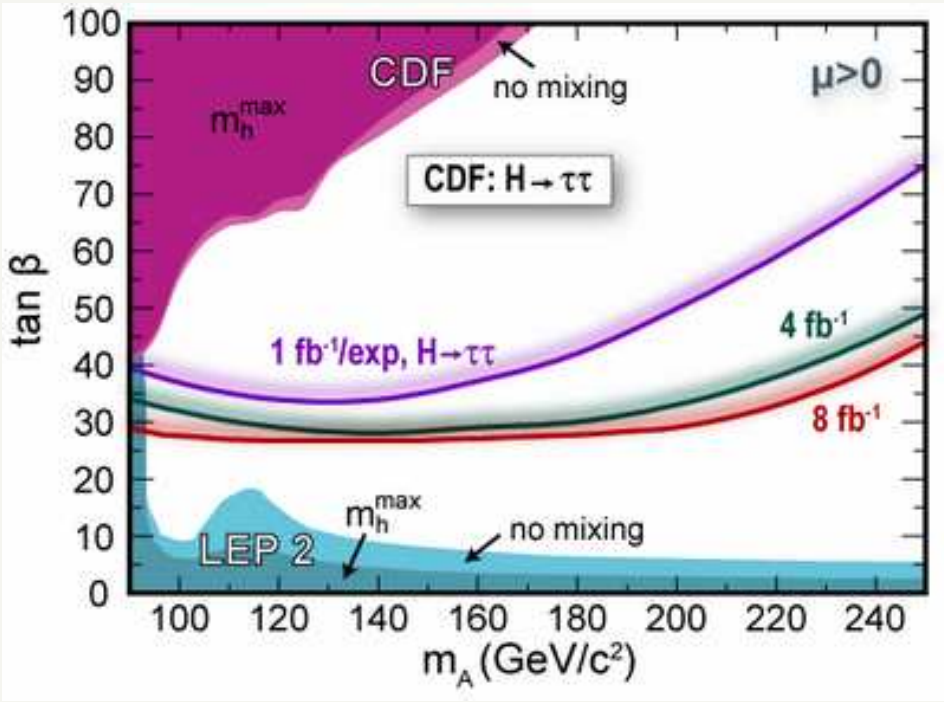
- D0 results combine the tau and the b channels
- New regions have been excluded with the current analyses
- Expecting big increase in sensitivity with larger data samples

Summary and plans for MSSM Higgs at Tevatron

⇒ **Much better prospects than for SM: already excluding unexplored regions.**

⇒ **Large gains in sensitivity in the short term (until systematics dominate)**



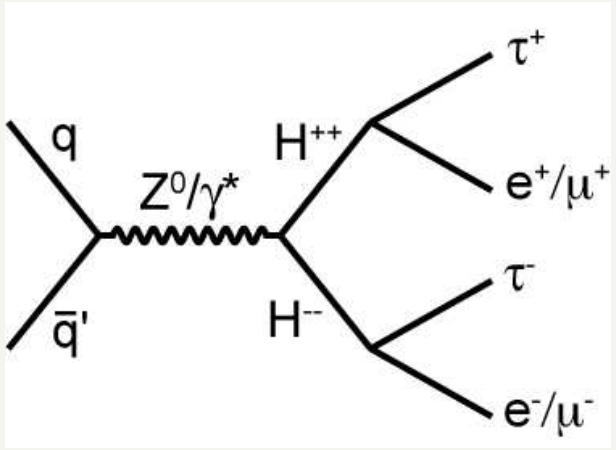


Results with 1 fb^{-1} will be coming soon and check how realisticly these predictions were done.

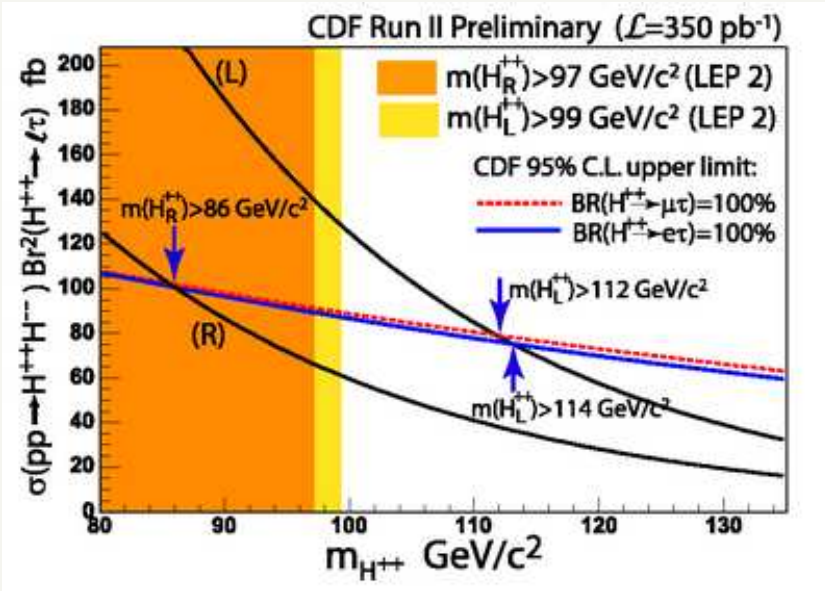
Other Higgs searches: Doubly-charged Higgs

$H^{++/--}$ predicted in extensions of the SM in L/R symmetric models (and H^{++} can have a mass ~ 100 GeV/c^2)

- **Electroweak pair production of $H^{++}H^{--}$**
- **Published CDF results in e/mu surpass the LEP limit**
- **Selection requires**
  - → **Two categories: 3 or 4 leptons (at least one e/μ and one τ)**
  - → **Background suppression done requiring large $\sum E_T$ for the identified leptons and vetoing lepton pairs in the Z-peak ($71 < m < 111$ GeV/c^2)**



- **Expected SM backgrounds:**
  $\sim 0.3(0.4)$ **for the $e\tau(\mu\tau)$ channels**
- **No events were found in either channel.**
- **Limits set by treating the 3 and 4 lepton channels separately.**
- **Limits are better for H_L^{++} than for H_R^{++}, and going beyond LEP values.**



Summary and Outlook

- Overview of the Higgs-search analyses performed at Tevatron.
- Some results not covered here (and those covered, very briefly): large effort invested in Higgs searches.

Do not forget to check the CDF and D0 web pages for details!

- No big news yet, but we are optimist for the near future, especially for MSSM Higgs searches, which is already exploring "untouched" regions.
- Tevatron and the experiments are performing well
- Much more data to be analyzed: results with new data coming soon.
- Plans in Run II for search analysis
  - $\Rightarrow$ 1 fb^{-1} already collected
  - $\Rightarrow$ $4-8$ fb^{-1} expected for end of shutdown (2009)
  - $\Rightarrow$ Working on improvements to get the most of the data
  - $\Rightarrow$ Optimistic about SM Higgs searches at the Tevatron
  - $\Rightarrow$ Working on combinations of analyses.

The best from Run 2 is yet to come!