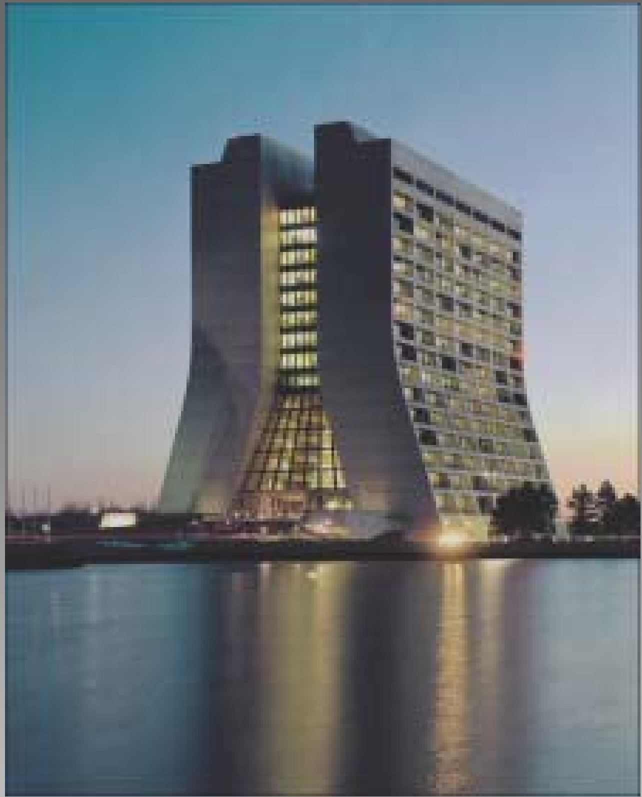


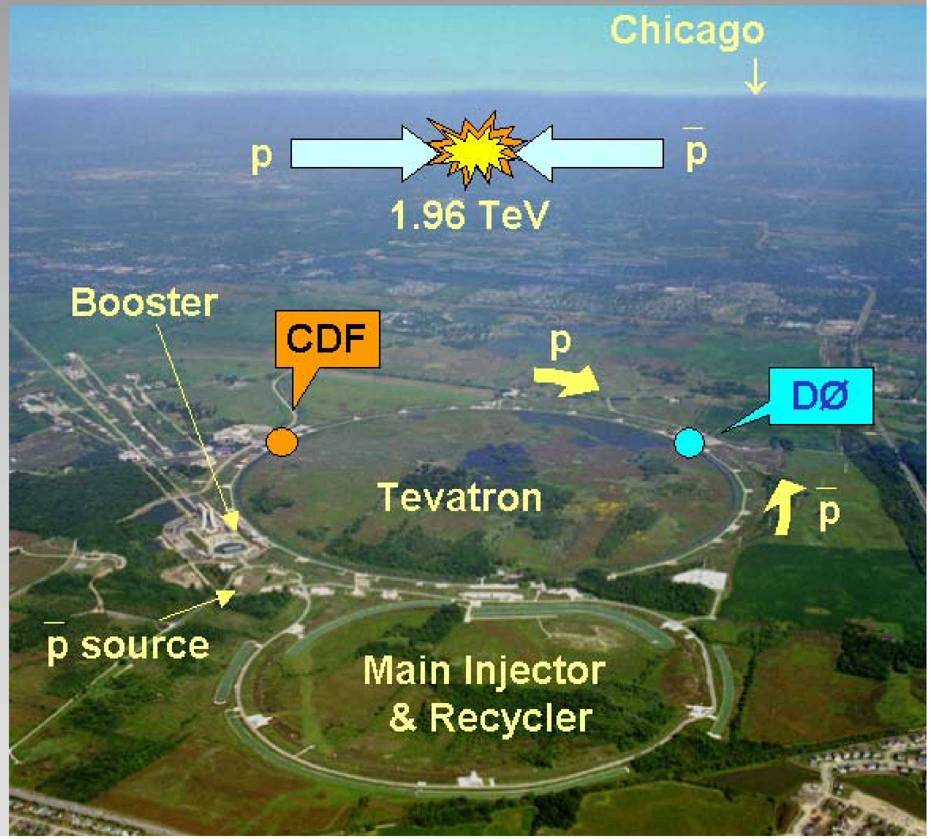
Searches for the SM and MSSM Higgs Bosons at CDF - II

Giorgio Cortiana, University of Padova and INFN

Representing the CDF Collaboration

Contents:

- Run 2 at the Tevatron
- Higgs Sensitivity WG predictions
- SM Higgs searches
- MSSM and beyond searches
- Conclusions



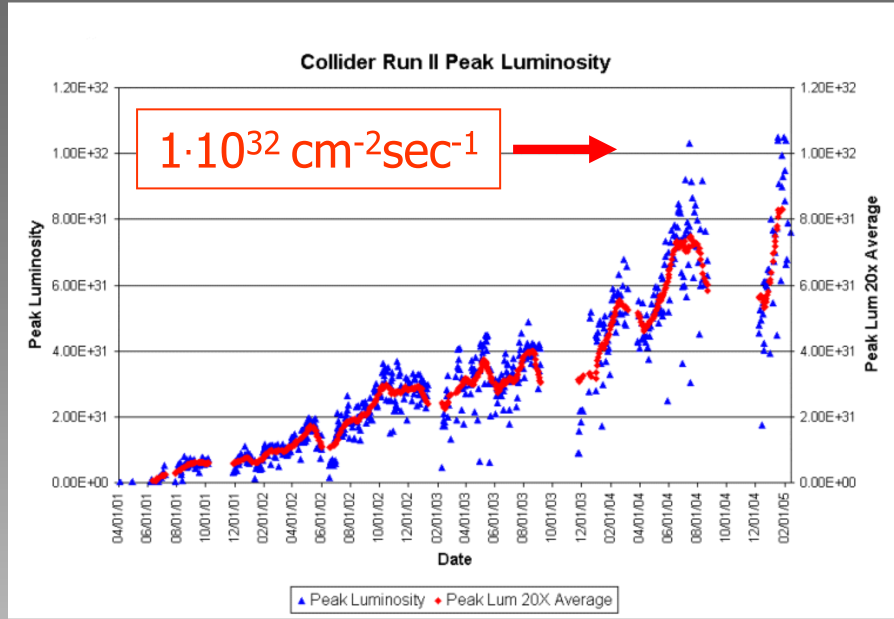
Tevatron Run 2 – Quick Overview

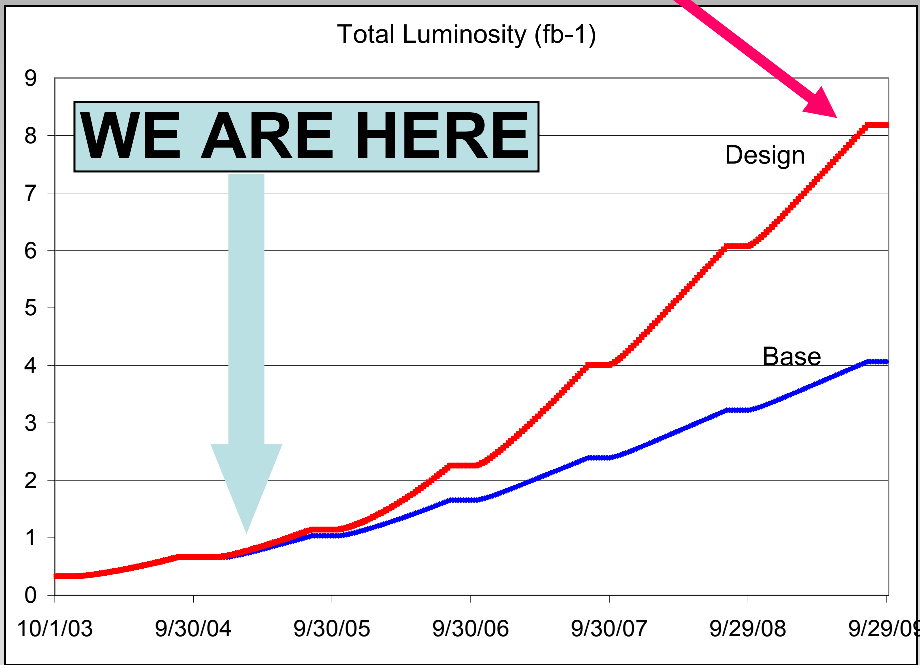
Tevatron is performing well – delivered 800 pb^{-1} so far. L_{start} above 10^{32} now common.

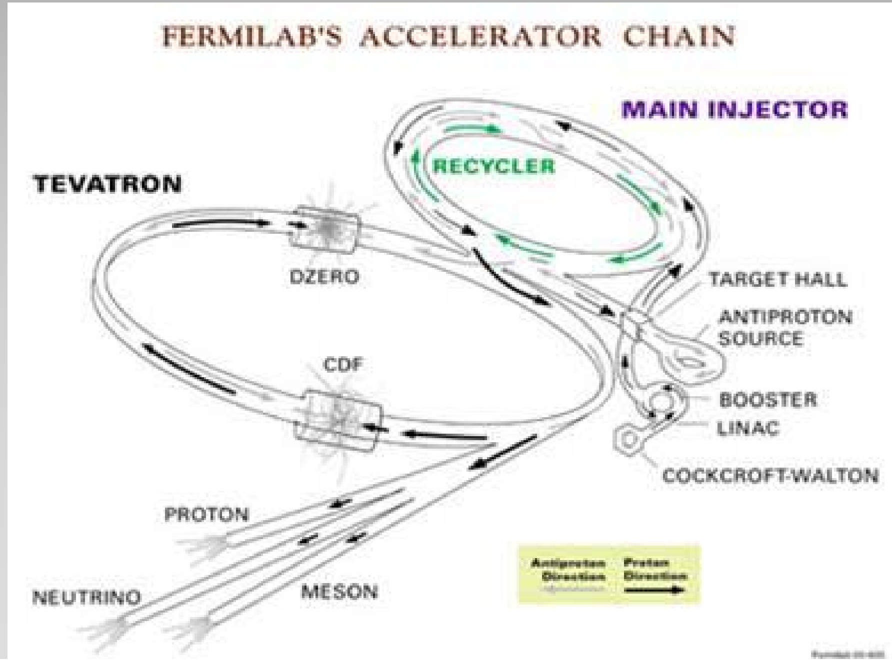
L has been following design curve!

As L increases, CDF catching up by modifying trigger tables, improving DAQ

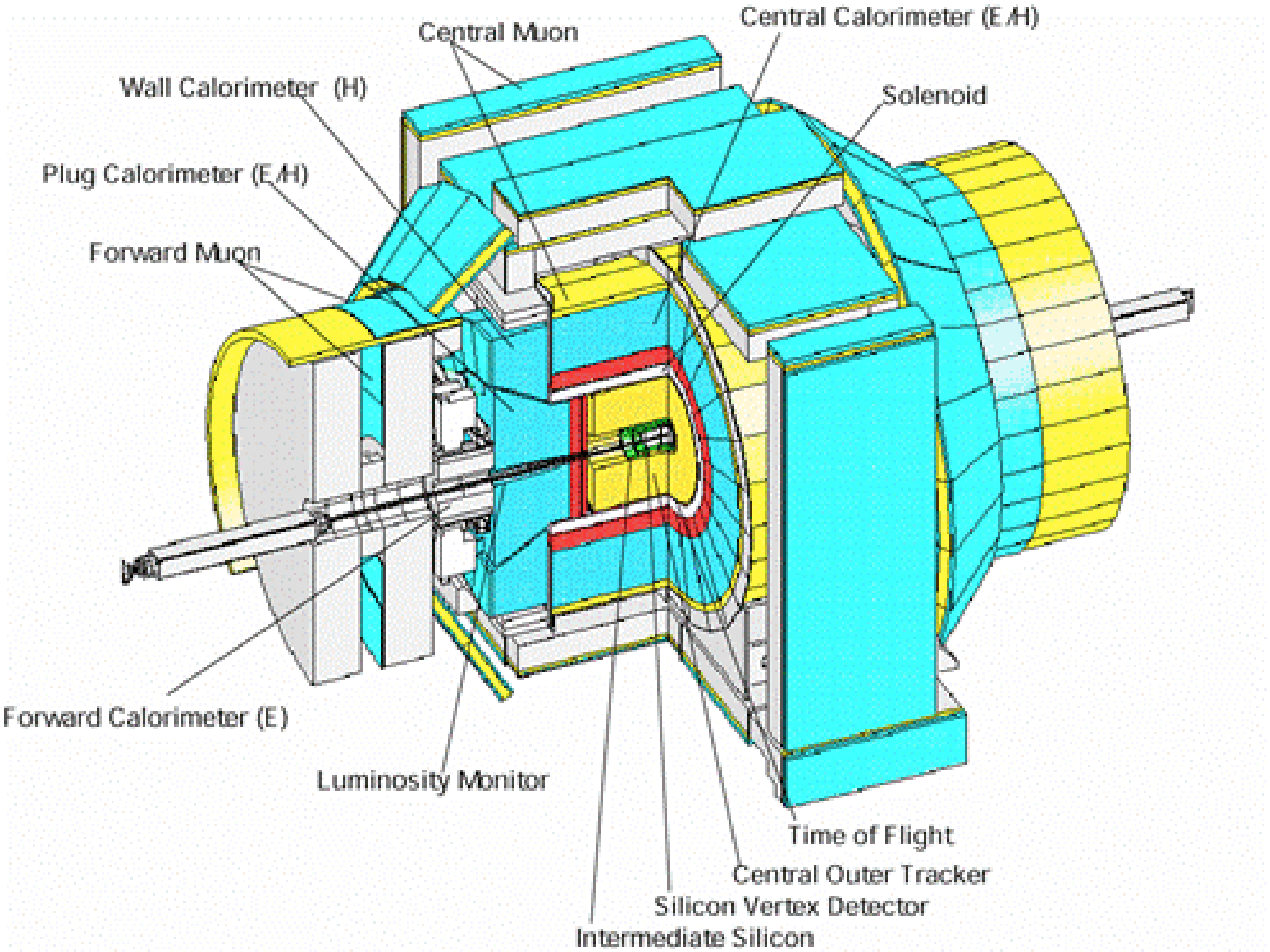
Design curve means 8 fb^{-1} by 2009!

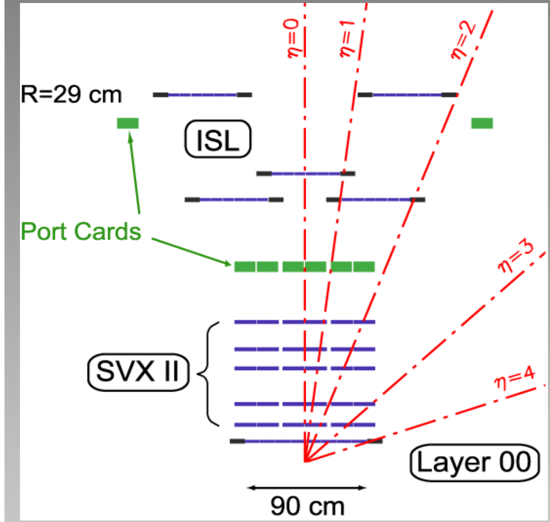


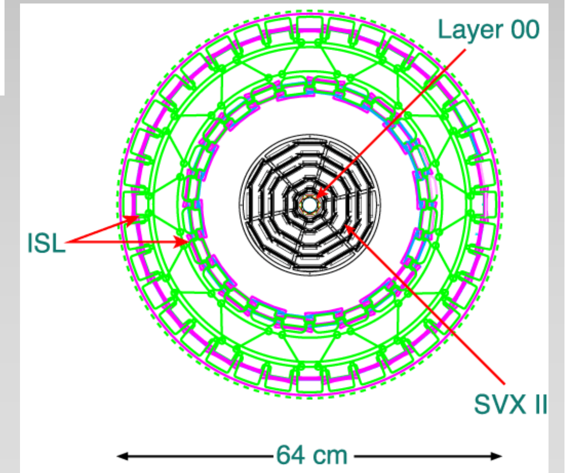




CDF II at a glance

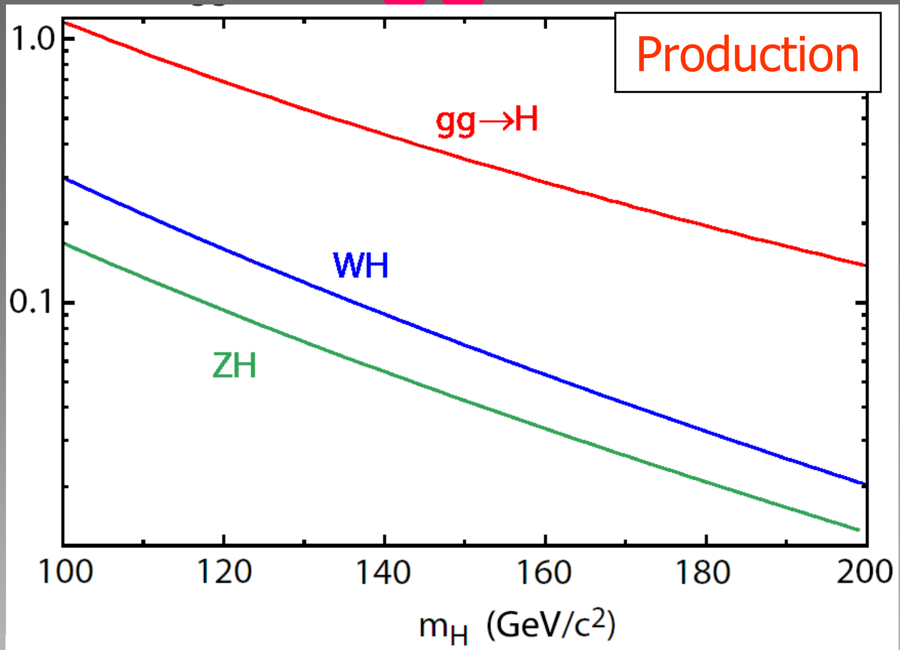


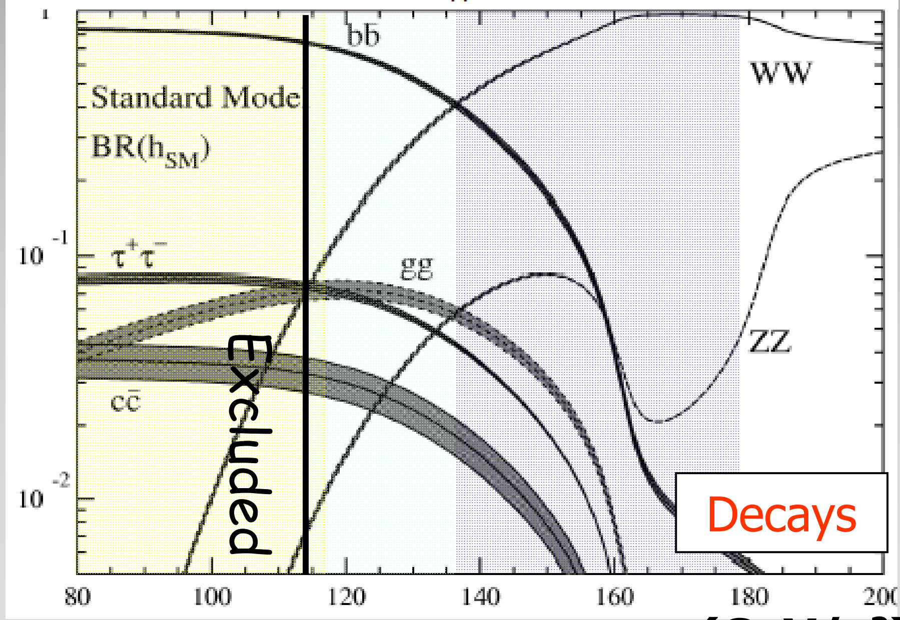




Counting outwards from the beampipe central line, the detector is comprised of a silicon vertex detector (SVX II), a multiwire drift chamber (COT) for particle tracking, lead-scintillator electromagnetic calorimeters, iron-scintillator hadronic calorimeters and drift-tube chambers and scintillators for muon detection.

SM Higgs: Production and Decays





m_H (GeV/c^2)

Production cross section

- in the 1.0-0.2 pb range for gg → H
- in the 0.5-0.03 pb range for VH → H

Dominant Decays

- bb for M_H < 135 GeV
- WW* for M_H > 135 GeV

Search strategy:

M_H <135 GeV associated production and bb decay W(Z)H → lν(ll/νν) bb
Backgrounds: top, Wbb, Zbb…

M_H >135 GeV gg →H production with decay to WW
Backgrounds: electroweak WW…

But also:

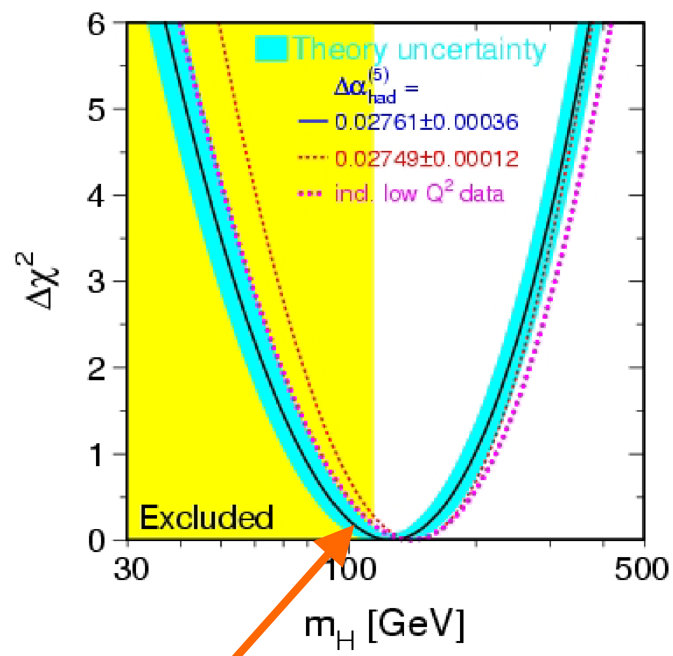
M_H >135 GeV also WH→WWW(*) is Interesting! striking signature of missing Et plus three leptons, two of which may be of the same charge but different flavor

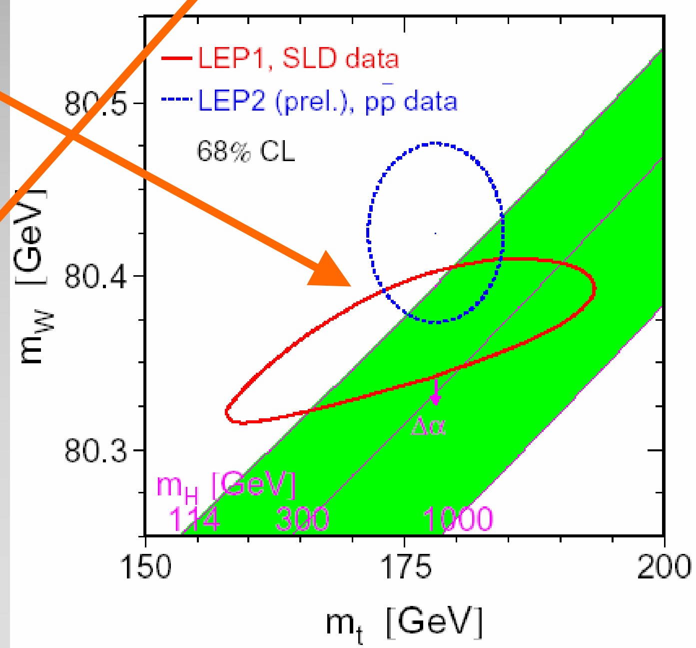
What we know about the SM Higgs

- LEP experiments have collected a wealth of information on the Higgs boson through comparisons of EW observables to EW theory + radiative corrections

- From theory we know its couplings, its decay modes, and how its mass impacts the W and top masses.
- If it exists, then we know its mass with about 60 GeV accuracy, and the direct search limit already cuts away a large part of the allowed mass region

- Latest LEP results: **$M_H=126^{+73}_{-48}$ GeV**, **M_H<280 GeV @ 95% CL** (Winter '05).



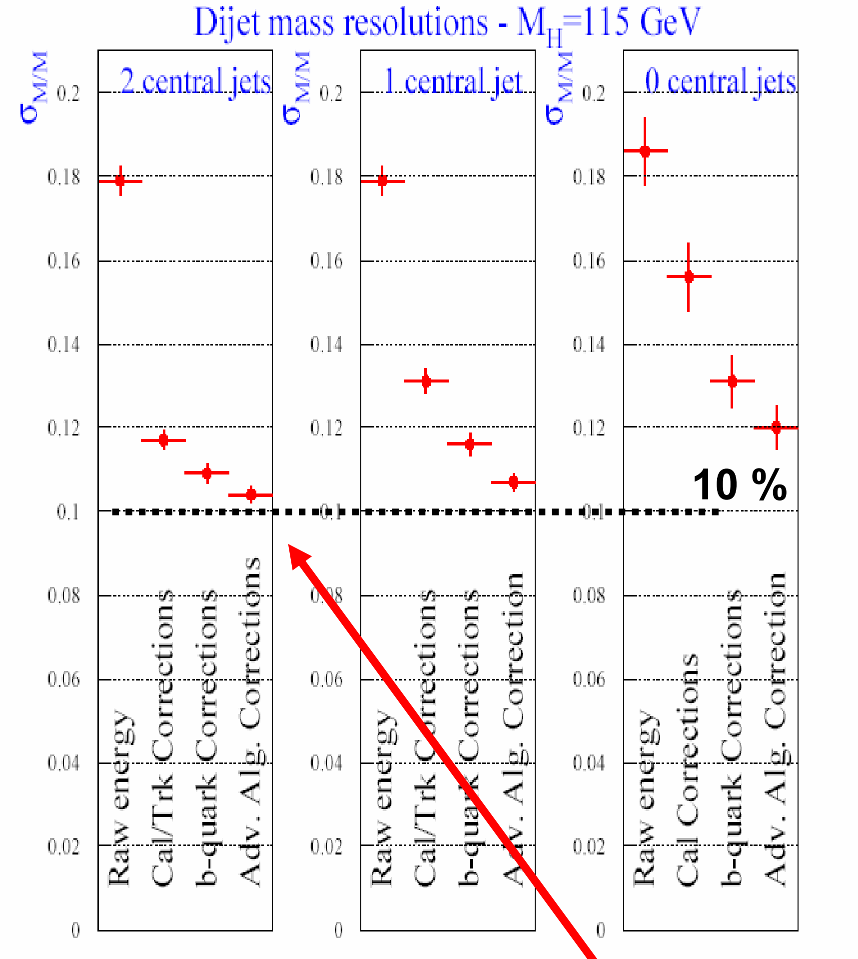


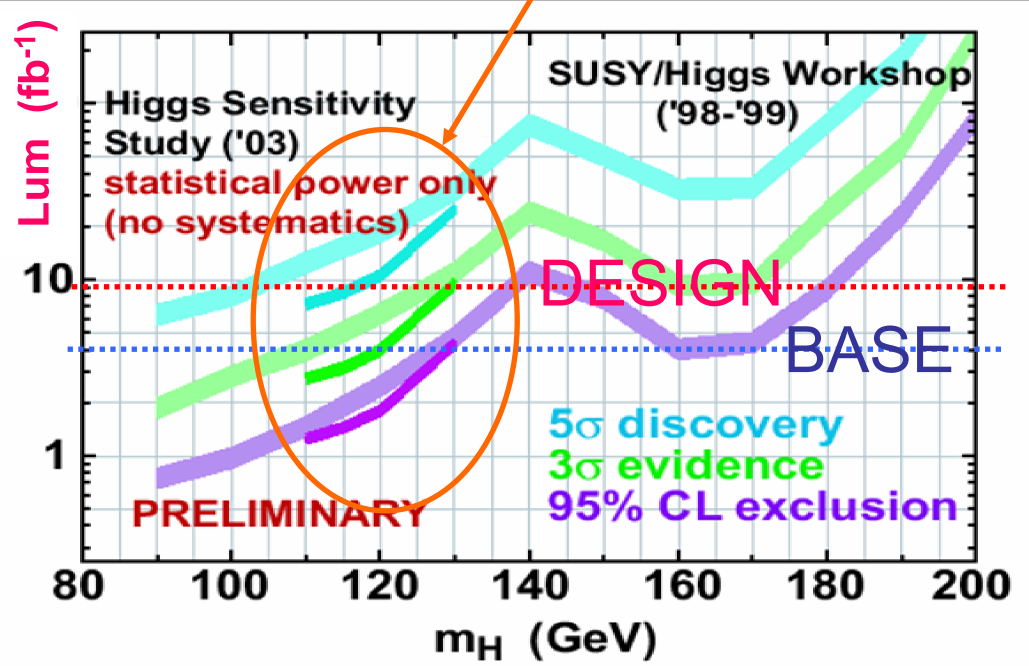
Higgs Sensitivity WG Predictions

In 2003 the Tevatron chances for Higgs discovery were re-evaluated

Idea: with available data and operating detectors, can better assess Tevatron reach

Surprisingly, the new results meet or exceed 1998 Susy/Higgs WG ones.



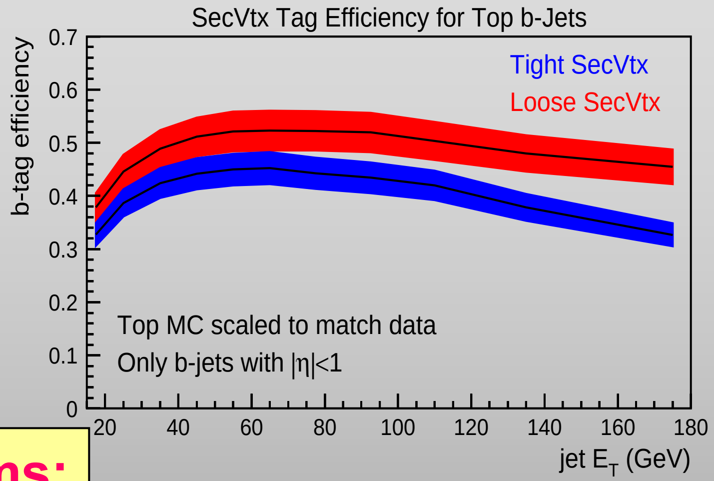


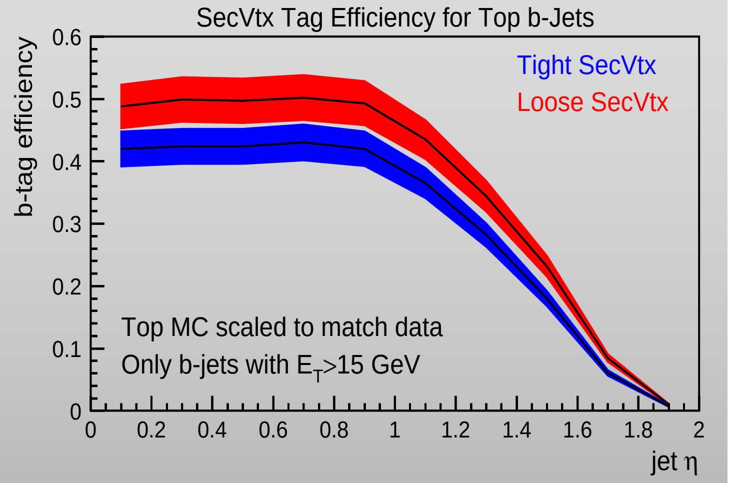
Keys to success:

- mass resolution improvements;
- optimized b-tagging;
- shape information vs counting.

Tagging b-jets

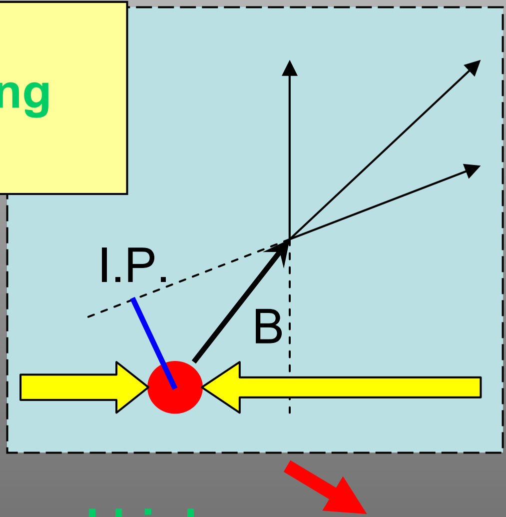
Identifying b-jets is of paramount importance for low-mass Higgs boson searches.

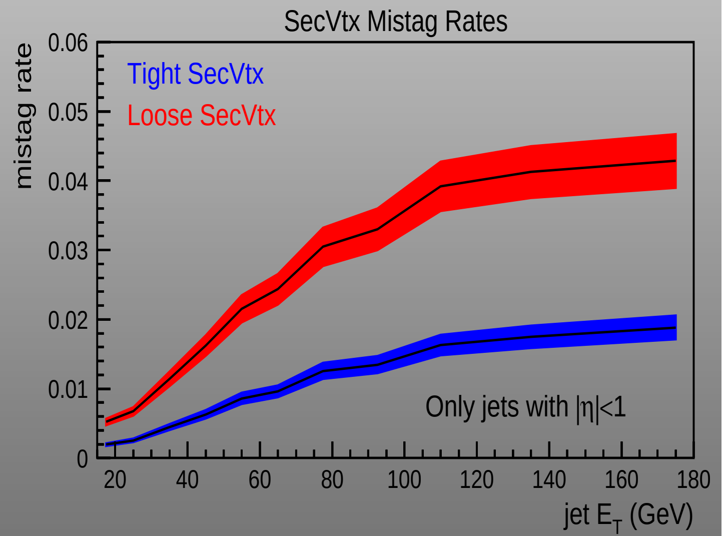




Tagging Algorithms:

- **Soft lepton tagging**
- **SECondary VerTeX tagging**
- **Jet Probability tagging**





For double tag searches, efficiency factors get squared! To retain signal, we need to have loose and tight tagging options

Efficiency drops at low jet Et and high rapidity but is 45-50% for central b-jets from Higgs decay

Mistag rates are kept typically at 4-5%

Secondary Vertex tagging: tracks with significant IP are used in a iterative fit to identify the secondary vertex inside the jet

Can we see dijet resonances?

A low mass Higgs search entails believing that we can:

- Appropriately reconstruct hadronically-decaying objects
- Accurately understand our background shapes

All of that can be proven if we see the Z→bb decay in our data.

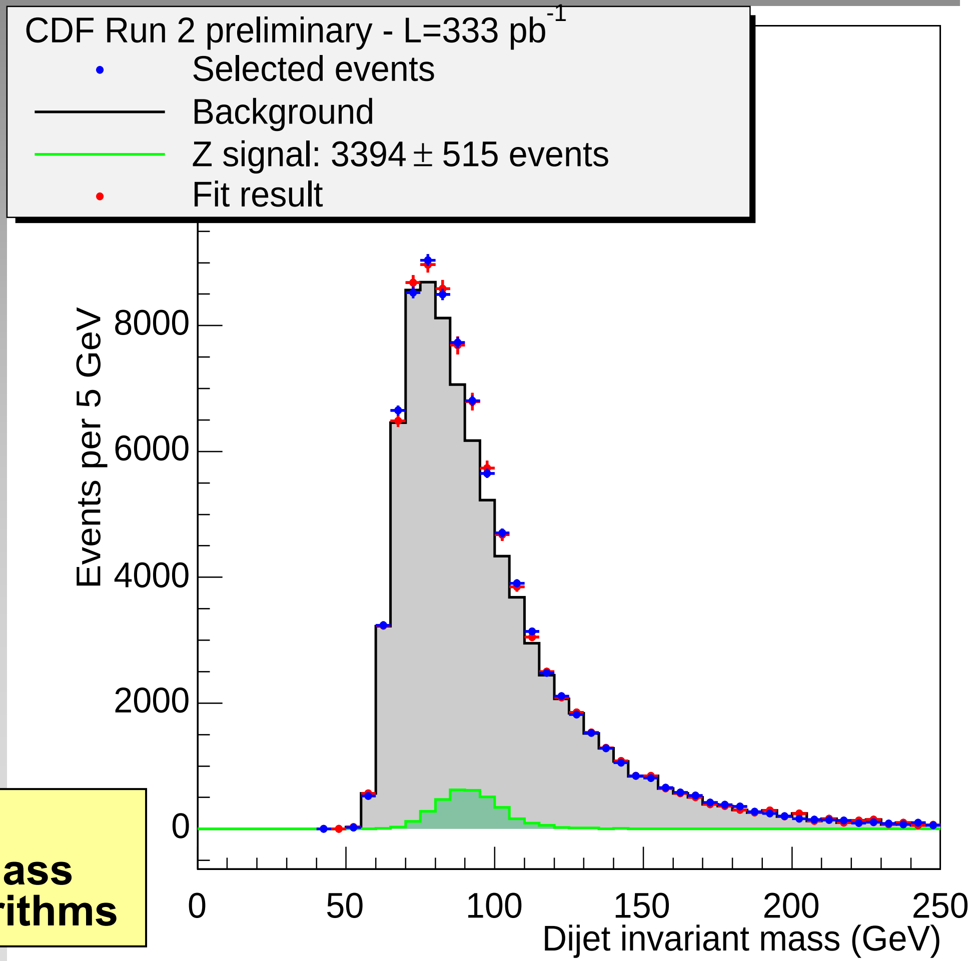
Double b-tagged events with no extra jets and a back-to-back topology are the signal-enriched sample:

E_t^3<10 GeV, $\Delta\Phi_{12}$>3

Among 85,784 selected events CDF finds 3400±500 Z→bb decays

- signal size ok
- resolution as expected
- jet energy scale ok!

CDF expects to stringently constrain the b-jet energy scale with this dataset



This is a good testing ground for H!

- **can use to test/improve dijet mass resolution with advanced algorithms**

Final SM Higgs Results @ CDF- I

The only chance to see H→bb at the Tevatron is through associated production with bosons

ZH→llbb is the cleanest signature, but it yields too few events

W/ZH→jjbb has the lowest S/N but the high BR helps at larger Higgs mass

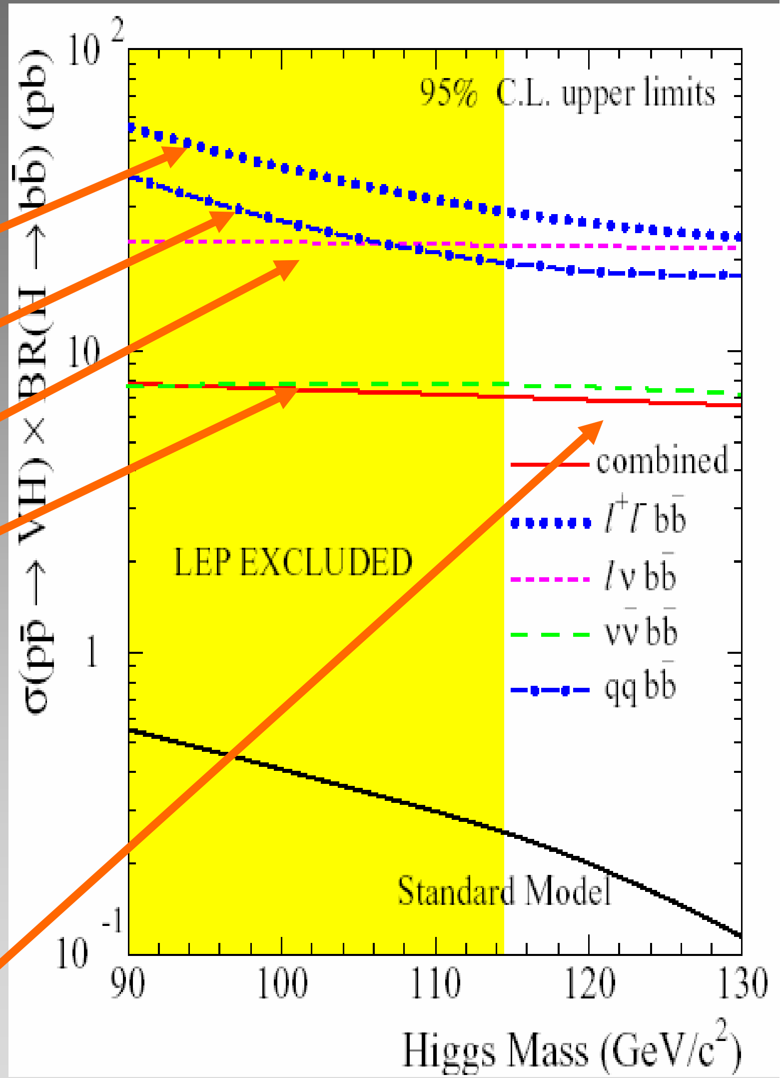
WH→lνbb is next-to-best

The best channel is ZH→ννbb

CDF has a new combination of Run 1 results with ZH→llbb, ννbb channels.

They search events with two jets with $\Delta\Phi<2.6$, missing $E_t>40$ GeV, no isolated track with $P_t>10$ GeV. The limit is obtained by a fit to the mass distribution of b-tagged events.

The Run 1 CDF limit is now at 7.2 to 6.6 pb for M_H=110 to 130 GeV.



Search for WH in Run 2

Low Mass

WH →lvbb is a promising channel for CDF to isolate the H→bb decay.

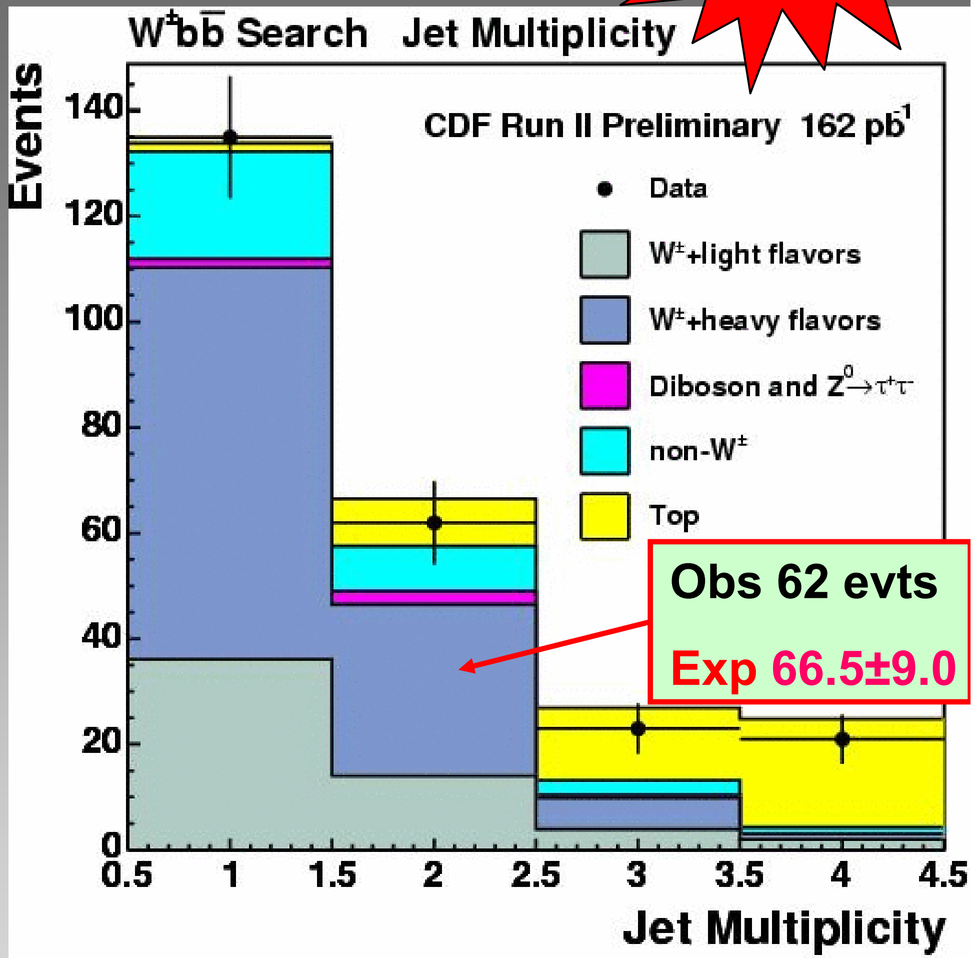
Initial data sample: inclusive lepton triggers, 162 pb^{-1}

Basic Selection: e/μ (20 GeV), missing E_T + 2 (15 GeV and |η| < 2) jets (one b-tagged) i.e. W+2jets signature

Main background: QCD and W+jets production, top

Top veto: no extra jets with E_T > 8 GeV, veto on isolated 20 GeV track with opposite charge wrt the lepton

Non top bckg enter the signal sample when either a b-jet is tagged or light quark jet is mis-identified as heavy flavour jet by the tagging algorithm.



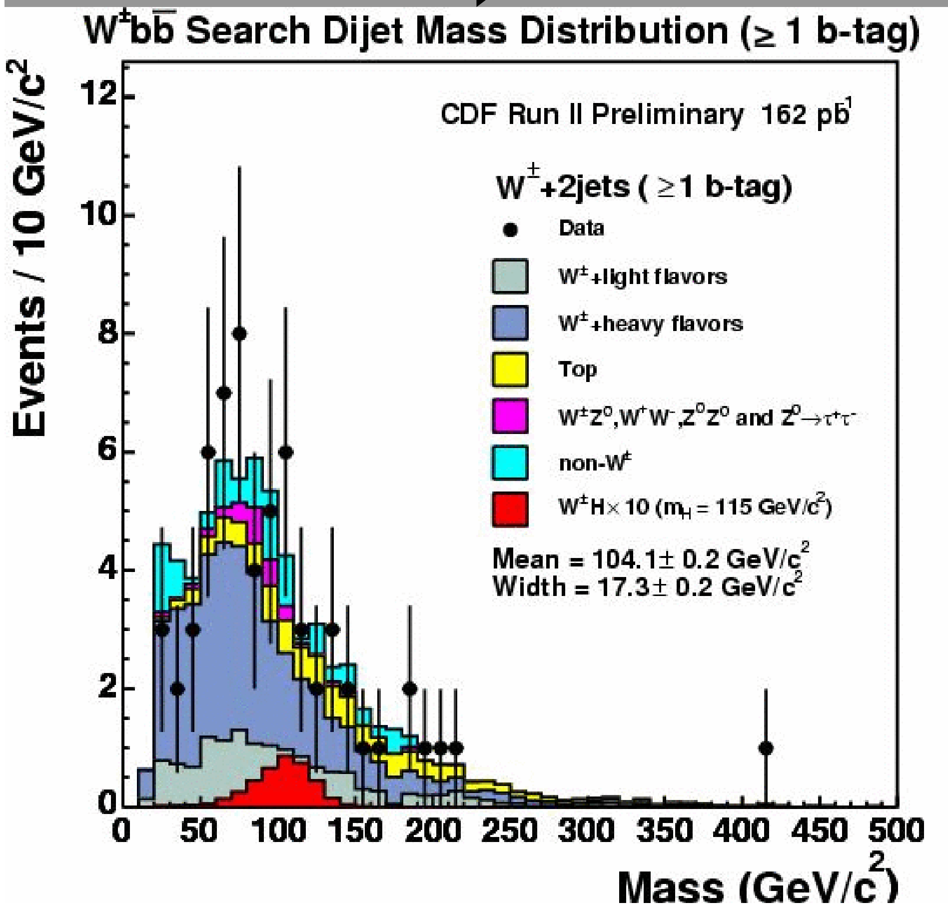
W+bb/cc bkg is estimated via ALPGEN MC
Non W bkg: i.e. events w/ mis-identified lepton

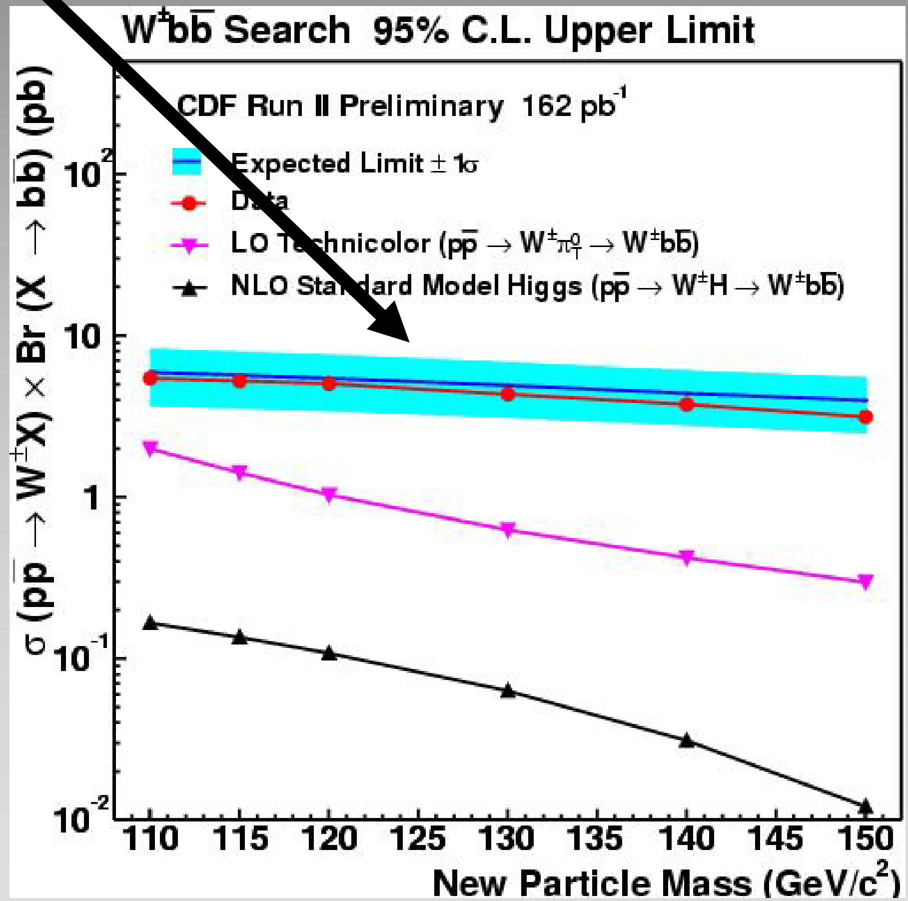
Search for WH in Run 2

Upper limits on production cross section are derived by using binned maximum likelihood technique by constraining background to the expectation in the di-jet mass distribution

Low Mass

Limits range from 5 to 3 pb for 110 GeV < M_H<150 GeV.





Search for WH in Run 2

WH →WWW* using High Pt Like-Sign Dilepton events

WWW* gives one of the cleanest signature in hadron collisions

Exploit the dominant Higgs decay mode for masses > 135 GeV

But is still important for low masses to test Higgs couplings.

High Mass

194 pb -1 of inclusive lepton data

Requirements:

1 e/μ (20 GeV) + ≥ 1 e/μ (6 GeV), same charge

Clean up cuts:

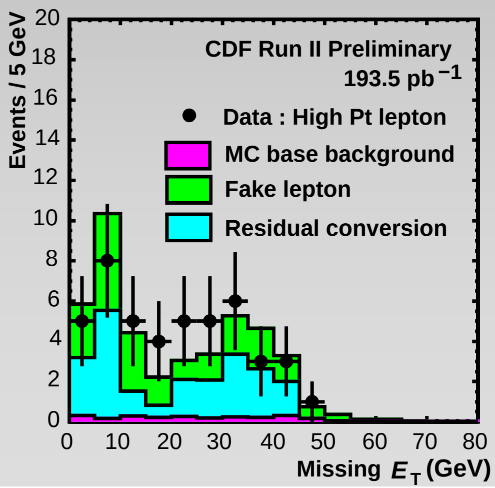
- **Conversion removal for e.**
- **Cosmic-ray veto**
- **M_{ll} > 12 GeV and Z removal**
- **Same vertex requirement**

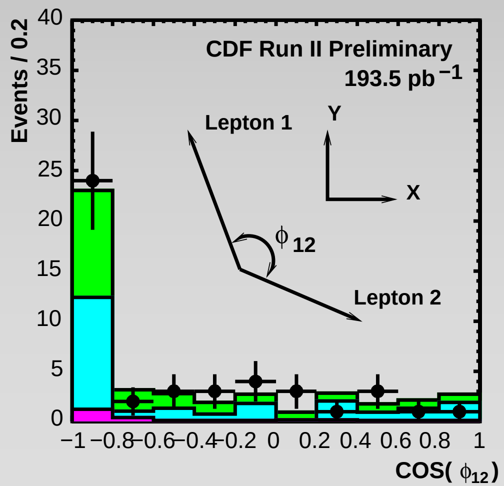
Backgrounds:

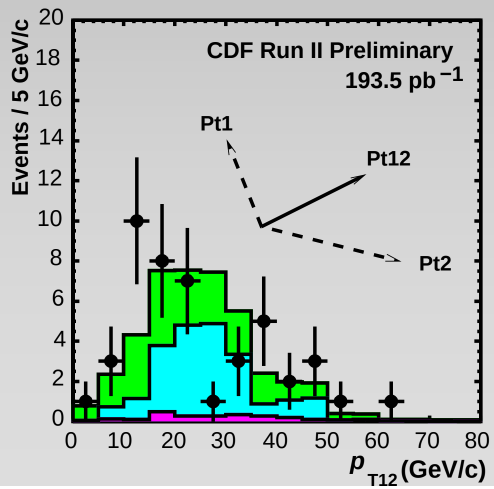
WZ, ZZ, WW, tt, W+bb/cc

Fake lepton

Residual photon conversion







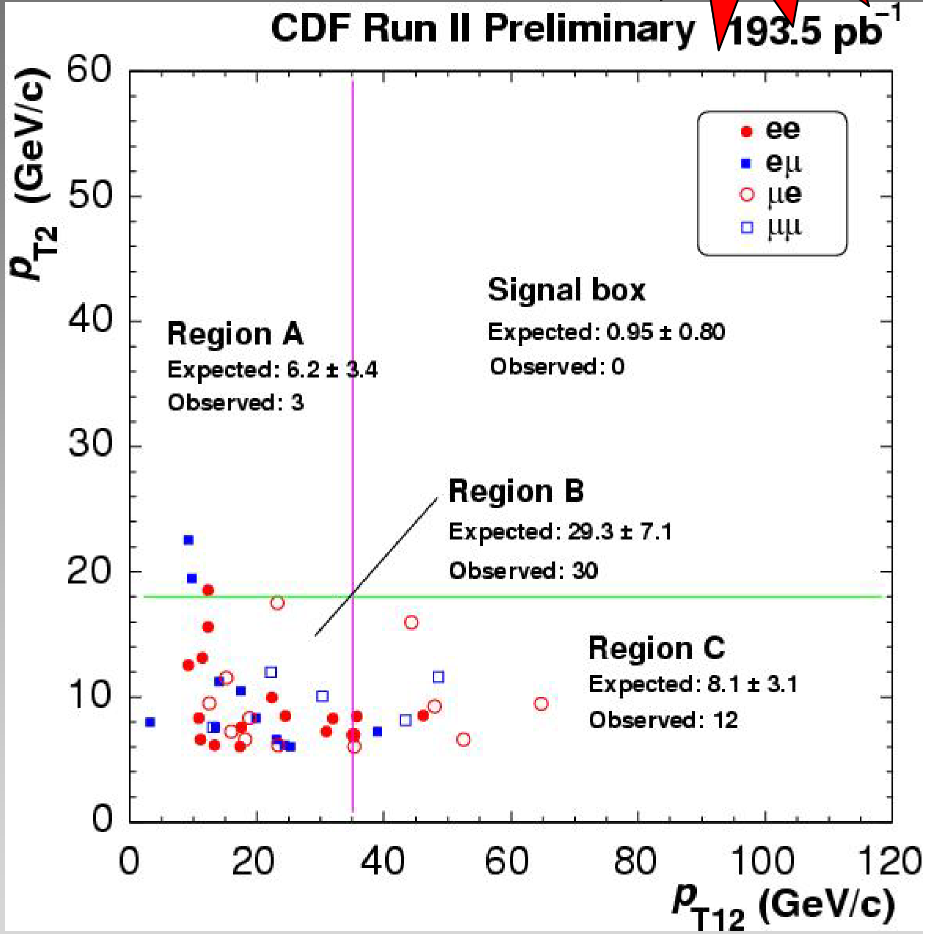
...Search for WH in Run 2

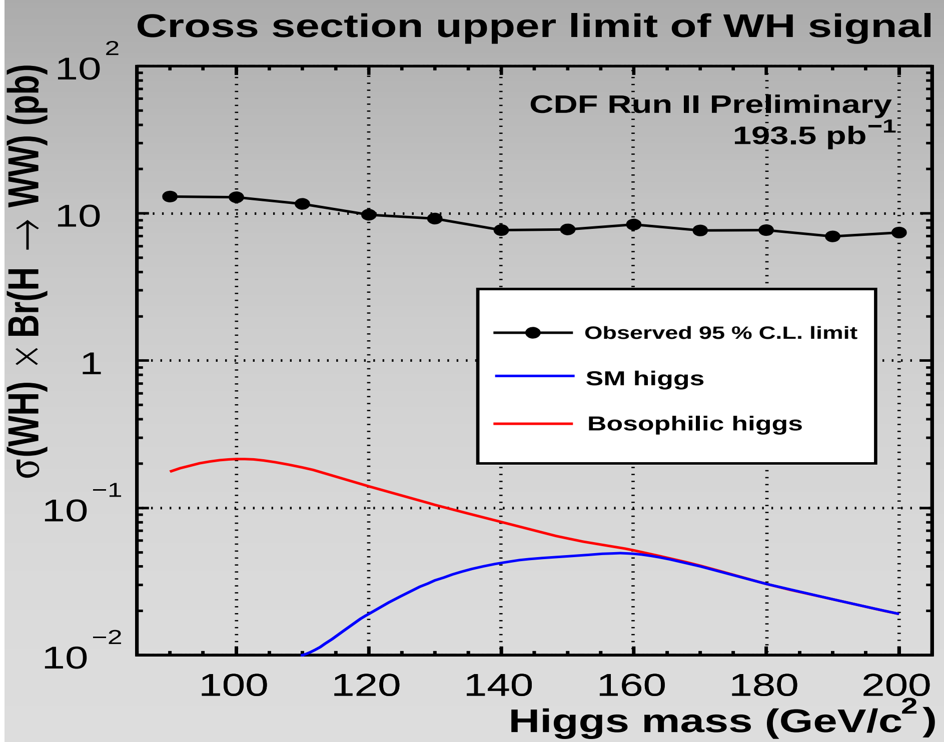
High Mass

WH →WWW* using High Pt Like-Sign Dilepton events

Then, optimized cuts are applied to the second lepton (e.g. P_t>18 GeV for M_H>160 GeV) and on the vector sum of leptons transverse momenta (P_t^{ll}>35 GeV).

Zero events are observed, when 0.95±0.61± 0.18 are expected from known sources.





95% CL limits are thus set at 12 (8) pb for M_H=110 (160) GeV.

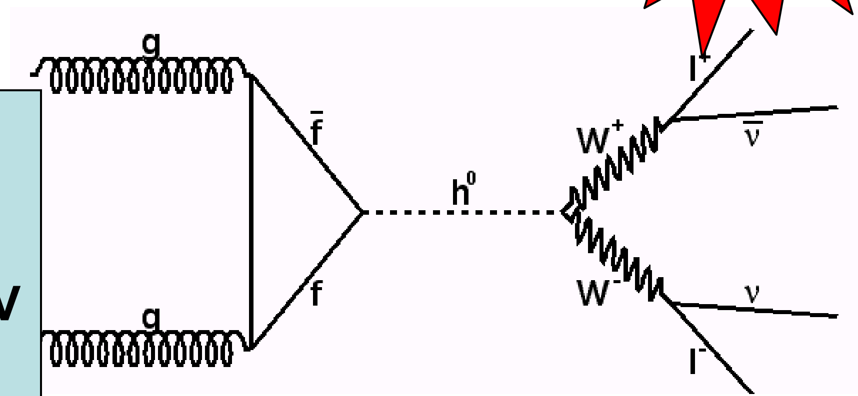
Search for H →WW in Run 2

High Mass

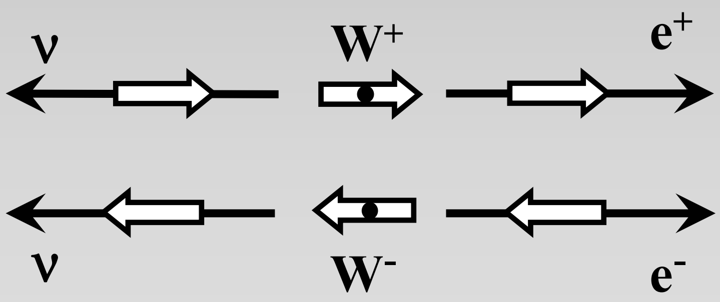
H →WW →l nu l nu

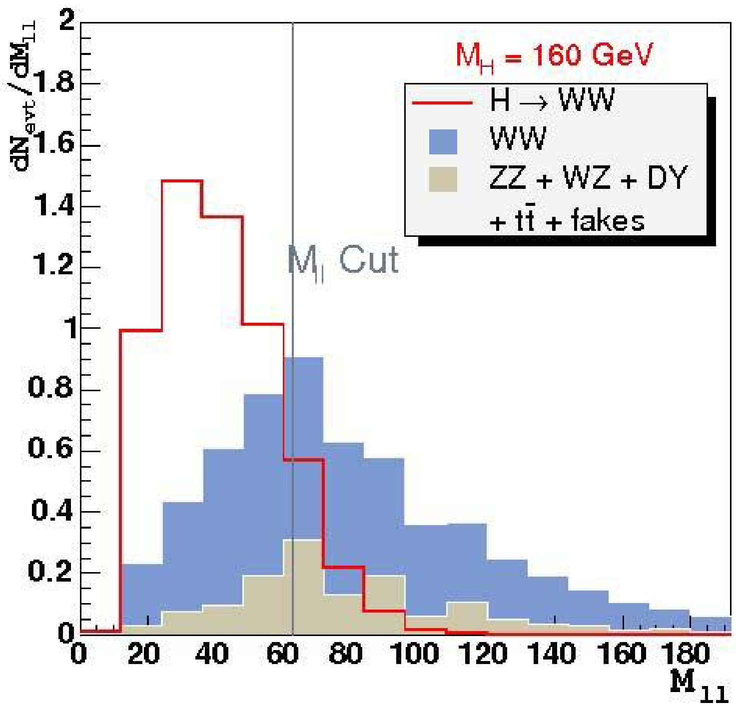
Inclusive lepton trigger data: 184 pb^{-1}

Select events by means of
- e/μ id
- Missing E_T > 25 GeV
- ΔΦ(Met, jet/lepton) > 20° for Met < 50 GeV
- Jet veto (all E_T > 15 jets)



Additionally: helicity-preferred alignment of charged leptons in Φ to discriminate known backgrounds.



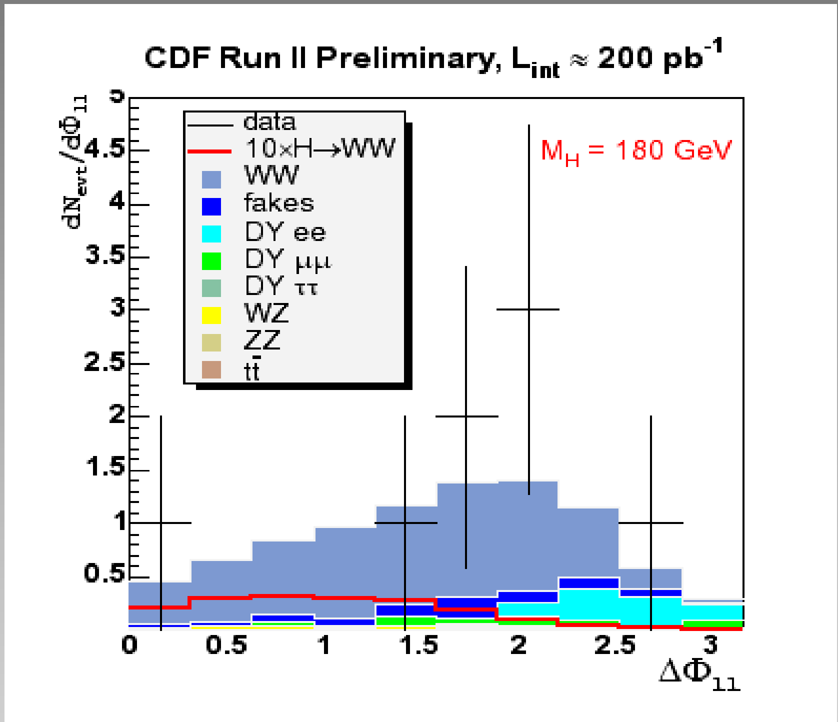


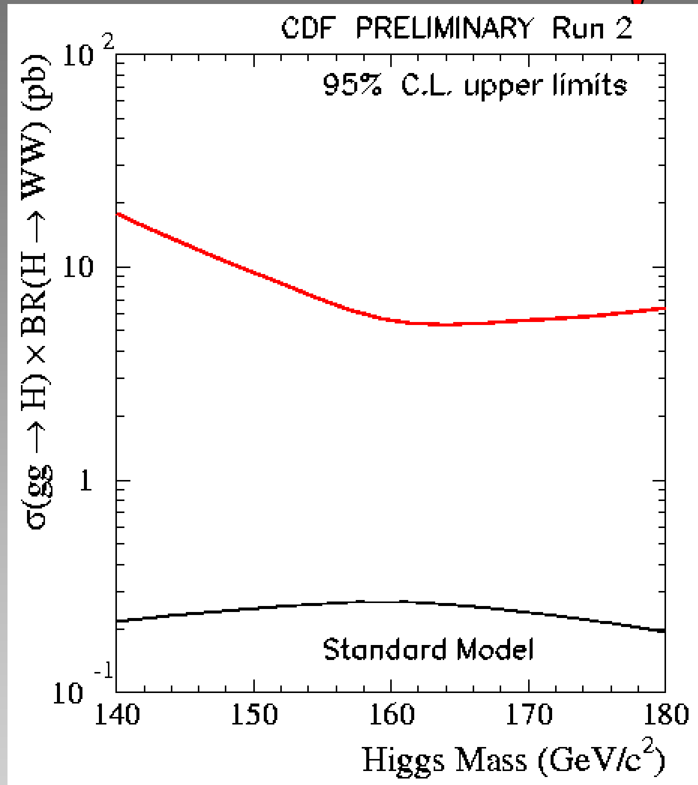
Search for H →WW in Run 2

High Mass

Main background sources are

- WW, ZW, ZZ, tt, Drell-Yan dilepton production (MC based estimate)
- W+jets w/ fakes lepton (data estimate)



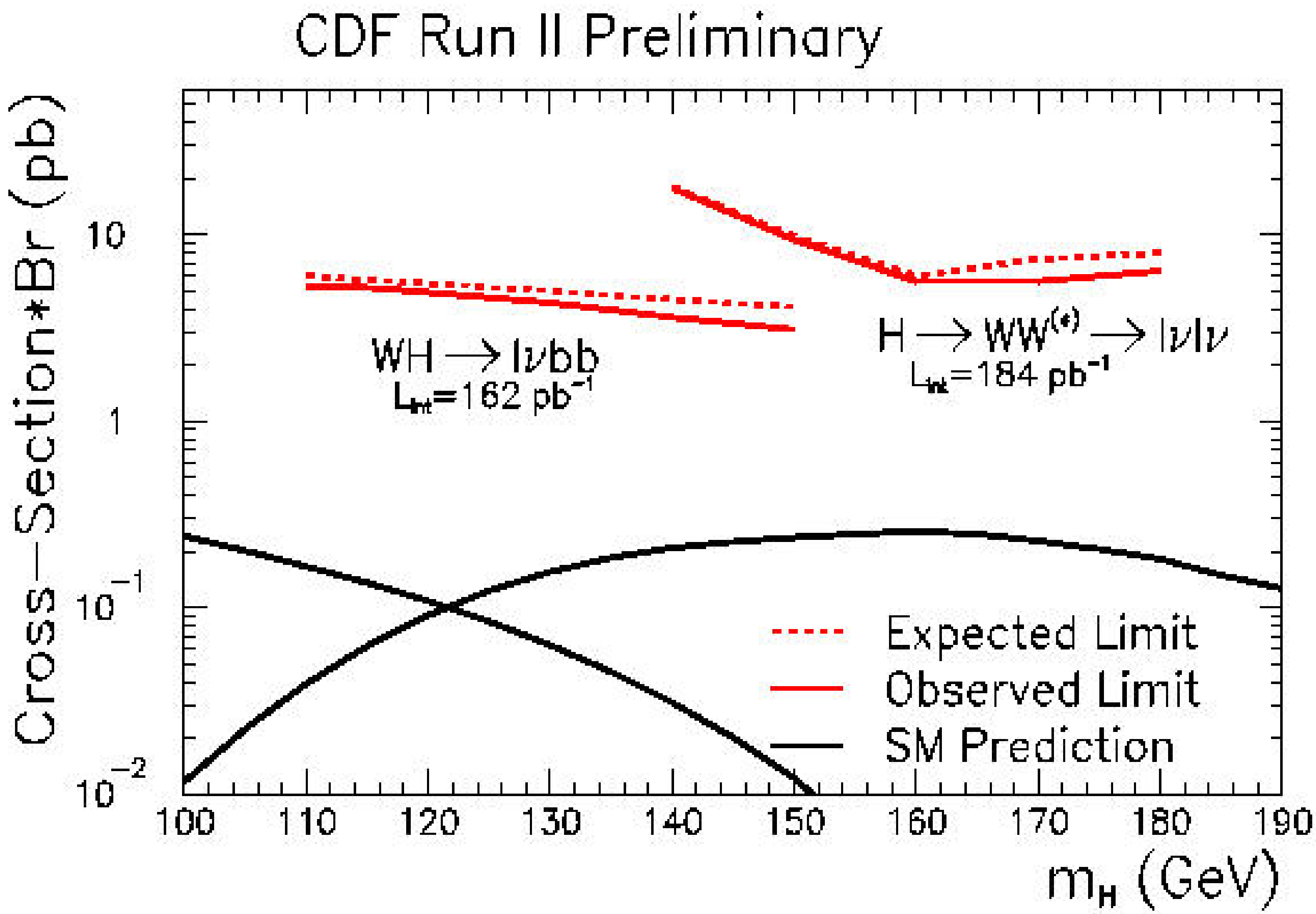


8 events are observed in 184 pb-1 of Run 2 data with the M_{ll} <80 GeV cut, with an expected background of **8.9±1.0**.

A likelihood fit to the $\Delta\Phi_{ll}$ distribution is performed to extract a limit on the H→WW cross section *BR as a function of its mass.

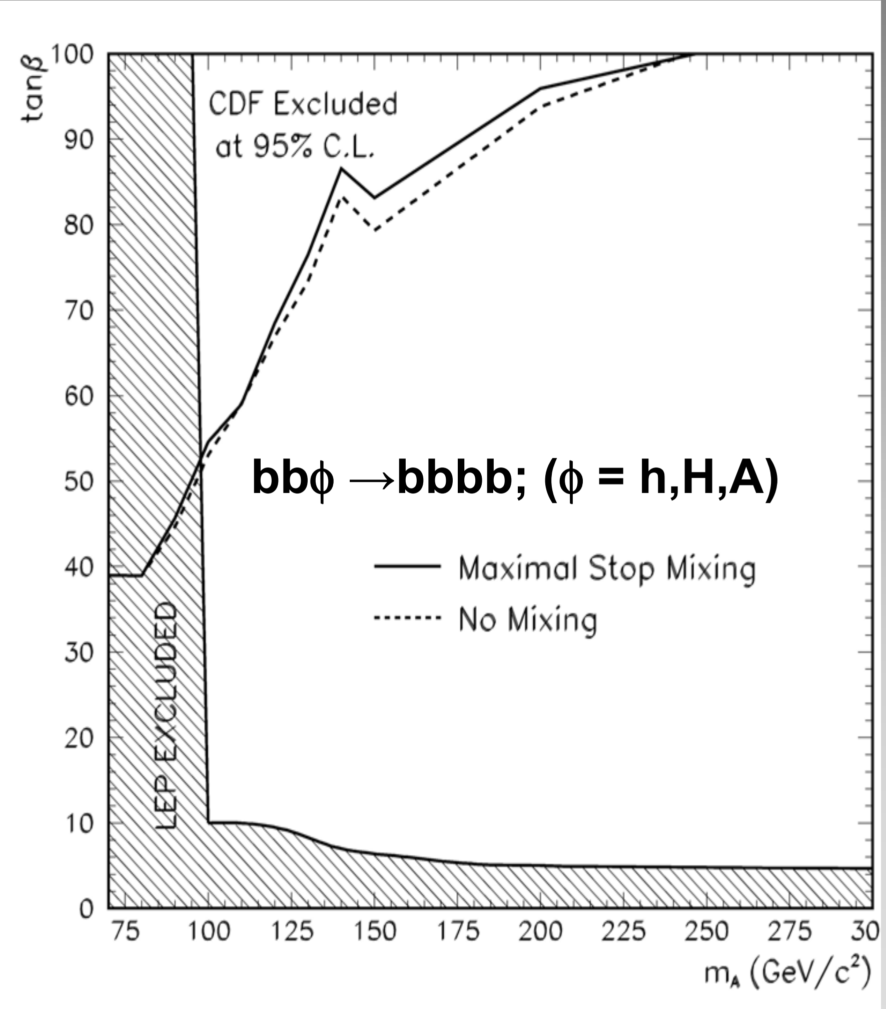
The result is σH→WW*B(WW→llνν)<5.6 pb for M_H=160 GeV.

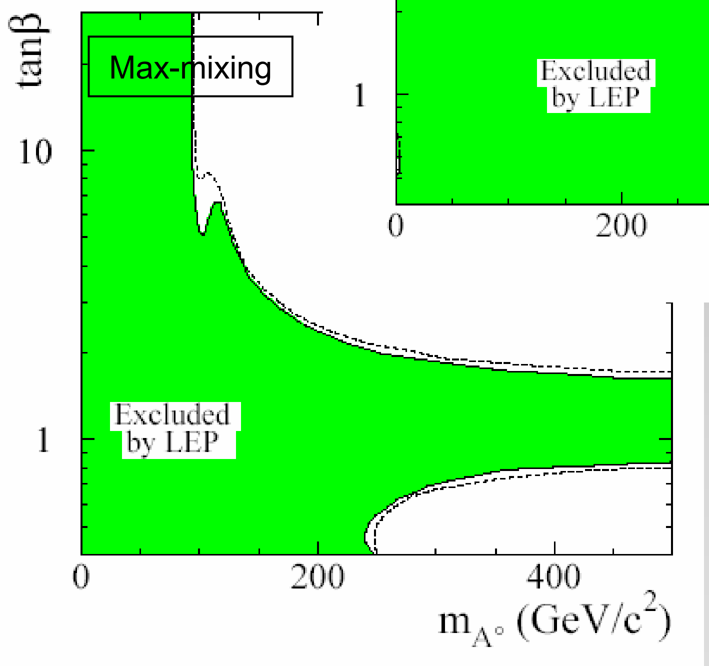
Summary of SM searches

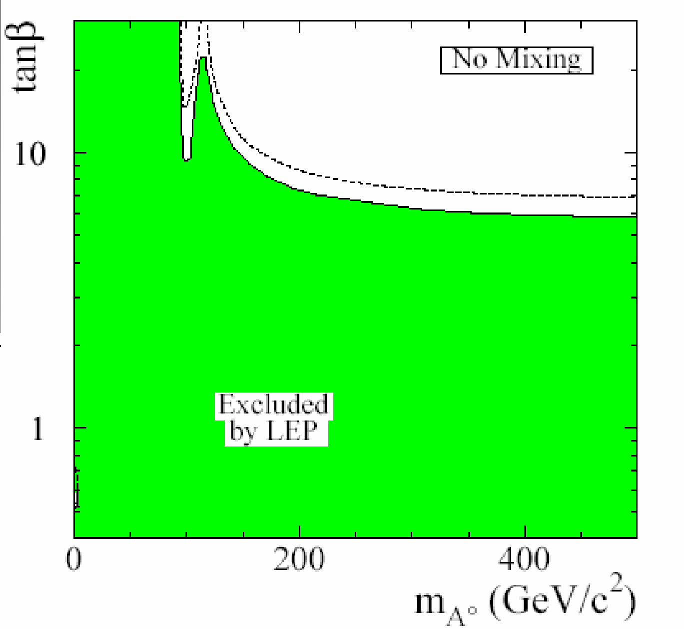


MSSM Higgs Bosons

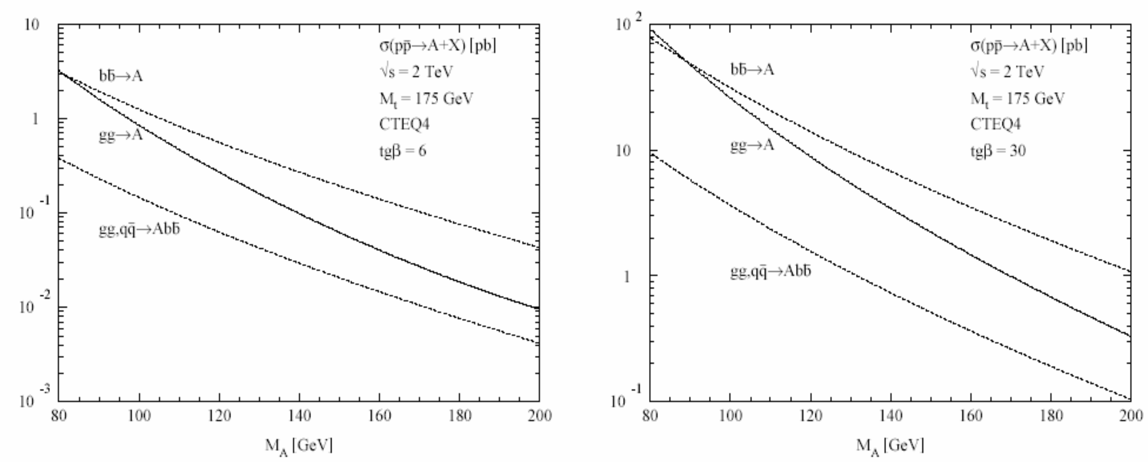
The Minimal Supersymmetric extension of the SM predicts the existence of 3 neutral, 2 charged Higgs: h, H, A and $H^{\pm}$. (h is SM-like Higgs boson)
At tree-level all Higgs Sector parameters are determined by two quantities: $\tan\beta = v_u/v_d$ (VEV ratio), and conventionally m_A.





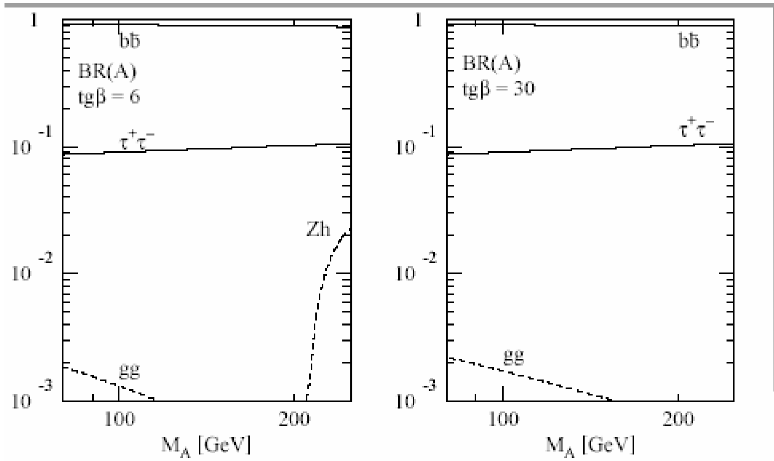


Search for MSSM A→tau tau



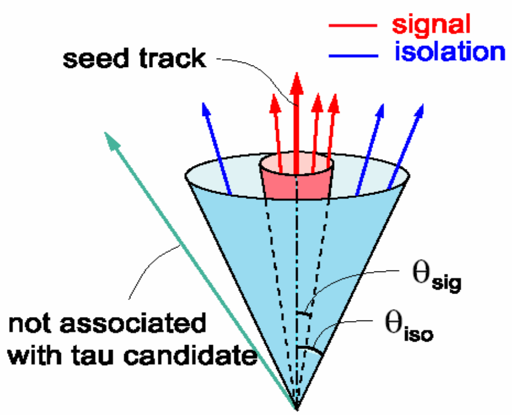
The production x-sec of the CP-odd A scale as $\tan^2\beta$.

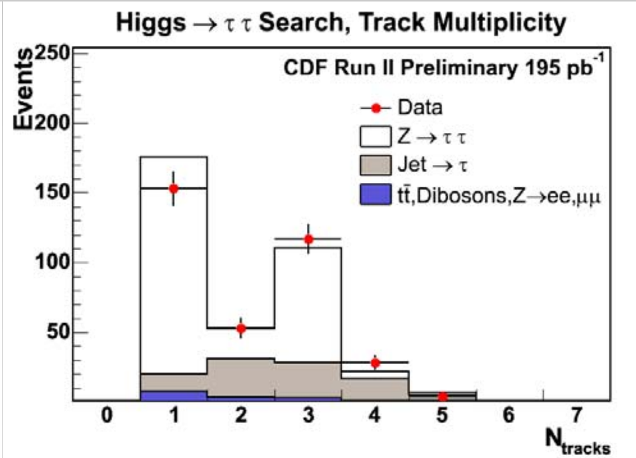
While in general gg→Abb (A →bb) is promising, gg→A is difficult to study when A → bb. The addition of the tau tau decay mode expand the CDF reach.



lepton+track triggered dataset 195 pb-1
Signal consists in a tau pair (had, tau → e/μ)
Hadronic taus appears as narrow jets that are reconstructeded by using both tracking and calorimetric quantities.

Signal and isolation cone are used to select good candidates.

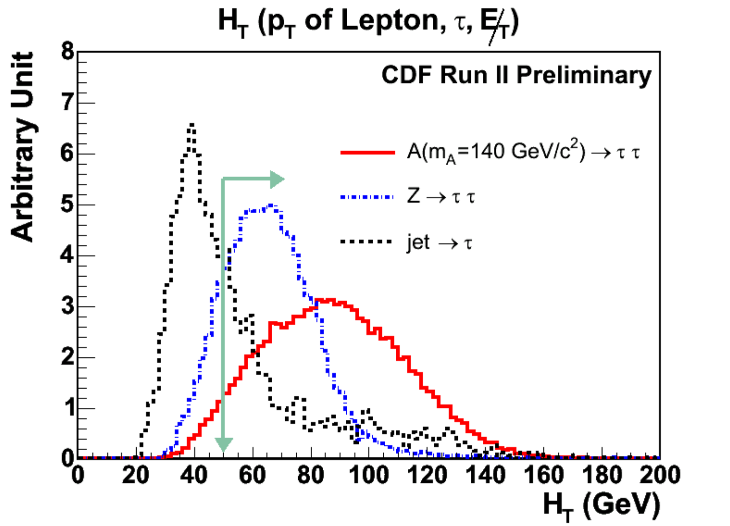




Search for MSSM $A \rightarrow \tau\tau$

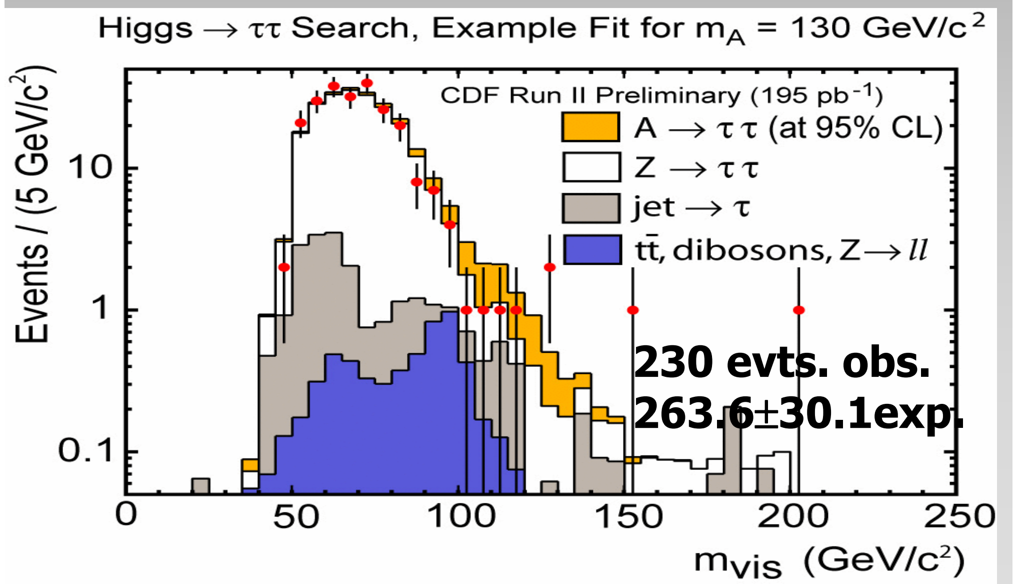
MSSM

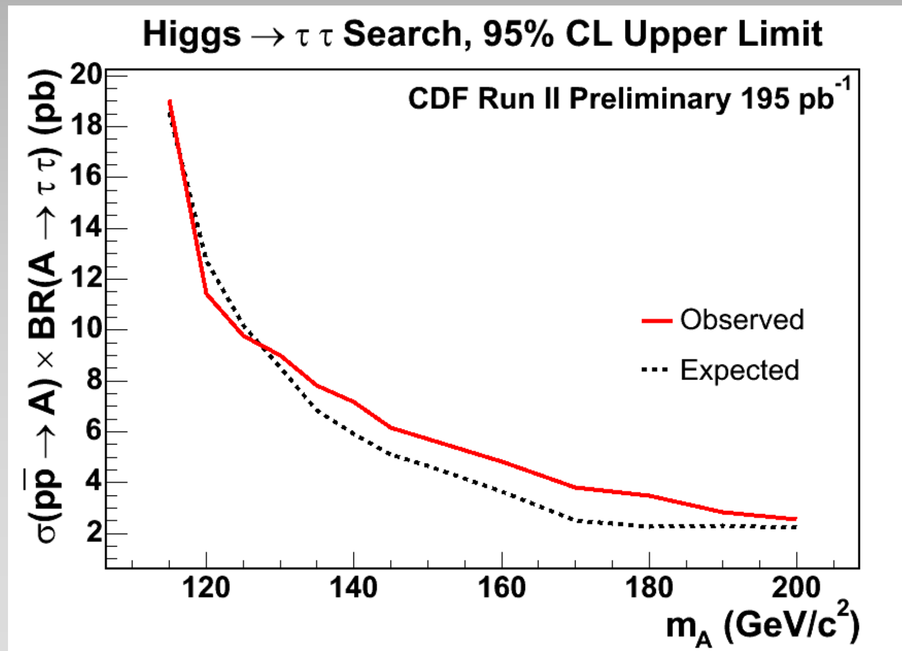
The τ candidates sample has significant contamination from quark and gluon jets.



Tau visible products and missing E_T directions are used to separate signal from W+jets bkg

$Z \rightarrow \tau\tau$ is the large source of background, can only be distinguished by partial mass distribution m_{vis}(lepton, tau, missing E_T)





Search for H^{++}/H^{--}

Predicted by some beyond SM models like Left-Right Symmetric Models

If short lived:

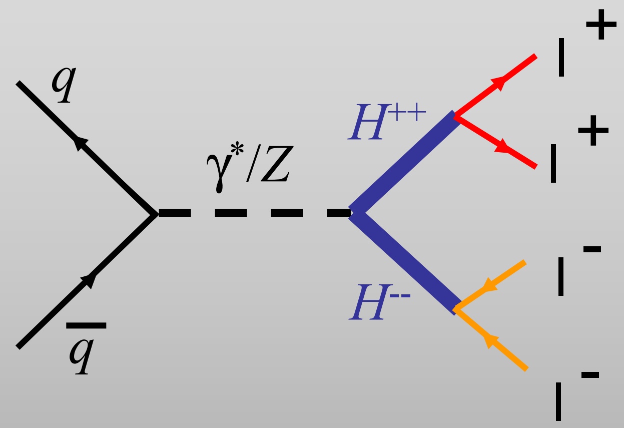
→ prominent signature – multiple high P_t leptons, like sign di-lepton mass peak

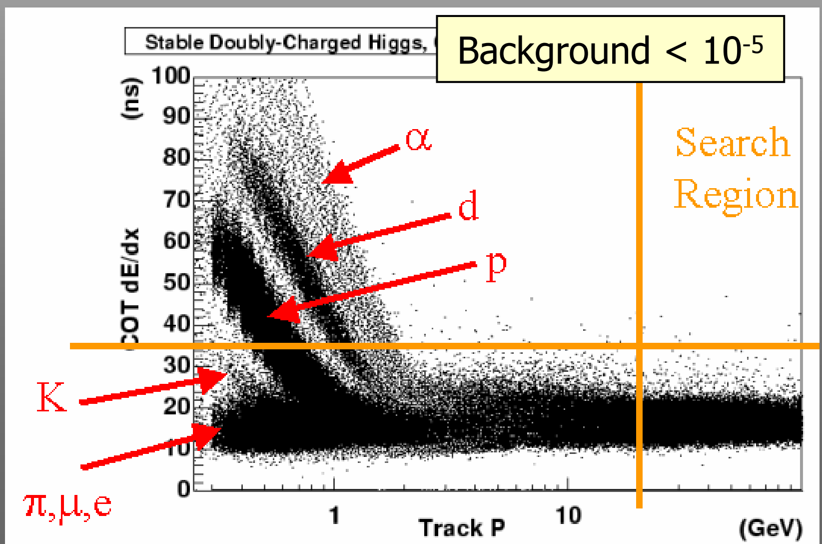
→ backgrounds: WZ, W+jets, conversions (e)

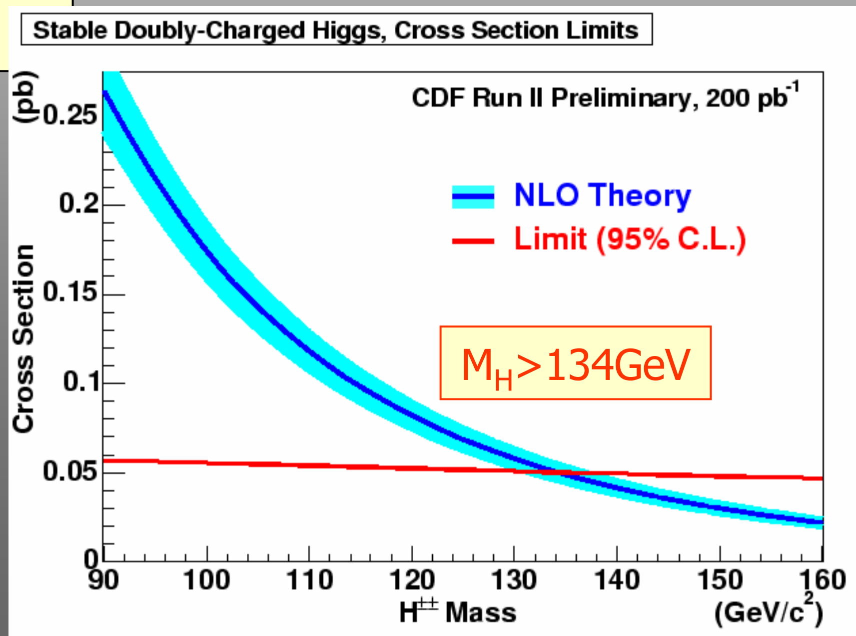
235 pb^{-1}: $M(H_L) > 133$ GeV (ee) at 95% C.L.
242 pb^{-1}: $M(H_L) > 136$ GeV ($\mu\mu$) at 95% C.L.
240 pb^{-1}: $M(H_L) > 115$ GeV ($e\mu$) at 95% C.L.

If long lived ($c\tau > 3$ m):

→ two high ionization tracks







Summary and Outlook

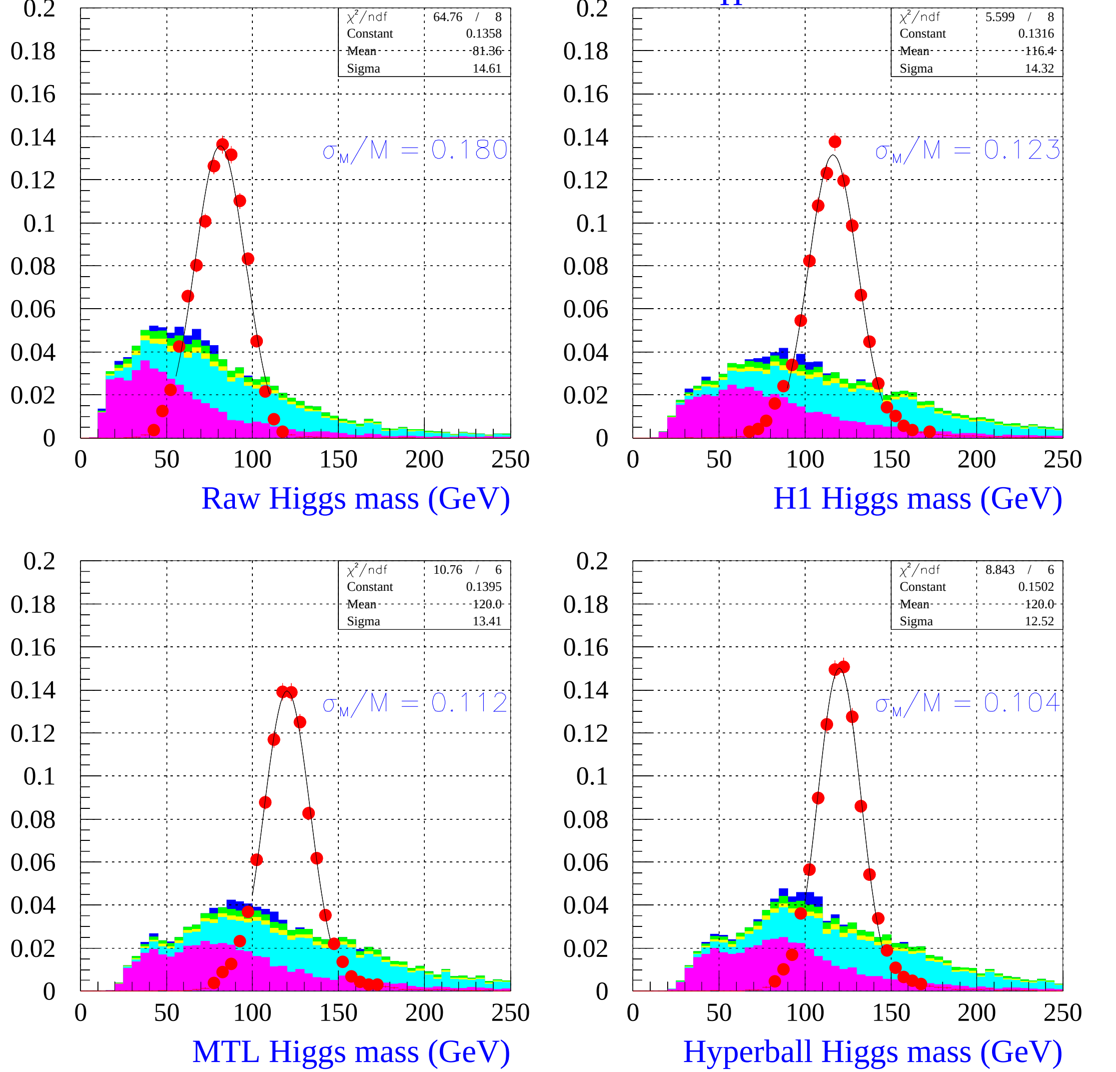
The Higgs boson is being hunted at the CDF II experiment in most of the promising search channels.

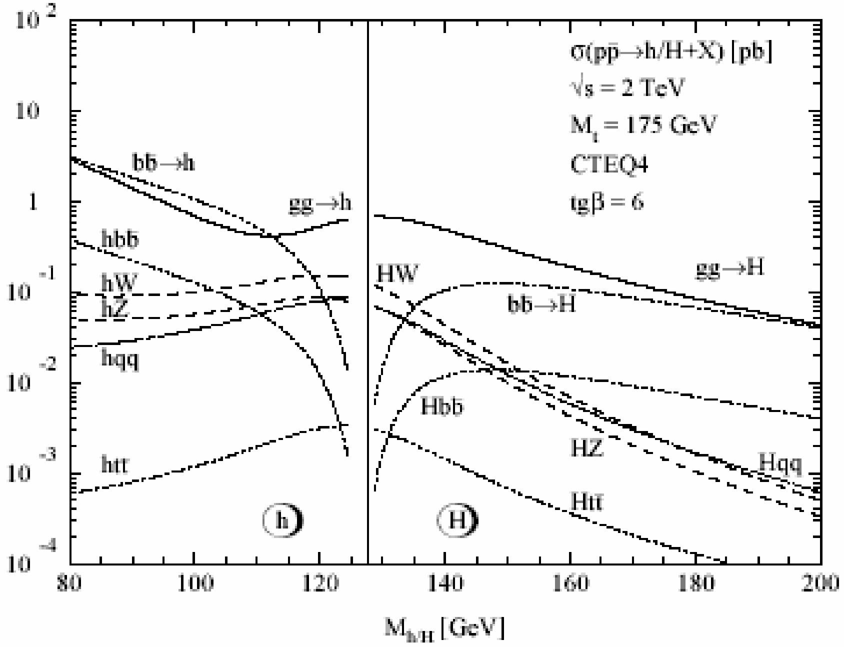
No surprises with the analyzed 200 pb^{-1} samples, but we have already three times more data on tape to look at!

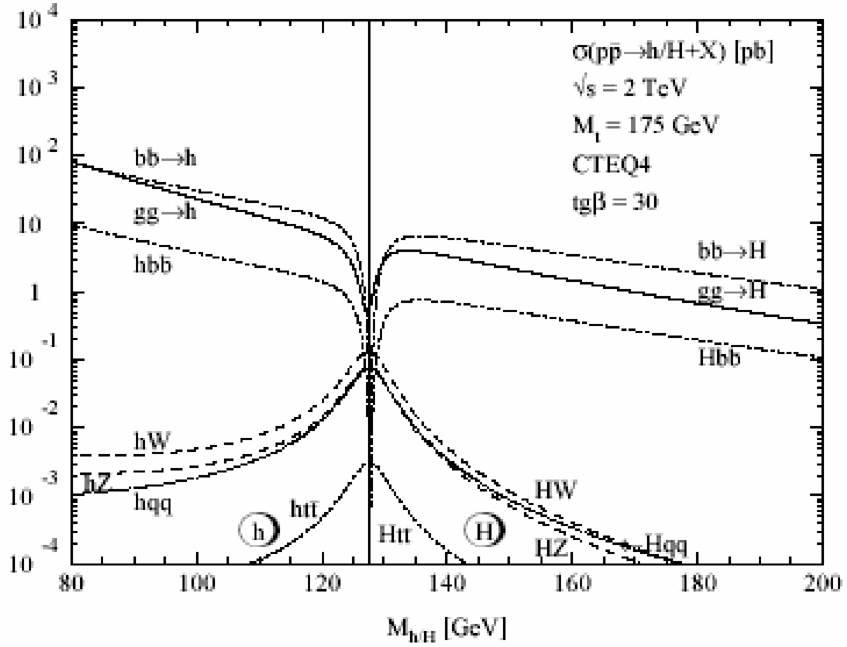
By the end of 2009, the Tevatron might be able to see a M_H=115 GeV Higgs at 5σ, or exclude it all the way to 180 GeV.

…but that will require both cunning and the Tevatron delivering according to the design plan!

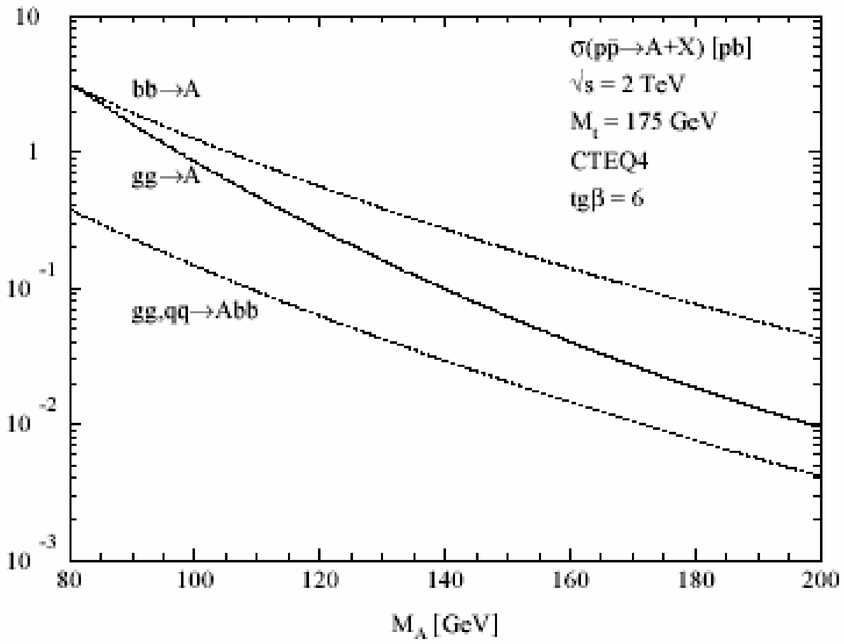
Higgs mass corrections - M_H=120 GeV

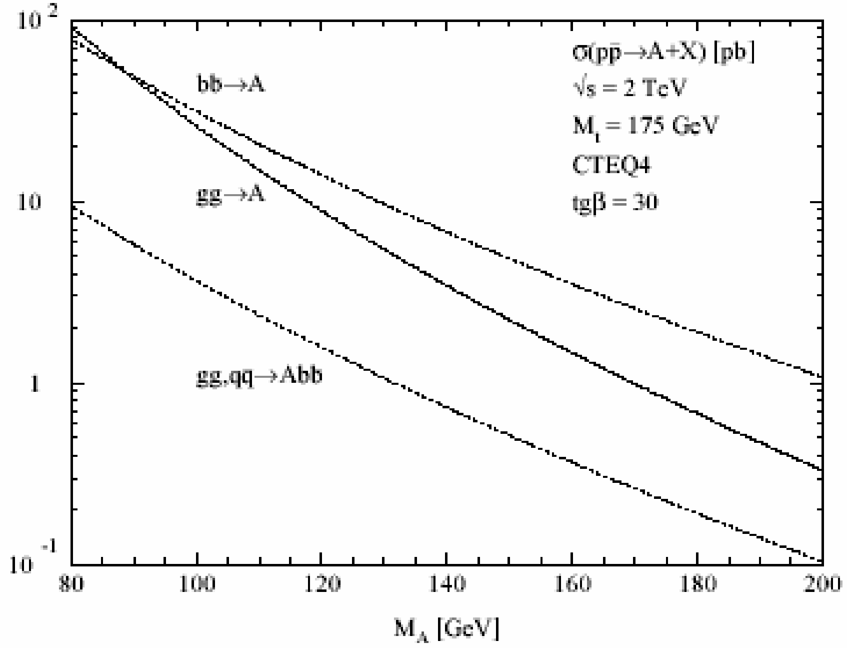


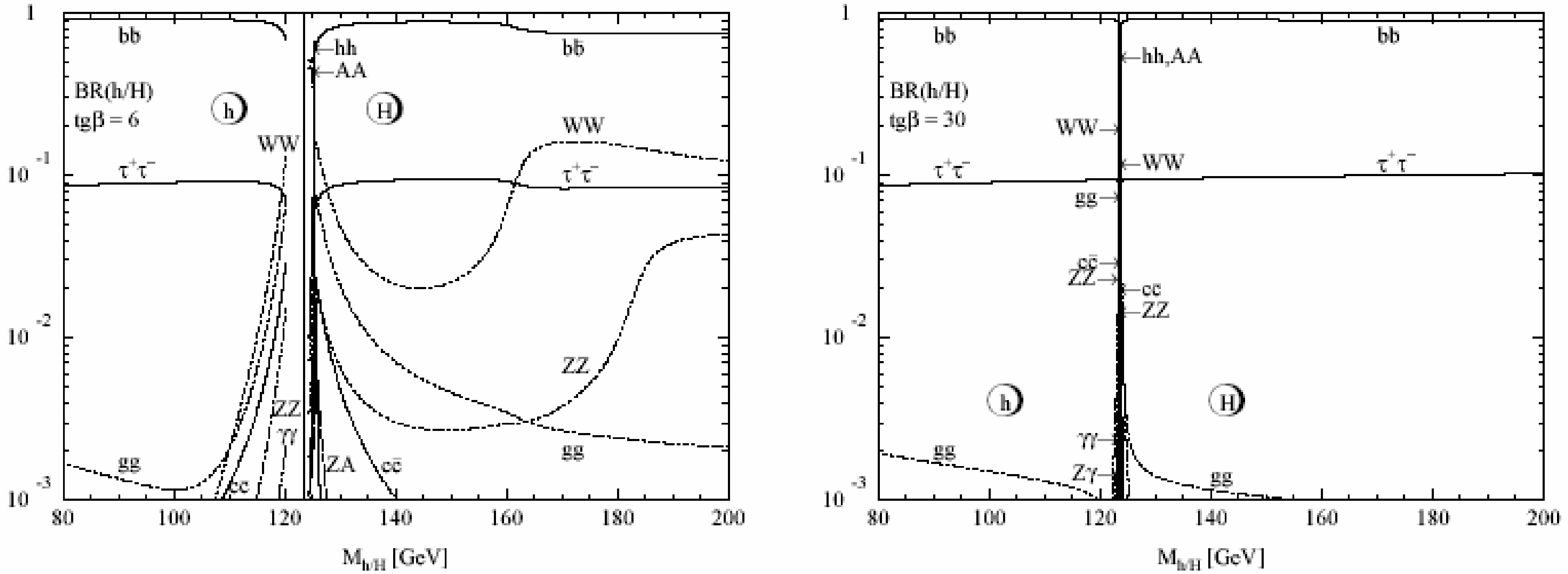




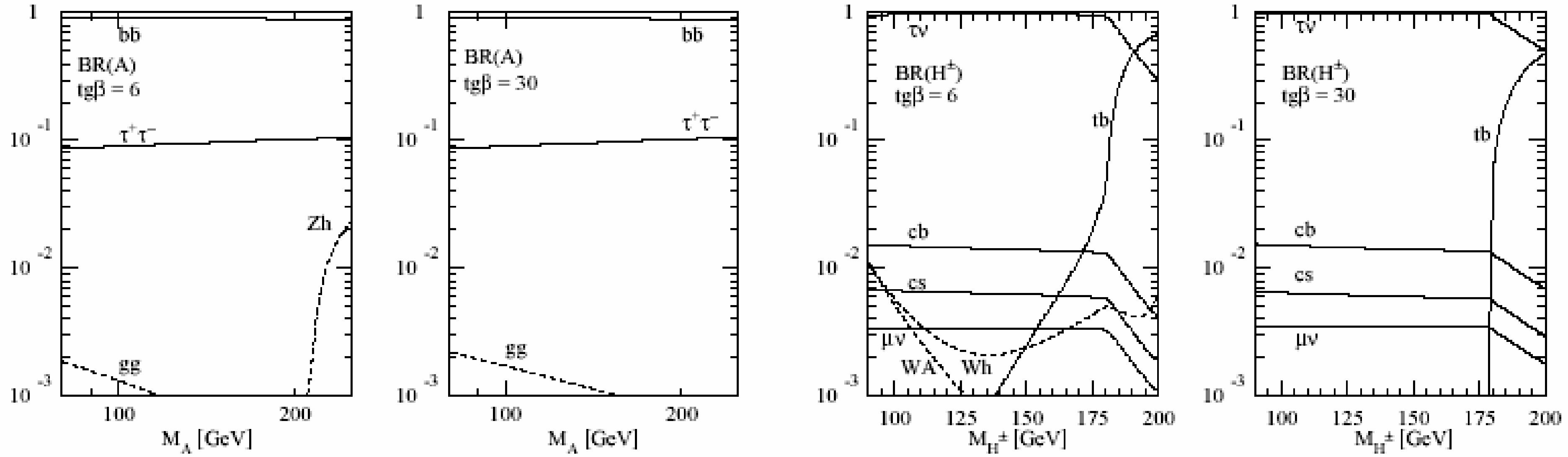
MSSM neutral Higgs production cross section

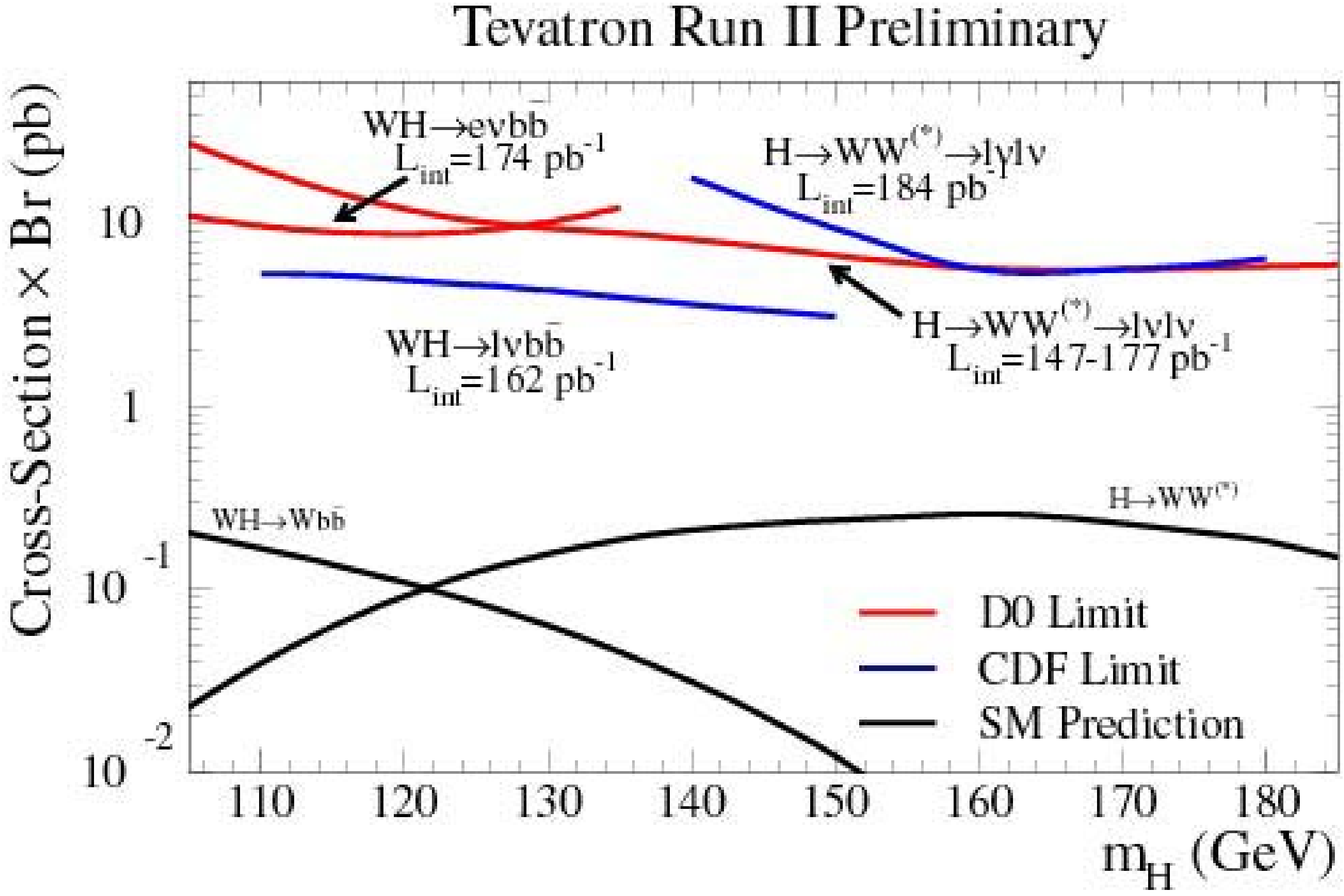






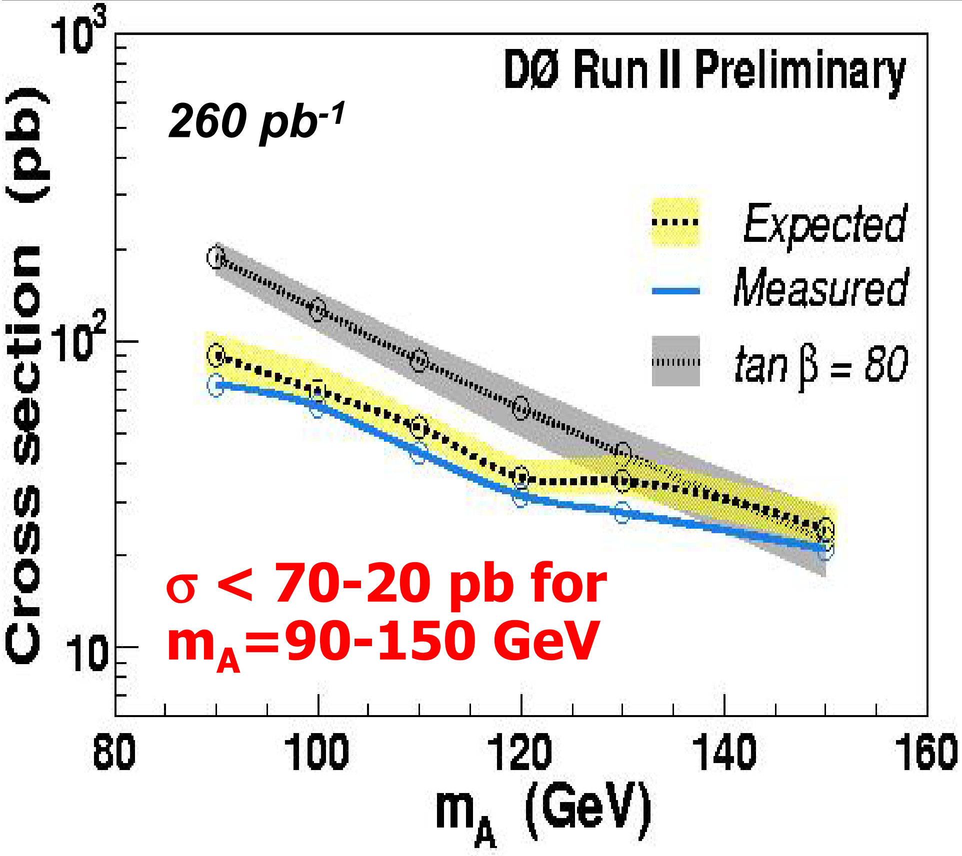
MSSM Higgs bosons decay modes

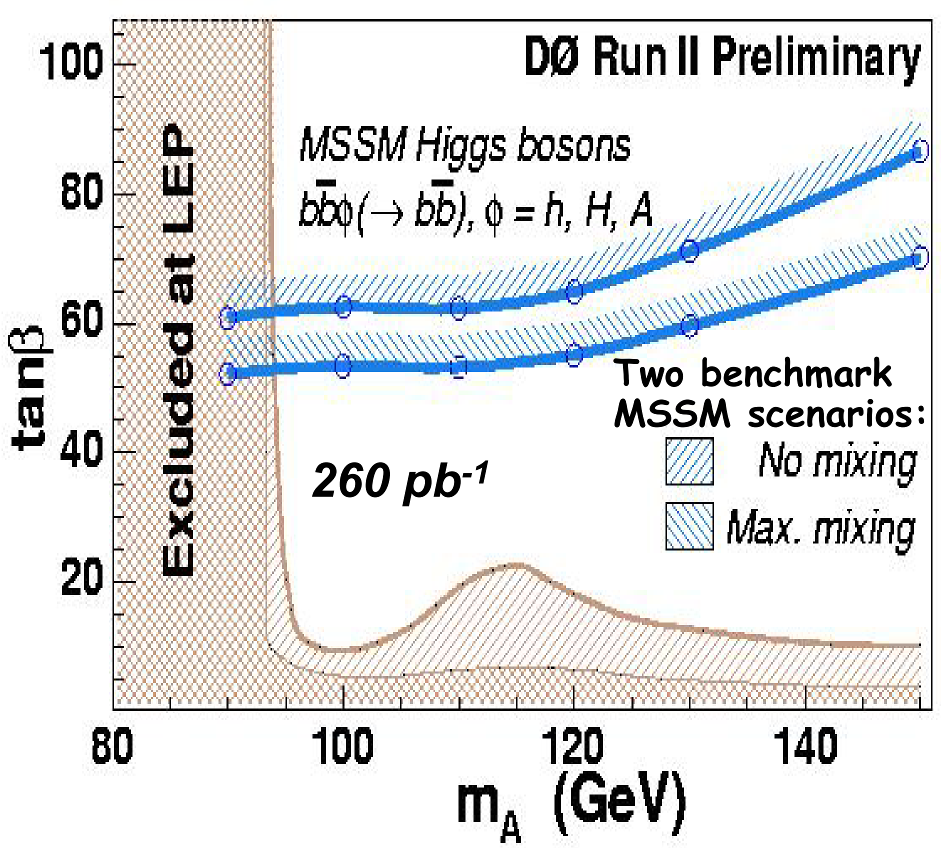




Tevatron Run II Preliminary
Cross-Section × Br (pb)
10
1
10^{-1}
10^{-2}
110
120
130
140
150
160
170
180
m_H (GeV)
$WH \to e\nu b\bar{b}$
L_{int}=174 pb^{-1}
$H \to WW^{(*)} \to l\nu l\nu$
L_{int}=184 pb^{-1}
$WH \to l\nu b\bar{b}$
L_{int}=162 pb^{-1}
$H \to WW^{(*)} \to l\nu l\nu$
L_{int}=147-177 pb^{-1}
$WH \to Wb\bar{b}$
$H \to WW^{(*)}$
D0 Limit
CDF Limit
SM Prediction

D0 Limits on signal production cross section & in the tan β vs. m_A plane:





Exclude significant portion of tan β down to 50, depending on m_A and MSSM scenario: (D0 Preliminary)

For m_A=120 GeV: σ < 31 pb-1 @ 95%c.l., tanβ < 55 @ 95%c.l. (Max Mixing)