SEARCH FOR SUPERSYMMETRIC HIGGS BOSONS AT THE TEVATRON

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on behalf of the DØ and CDF Collaborations

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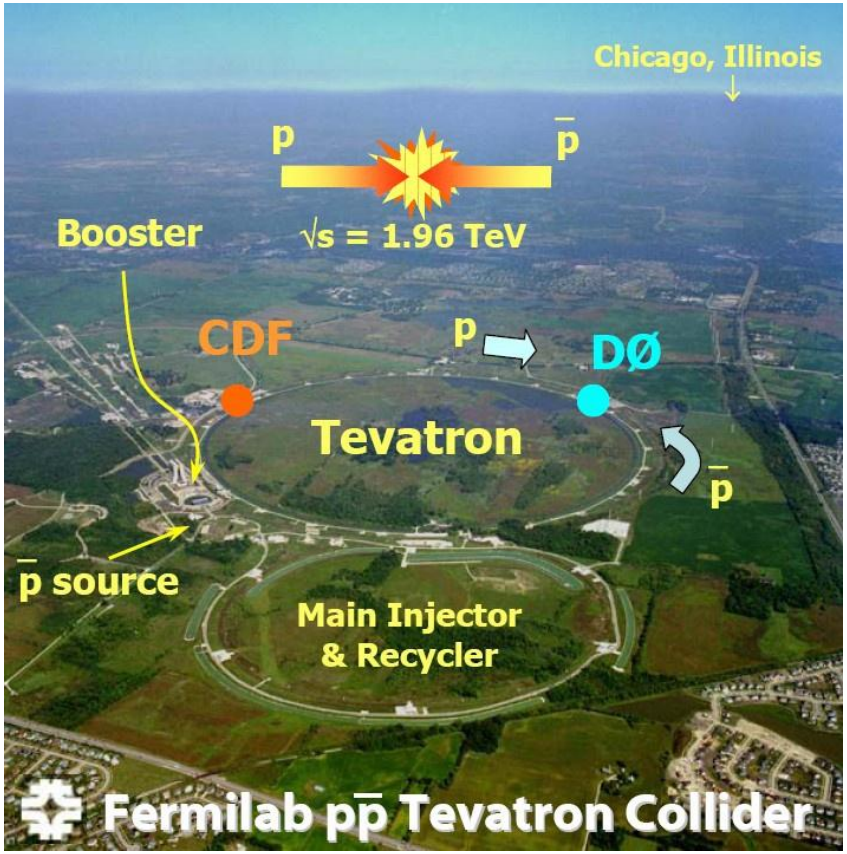
Outline

- Introduction
- Results for individual channels
- Combined upper limit on neutral MSSM Higgs-boson production from DØ
- Summary



Up to date ~7 fb^{-1} delivered luminosity. Expect ~10 fb^{-1} by the end of Run II. Results are based on up to 2.6 fb^{-1} data.

Motivation and channels to be discussed

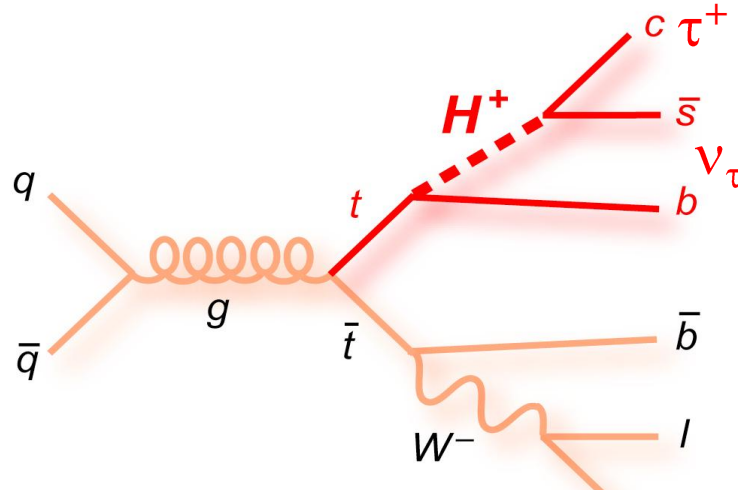
- SUSY as an extension of the SM provides
  - a natural solution to the hierarchy problem
  - a dark matter candidate and GUT-scale unification.
- MSSM predicts the existence of five physical Higgs bosons
  - Two charged, H^+ and H^-
  - Three neutral, $\phi = \{h, H, A\}$
- Coupling to weak isospin members of the fermion doublets is proportional to tan $\beta \rightarrow$ expect a big enhancement of the cross sections

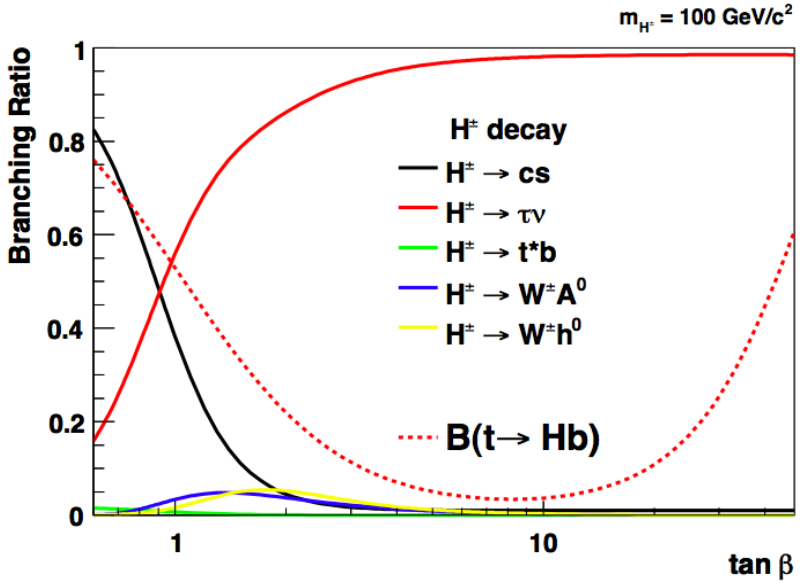
- Search for a charged Higgs bosons:
  - $m_h < m_t$: $t \rightarrow H^+ b$ with higgs boson decaying as
    - $H^+ \rightarrow \tau^+ \nu$
    - $H^+ \rightarrow cs$
  - $m_h > m_t$: $qq' \rightarrow H^+ \rightarrow tb$
- Search for a neutral Higgs bosons :
  - $\phi \rightarrow \tau\tau$
  - $b\phi \rightarrow b\tau\tau$
  - $b\phi \rightarrow bbb$

  } Combination

Charged Higgs boson in top quark decays

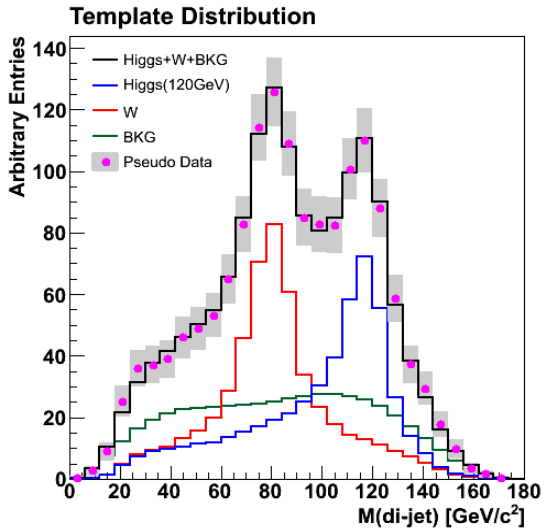
- Consider purely tauonic decay ($H^+ \to \tau^+ \nu_\tau$) and leptophobic decay ($H^+ \to c\bar{s}$)
- Indirect search: Search for H^+ using ttbar cross-section measurements in different final states (ℓ+jets, dileptons and τ+ℓ)
- Direct search: Search for H^+ as a peak in mass distribution of two jets

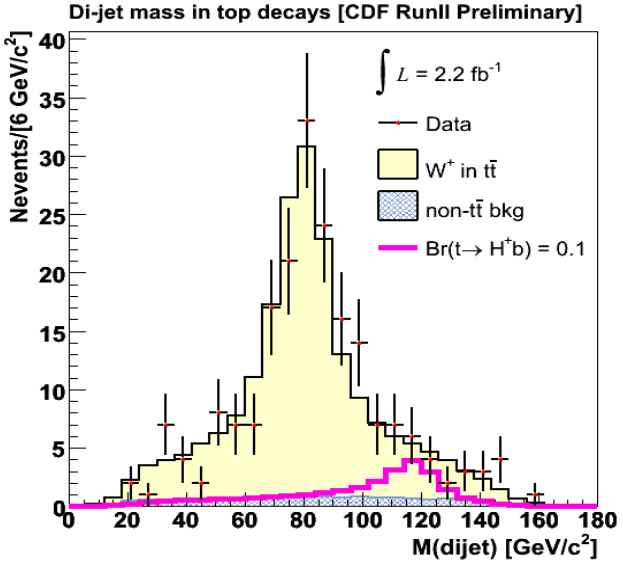




Search for a charged Higgs boson in $H^+ \rightarrow cs$ channel (CDF)

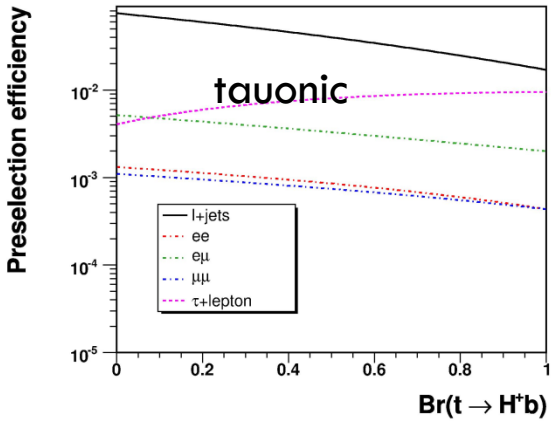
- Search for a second peak in an invariant mass of two light jets in top quark decays using mass templates
- A binned likelihood function is constructed using the probabilities P^W, P^H and P^{bkg} from mass templates. Fit parameters are N_{ttbar}, $Br(t \rightarrow H^+b)$, and N_{bkg}.
- No excess observed, upper limit for $Br(t \rightarrow bH^+)$ for Higgs boson mass interval from 90 to 150 GeV

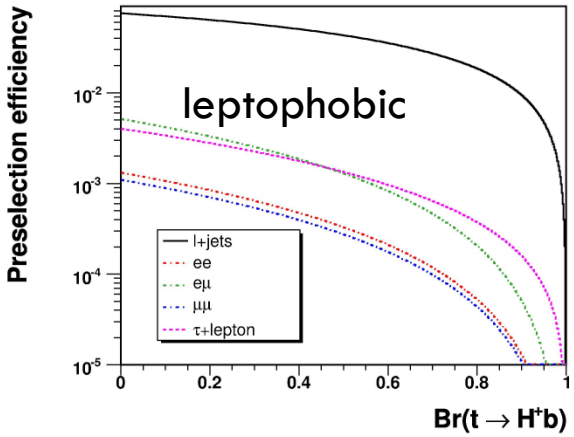




Search for a charged Higgs boson in $H^+ \to \tau^+ \nu_\tau$ and $H^+ \to cs$ channels (DØ)

- Tauonic: search for a deficit of the expected number of events compared to SM prediction in all but $\ell+\tau$ channel
- Leptophobic: Search for a deficit of events compared to the expected number of tt events in all channels considered.
- Selection:
  - One isolated lepton (e or μ) with p_T>15 GeV for the $\ell+\tau$ channel;
  - Identified hadronic tau
  - Two jets with p_T>20 and 30 GeV;
  - At least one jet is identified as b-jet

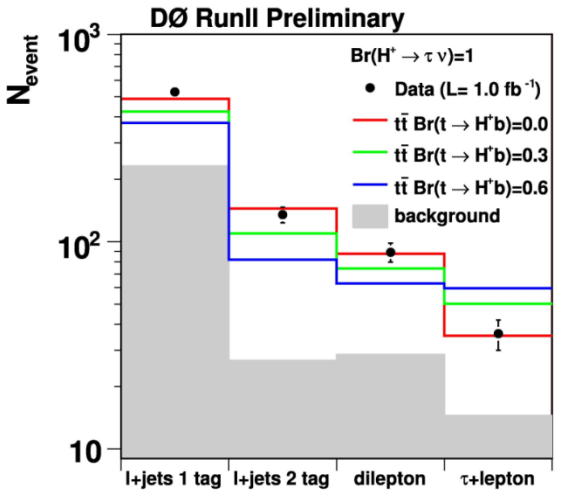


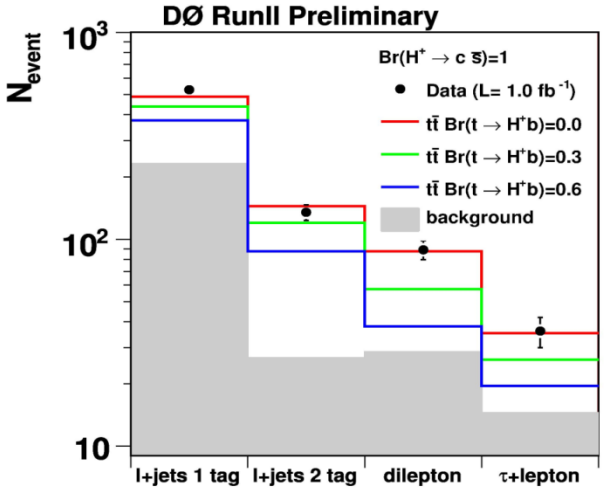


M(H⁺) = 80 GeV

Search for a charged Higgs boson in $H^+ \to \tau^+ \nu_\tau$ and $H^+ \to cs$ channels (DØ)

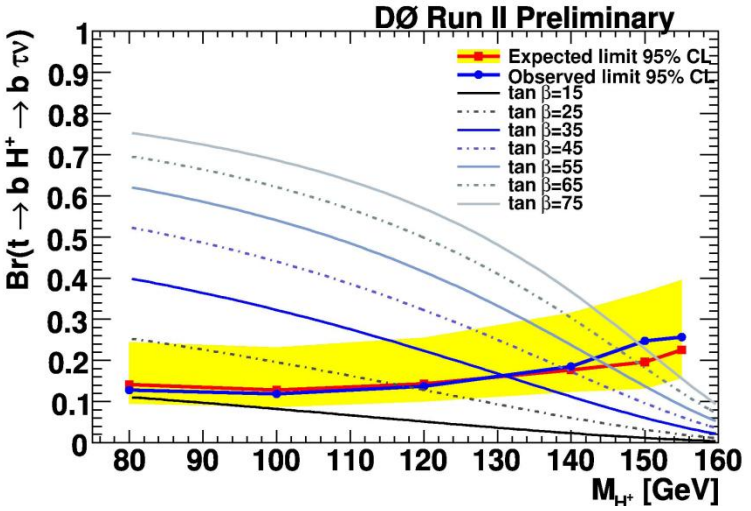
- Upper plot: tauonic model; bottom plot: leptophobic model
  - Good agreement with the SM top quark decay
- Calculate expected numbers of events with charged Higgs boson in 14 channels (l+jets with 3 and 4 jets, with 1 and 2 tags, ee, μμ and eμ +1 and 2 jets, eτ and μτ channels), for various Higgs masses and branching ratios
- Perform a maximum likelihood fit to the number of the observed events in data
- Br(t→H^+b) is free parameter of the fit

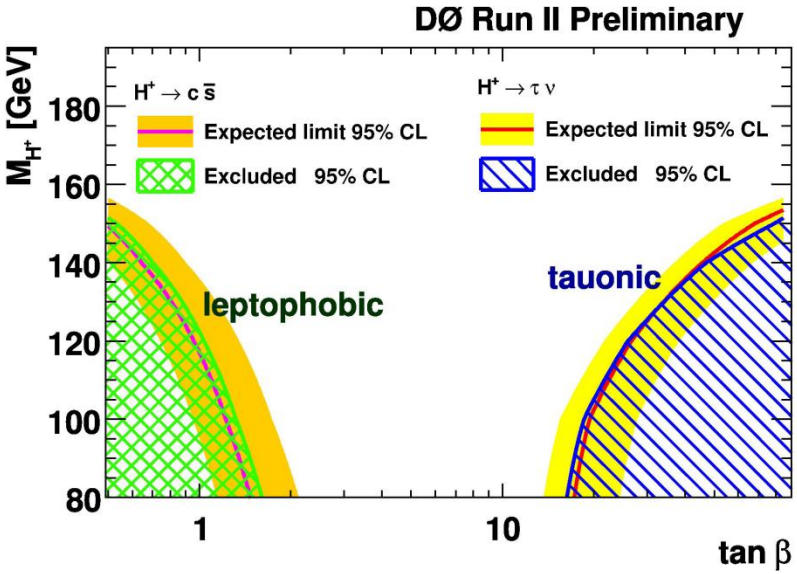


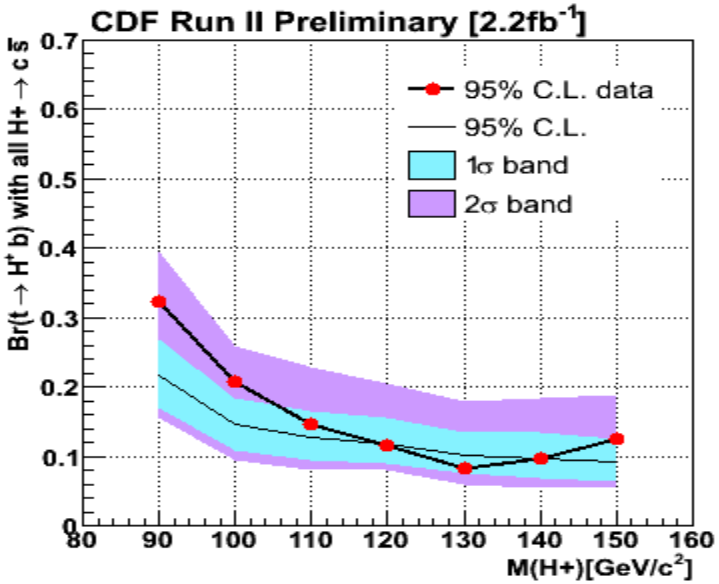


DØ and CDF results on search for a light charged Higgs boson

- **Tauonic model:** exclude Br from above 0.16 to above 0.2 for the m_{H+} range between 80 and 155 GeV. **Model-independent** measurements exclude Br from 0.12 to 0.26 depending on m_{H+}.
- **Leptophobic:** DØ excludes Br fraction above 0.2 for the same mass range.

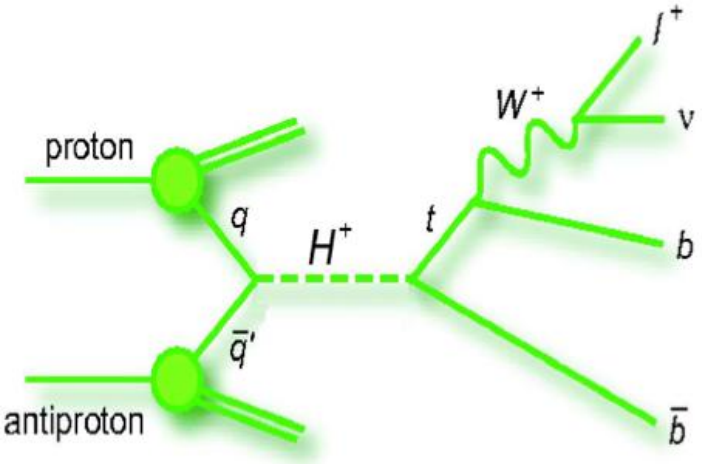


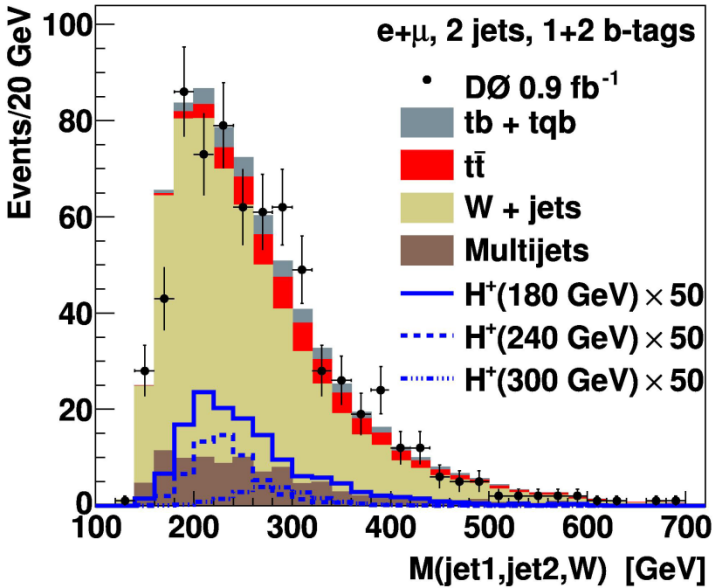




Search for a Higgs boson with $m_{H^+} > m_t$

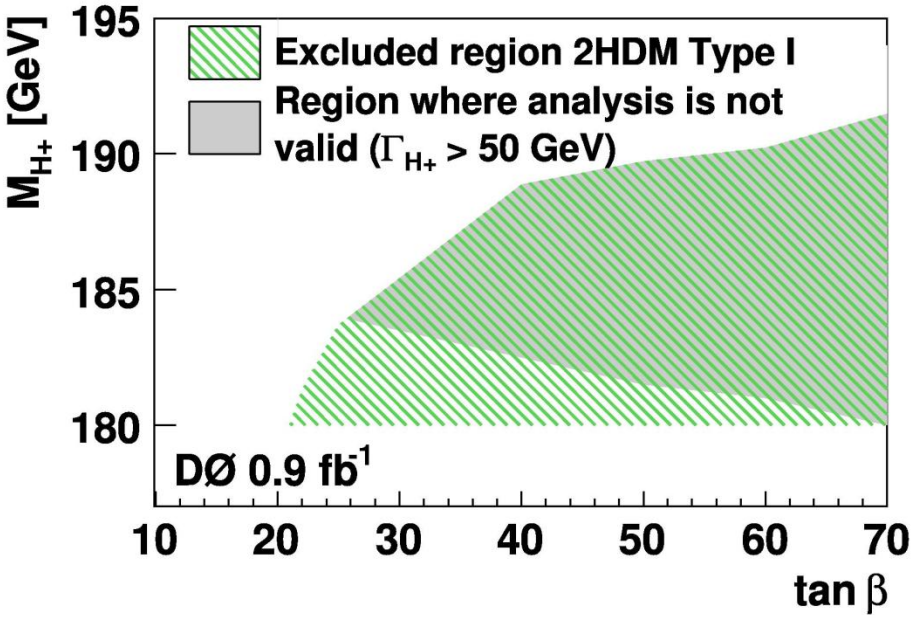
- Selection:
  - Exactly 2 jets with p_T>20 and 25 GeV, at least 1 jet b-tagged
  - Only one high p_T isolated lepton
  - 15<MET <200 GeV
- Search for an excess of the events in the invariant mass distribution of the (jet, jet, W) system
- Simulate different 2HDM by combining in different proportions purely left and right-handed signal samples
- Perform binned likelihood fit using Bayesian method to calculate cross-section limits





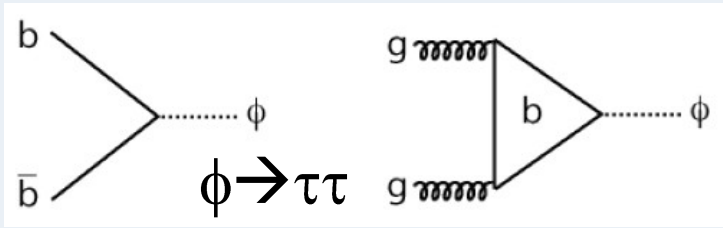
Result on search for a heavy charged Higgs boson

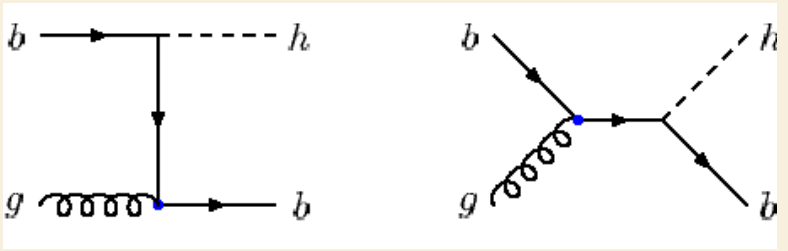
- A region in the M_{H+} vs tan β plane has been excluded at the 95% C.L. for Type I 2HDMs.
- The analysis sensitivity is currently not sufficient to exclude regions of tan $\beta < 100$ in the Type II 2HDM.
- In a Type III 2HDM, the width of the Higgs boson depends quadratically on the mixing parameter, limiting our ability to exclude regions in M_{H+}-ξ parameter space.

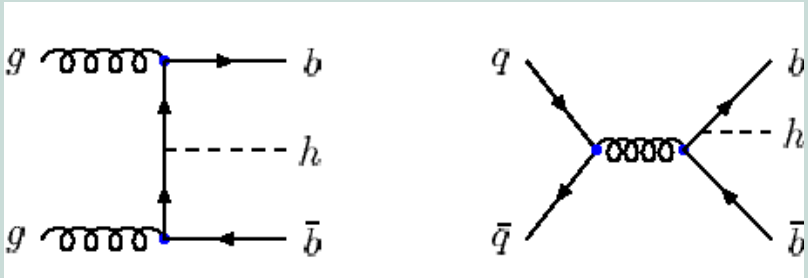


Search for a neutral MSSM Higgs bosons

- $\phi \to \tau\tau$
  - BR ~10%, clean signature
- $b\phi \to b\tau\tau$
  - additional sensitivity at low m_A
- ***(b)bφ→(b)bbb***
  - BR ~90%, large multijet background
  - For large tanβ at least two Higgs bosons have approximately the same mass and couplings to down-type quarks.
  - The production of Higgs boson associated with b-quark is enhanced by a factor of $2\times\tan^2\beta$





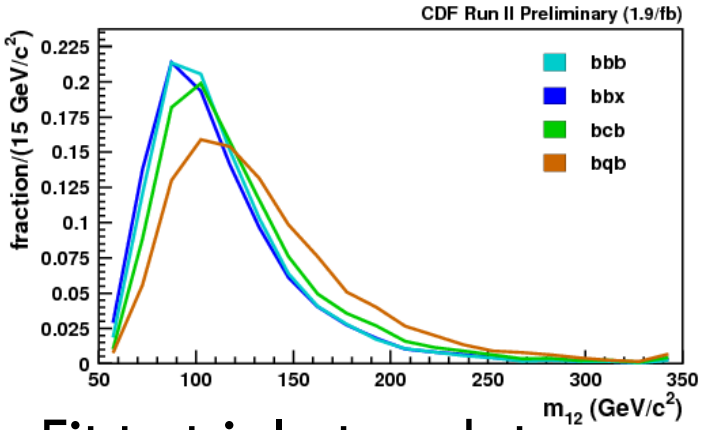


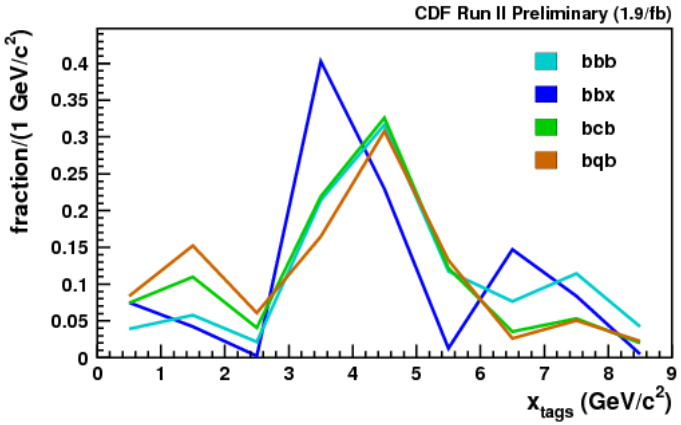
Search for $b\phi \rightarrow bbb$ (CDF)

- Search for an enhancement in the mass distribution of the two lead jets in triply b-tagged events, m_{12}.
- In addition, have discriminant, x_{tags} , which is based on the mass of the tracks forming the displaced vertex.
- Main background: QCD (know from MC simulation that at least two jets are real b-jets: *bbb, bbc, bbq, bcb, bqb*)
  - Start with double tag 3-jet event,
  - Apply MC derived tagging efficiencies to get *bbb, bbc, bbq* templates
  - Assume that m_{12} in *bcb* is similar to m_{12} in *bbb*; correct for tag masses only
  - Derive m_{12} and x_{tags} templates, apply to data and let them float during the fit

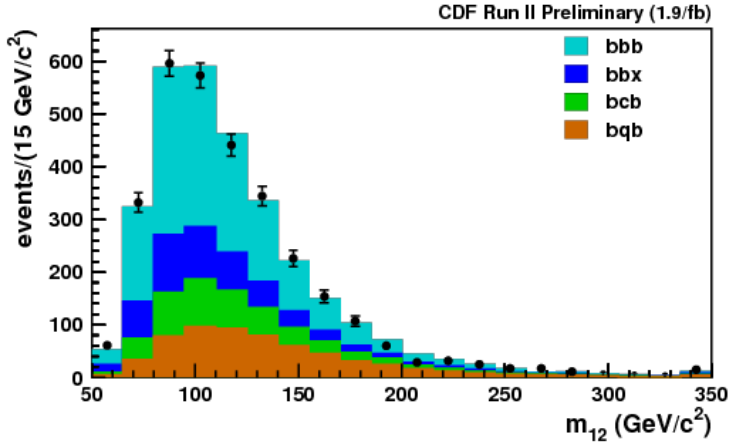
Search for $b\phi \rightarrow bbb$ (CDF)

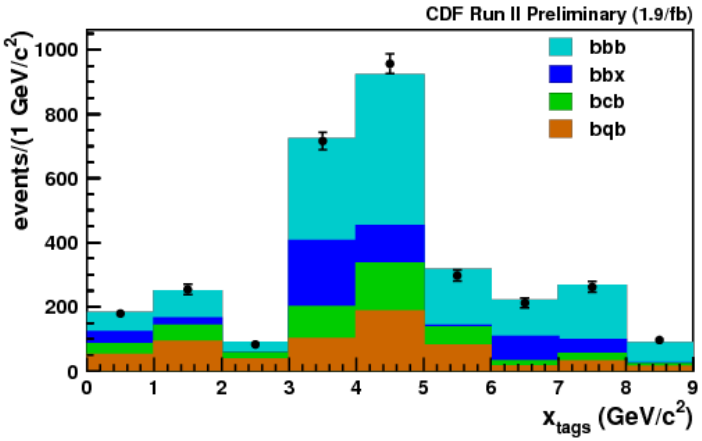
- Templates obtained on 2-tag data with applied tagging efficiencies





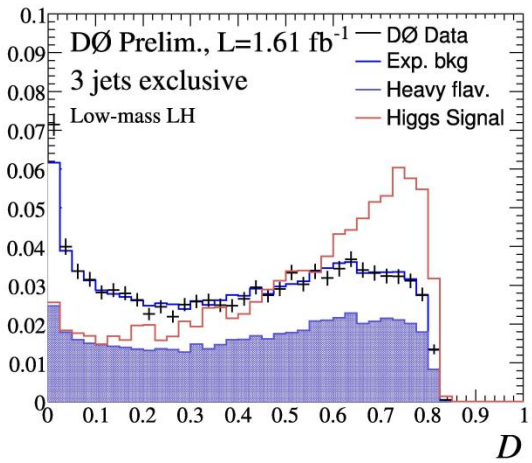
- Fit to triple tag data

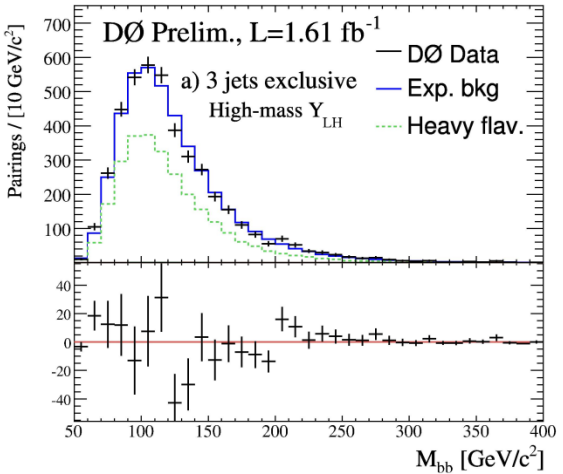




Search for $b\phi \rightarrow bbb$ (DO)

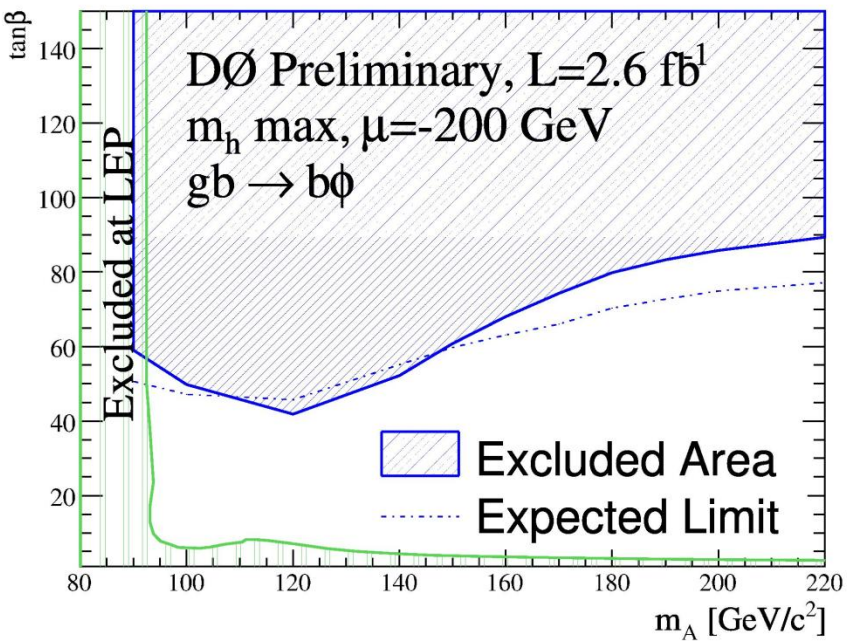
- Selection:
  - At least 3 tagged jets; p_T of two leading b-tagged jets > 25 GeV
  - Two jet pairs with largest sum p_T are considered as Higgs boson candidates. Required: $\Delta R>1$ to remove $g \rightarrow bb$ process
- Background:
  - The di-jet invariant mass distribution of the expected triple b-tagged sample is obtained from the double b-tag data shape times ratio of MC shapes in triple and double tagged events.

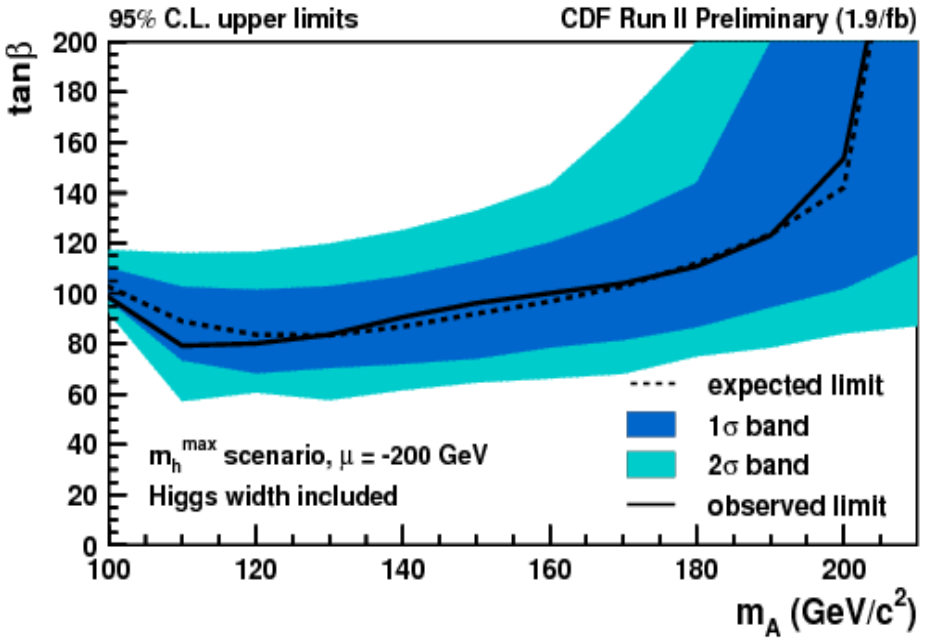




Results on $b\phi \rightarrow bbb$ search

- Width is included in the limit calculations (not negligible at high tanβ)
- Strongest limits for Higgs field mixing parameter, $\mu < 0$
- Systematic uncertainties include: theoretical, Jet ID, Jet energy corrections, b-tagging, trigger, shape of the BG modeling





DO Combination on neutral MSSM Higgs bosons search

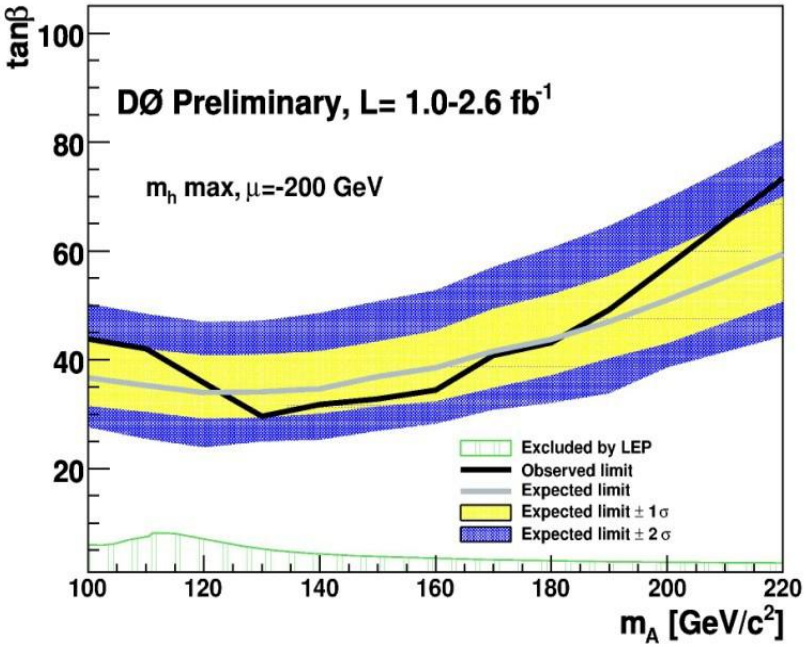
- Limit was obtained on neutral Higgs bosons production using three channels: $h \rightarrow \tau\tau$, $bh \rightarrow b\tau\tau$ and $bh \rightarrow bbb$
  - 19 sub-channels with measurements done on 1 to 2.6 fb^{-1} data
- Four benchmark MSSM scenarios:
  - Maximal mixing ($M_{SUSY} = 1TeV$, $M_2 = 200$ GeV, $X_t = 2M_{SUSY}$, $A_b = A_t$, $m_{\tilde{g}} = 0.8M_{SUSY}$) with $\mu = \pm 200$ GeV
  - Minimal mixing ($M_{SUSY} = 2$ TeV, $M_2 = 200$GeV, $X_t = 0$, $A_b = A_t$, $m_{\tilde{g}} = 0.8M_{SUSY}$) with $\mu = \pm 200$ GeV

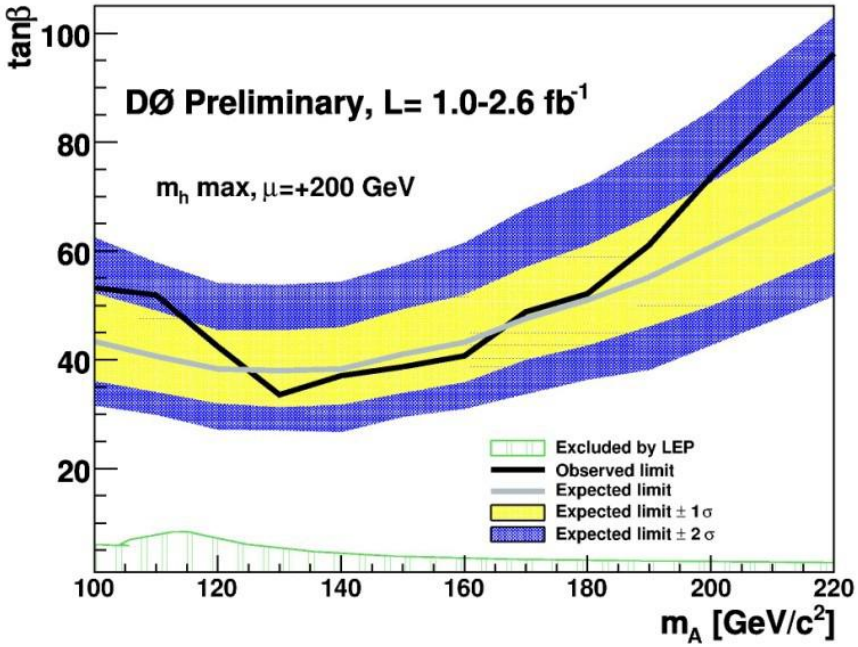
DØ Combination result

- Limits are set using the modified frequentist (or CLS) technique

$$CL_S = CL_{s+b} / CL_b$$

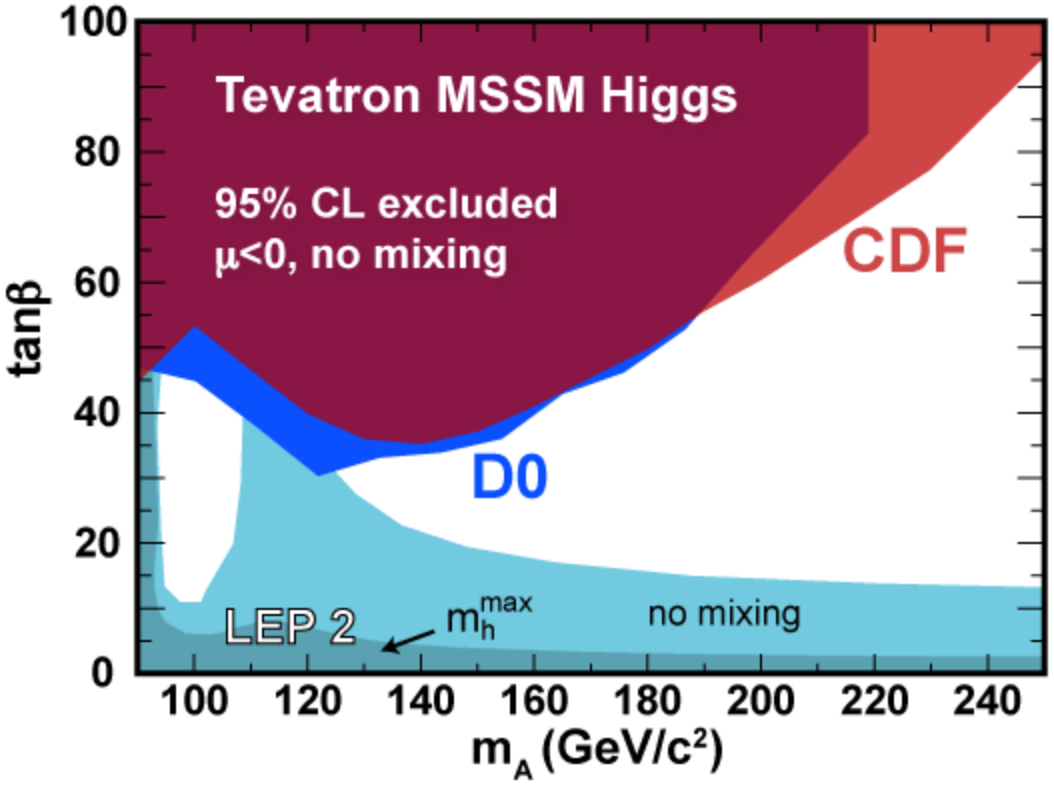
- Strongest limit on neutral MSSM Higgs bosons in tanβ –m_A plane to date at a hadron collider
- Combination between D0 and CDF to come…





Summary on the MSSM neutral Higgs boson exclusion

- Limits from both experiments:



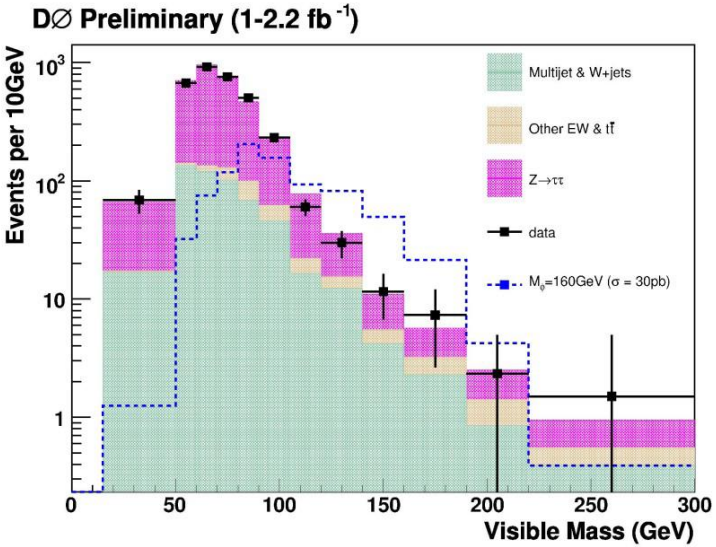
Summary

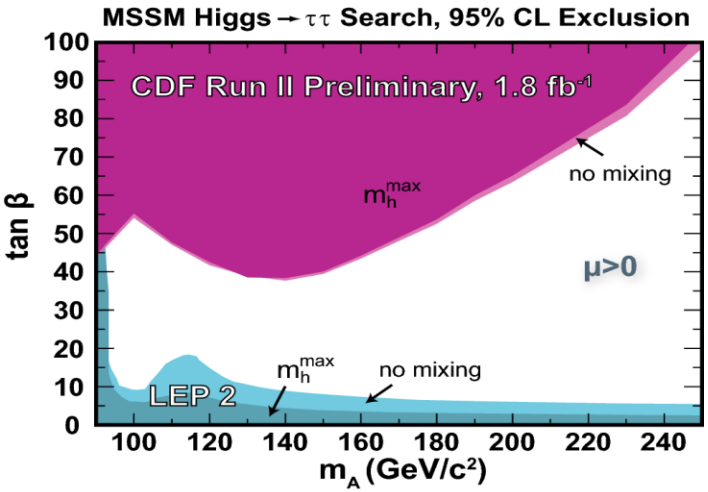
- Tevatron performs very well – expect 10 fb^{-1} per experiment by the end of Tevatron era
- Both D∅ and CDF are actively searching for hints of supersymmetric Higgs bosons in data
- Combining various channels and results from both experiments significantly improve Tevatron's sensitivity to new physics
- Only 2.6 fb^{-1} of data has been used so far by each experiment – expect to have new results on much larger statistics in the near future
  - **Better limit or Discovery?...**

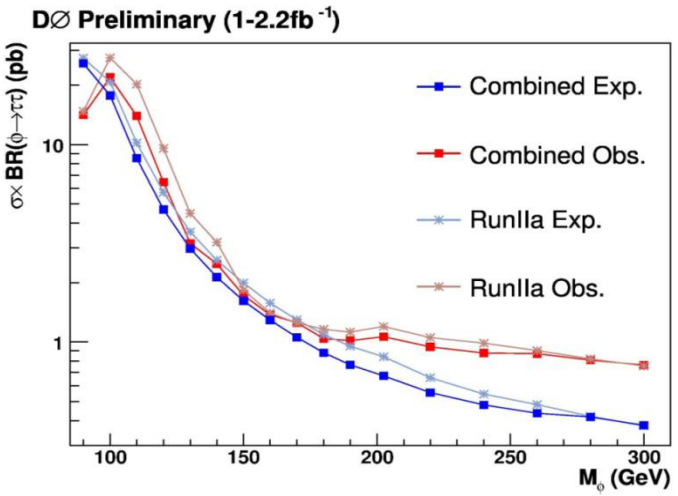
Backup slides

Search for $\phi \rightarrow \tau\tau$

- Event selection:
  - Isolated electron or muon + hadronic τ
  - Isolated electron + isolated muon
- Backgrounds: $Z \rightarrow \tau\tau$, multijets, W+jets, $Z \rightarrow ee/\mu\mu$, di-bosons
- Discriminating variable: Visible mass







Search for $b\phi \rightarrow b\tau\tau$

- Search in $\mu\tau_{had}$ channel
  - isolated muon + opposite sign hadronic tau
  - at least one b-tagged jet
- Background: ttbar, QCD, $Z(\rightarrow\tau\tau)$+heavy flavor jets
- Events selected using combination of NN(trained against tt) and likelihood (multi-jet)