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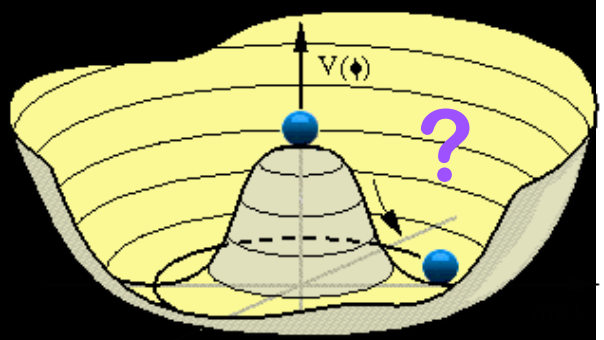


BSM Higgs at Tevatron

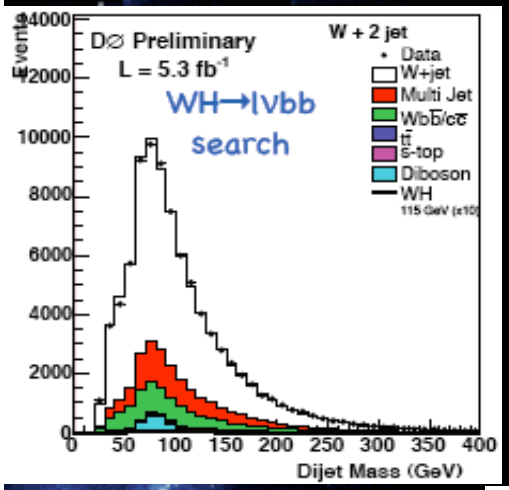
Un-Ki Yang

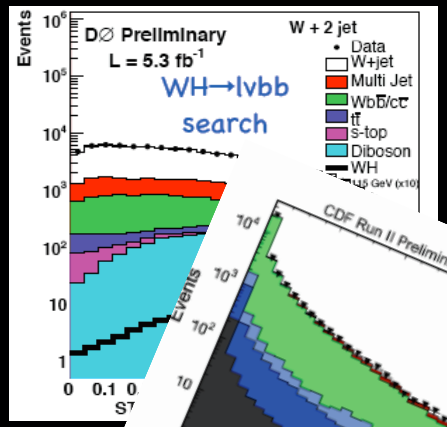
The University of Manchester

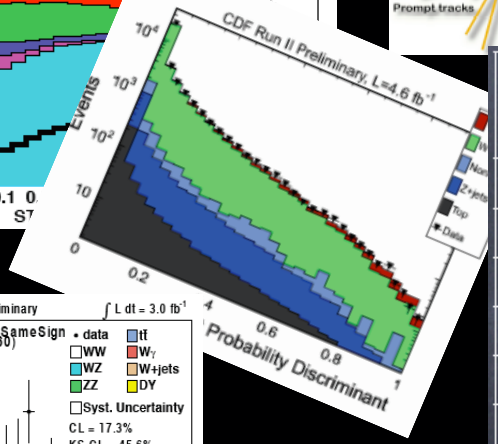
for the CDF and DØ collaborations

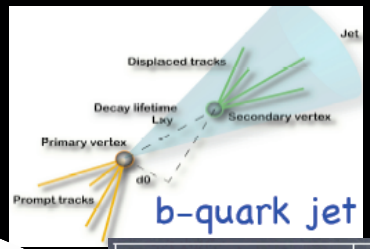
Higgs Hunting Workshop, July 29-31 2010, Orsay, France

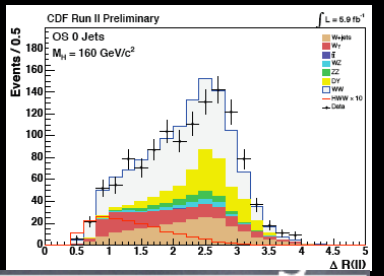
Incredible efforts by thousands of physicists: the SM Higgs

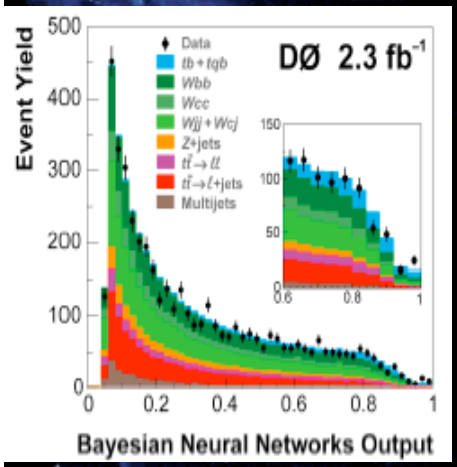


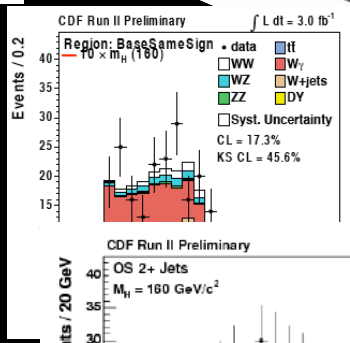


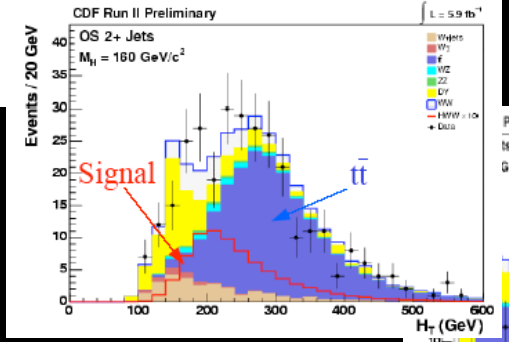


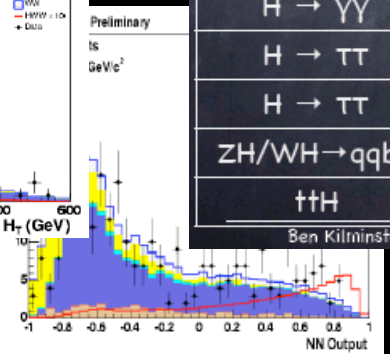






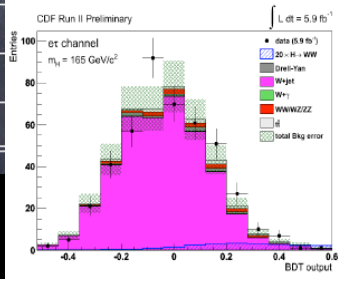






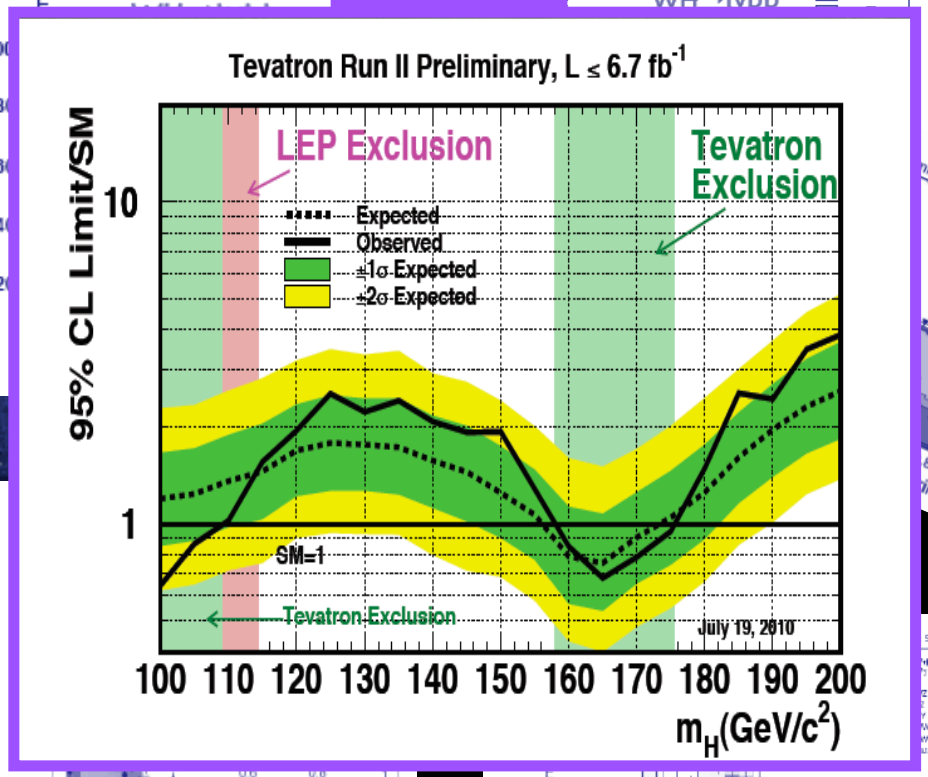
Channel	Expt	Dataset now	Increase since Nov. 2009 combination
H → WW	DO	6.7	24%
H → WW	CDF	5.9	23%
WH → lνbb	CDF	5.7	30%
WH → lνbb	DO	5.3	6%
ZH/WH→METbb	CDF	5.7	60%
ZH/WH→METbb	DO	6.4	23%
ZH → llbb	CDF	5.7	40%
ZH → llbb	DO	6.2	45%
H → γγ	CDF	5.4	New!
H → γγ	DO	4.2	0%
H → ττ	CDF	2.3	15%
H → ττ	DO	4.9	
ZH/WH→qqbb	CDF	4	
ttH	DO	2.1	

Ben Kilminster, ICHEP 2010

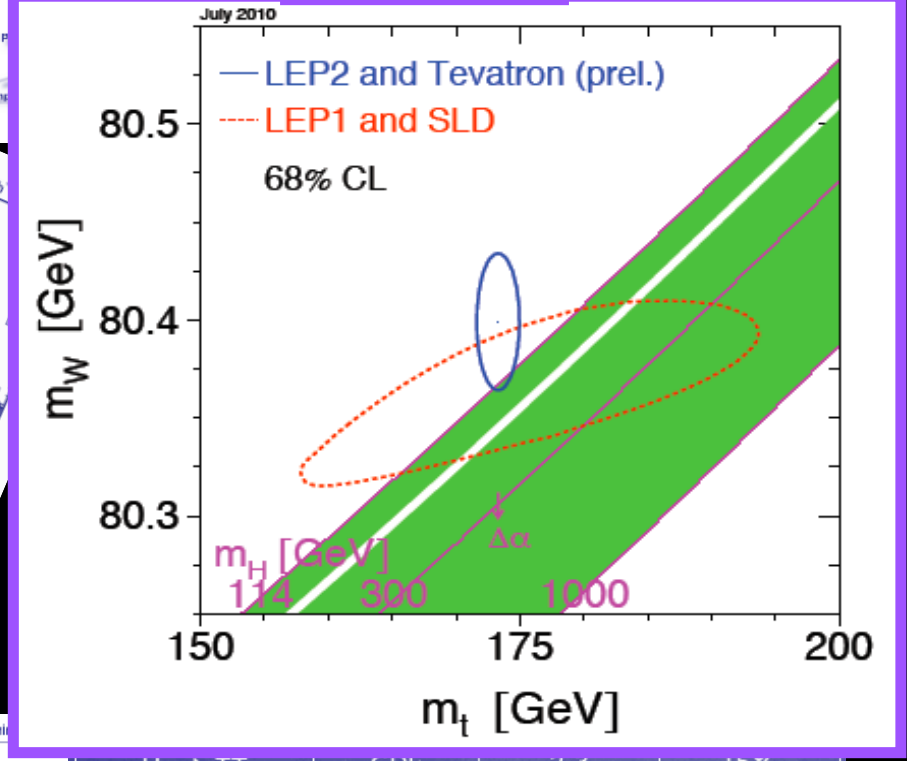


Incredible efforts by thousands of physicists: the SM Higgs

Direct



Indirect

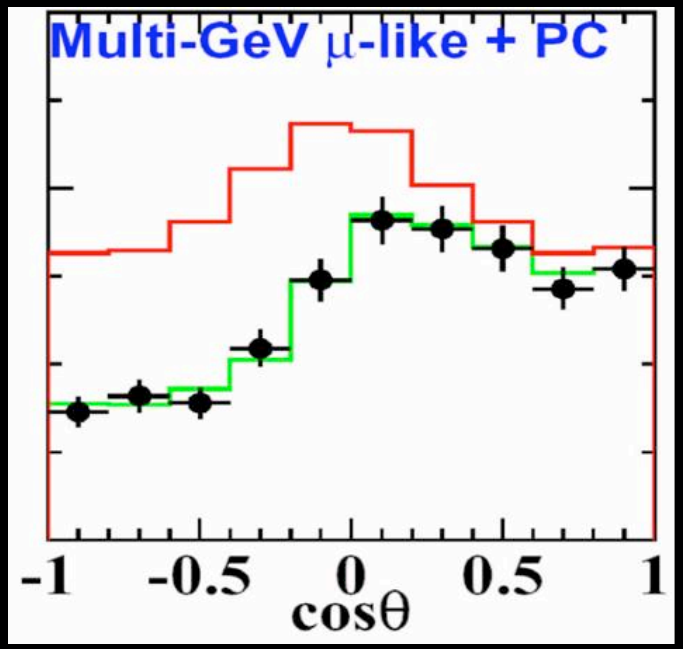


- The searches for the SM Higgs are extremely challenging
- But very crucial to discover it !!!

But the Real World is … the BSM Higgs(?) World

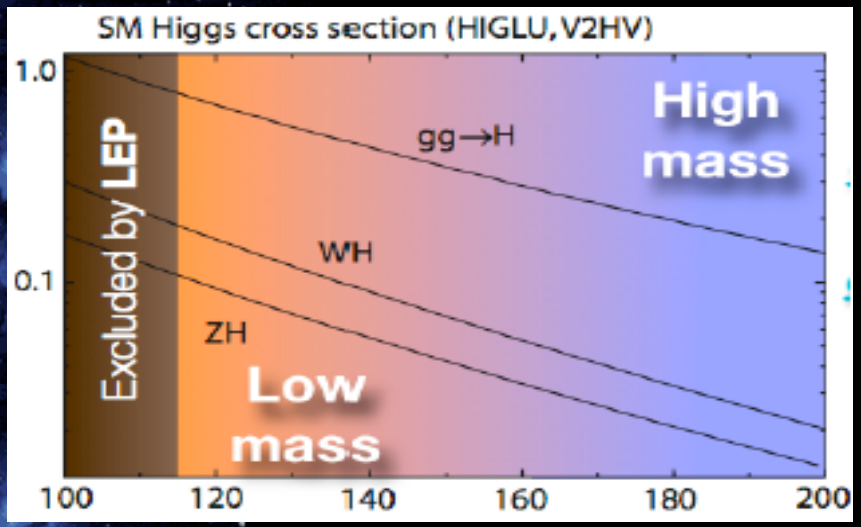
- The SM is not complete;
  - Hierarchy problem (fine tuning)
  - …
  - Effective theory at low energy?
- Dark Matter

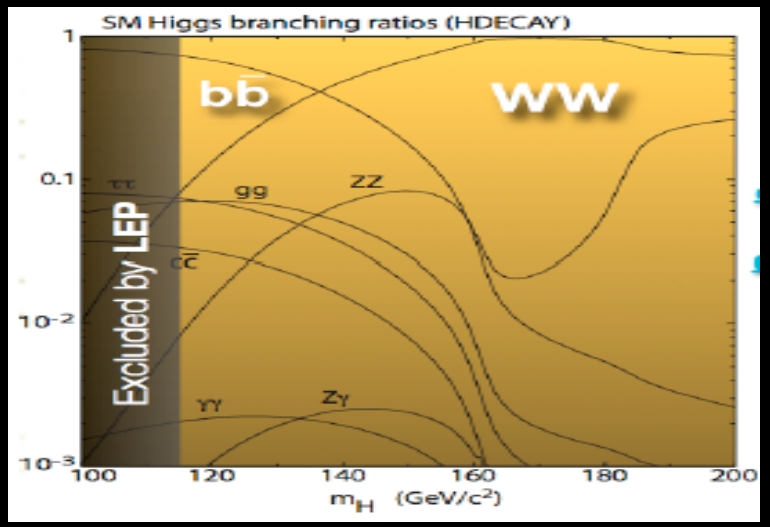
- Neutrino Oscillation

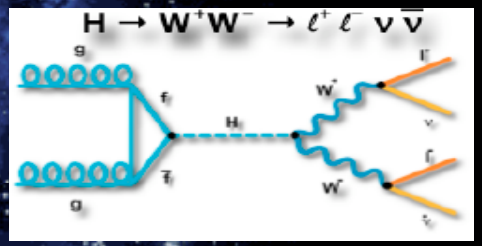


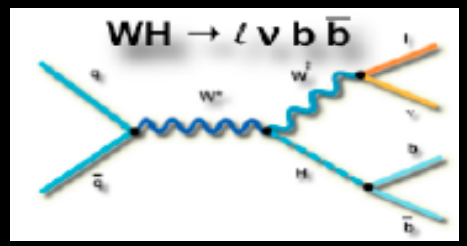
The Strategy: SM Higgs

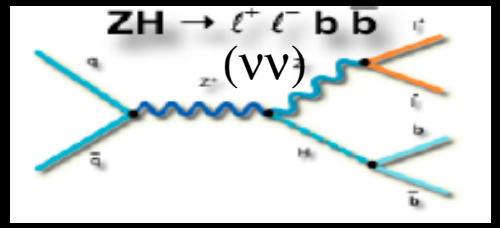
See talks by R. Hughes & M. Kirby







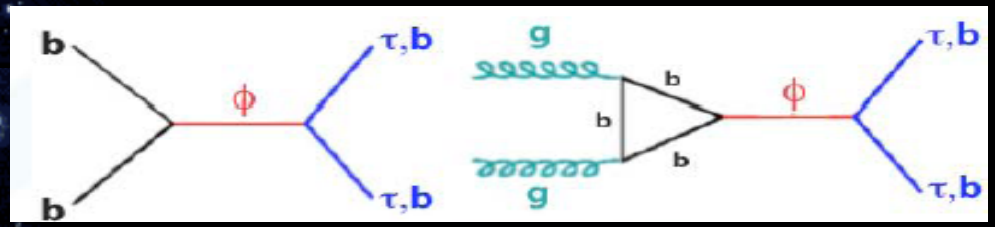




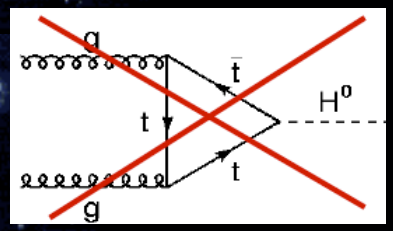
- Maximize acceptance while reducing bkgds: better triggers, lepton IDs, b-tagging, mass resolution etc)
- Use advanced analysis algorithms (NN, BDT, MET etc)
- Analyse all possible channels separately, then combine them

The Strategy: BSM Higgs

- Maximize signal sensitivity by exploring the Beyond SM from many different angles armed with the search tools for the SM Higgs searches
- Enhance production: MSSM, 4th gen. model



- Different Higgs couplings to fermions & bosons: fermiophobic, example, large Br($H\rightarrow\gamma\gamma$) but Br($H\rightarrow bb$)=0



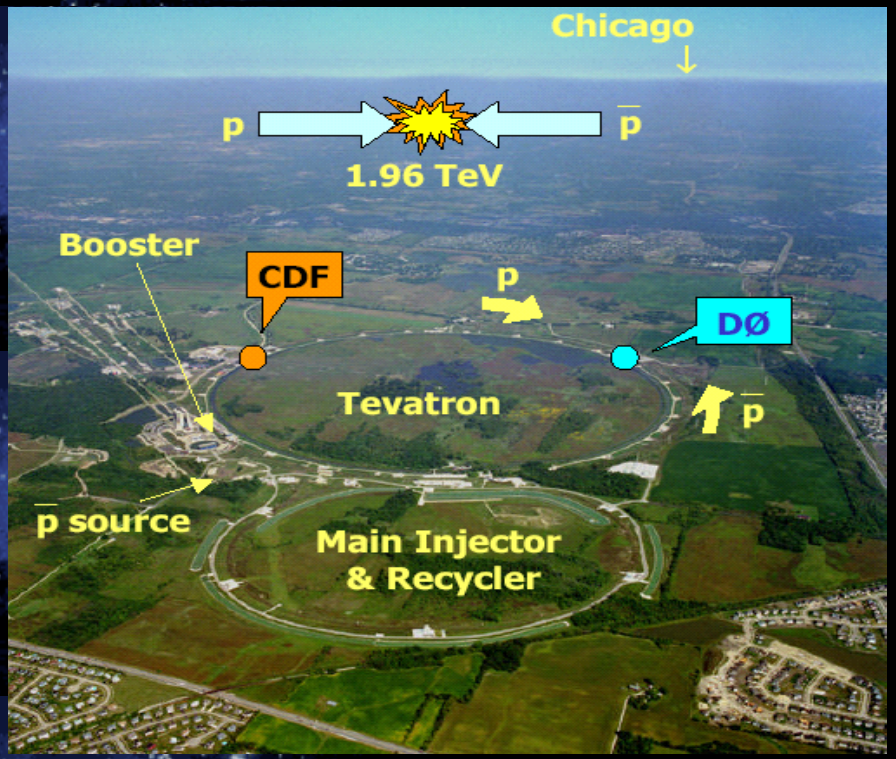
- New allowed final states:

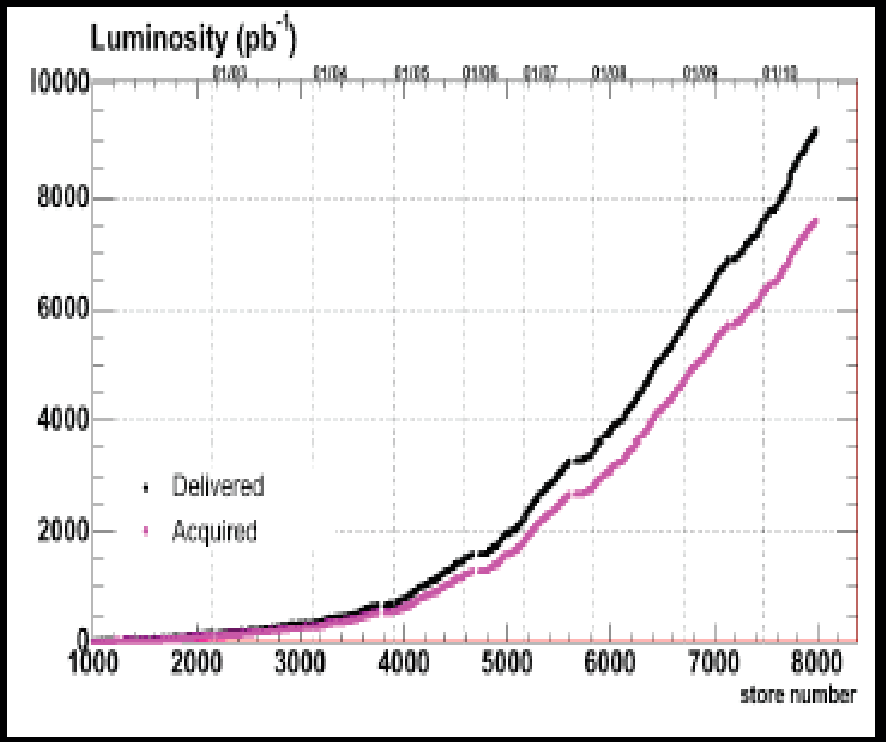
NMSSM (2 extra Higgs, $h\rightarrow aa\rightarrow 4\tau$), charged Higgs ($t\rightarrow H^{\pm}b$)

BSM Higgs Searches

- Tevatron Status
- MSSM Higgs
  - Neutral Higgs ($\phi \rightarrow \tau\tau$, $b\phi \rightarrow bbb$, $b\phi \rightarrow b\tau\tau$)
  - Charged Higgs
- NMSSM Higgs
- Fermiophobic Higgs
- 4^{th} generation of fermions
- Higgsless model (NO Higgs, not supposed to talk about)

Tevatron : Great Performance

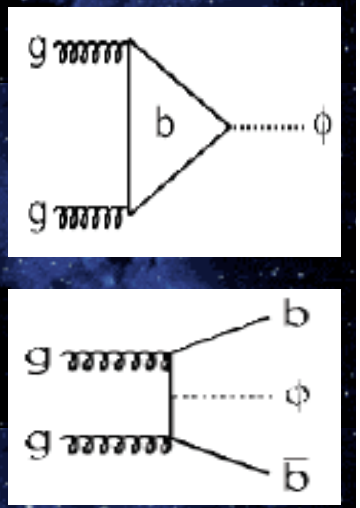


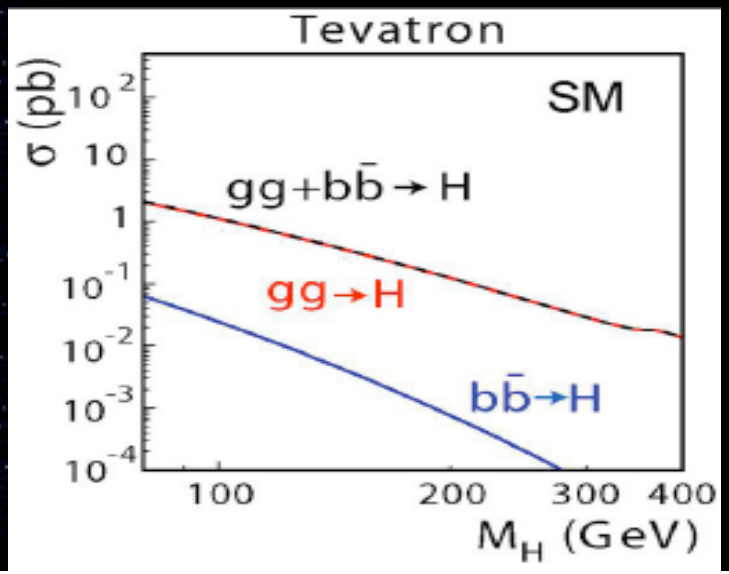


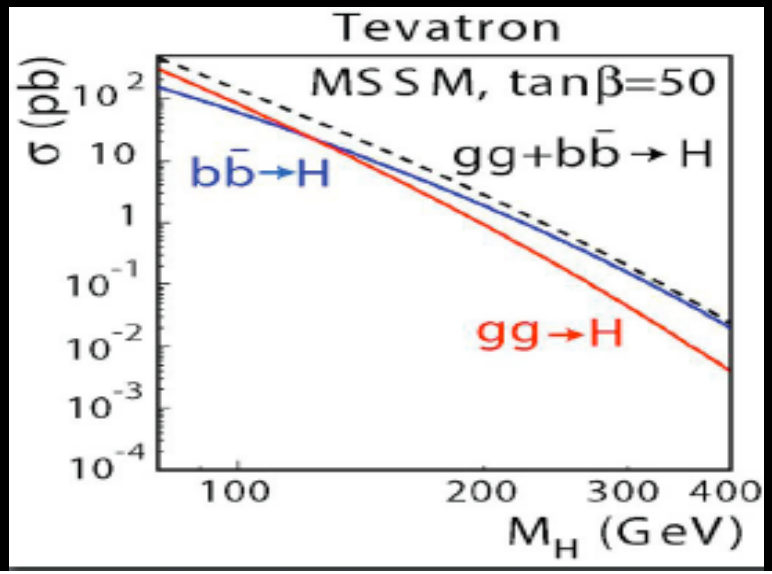
- The Tevatron has been running beautifully
- Delivered lum. 9.0 fb^{-1} per experiment (acquired lum. 7.5-8 fb^{-1})
- The highest inst. lum. 4.08x10^{32} cm^{-2}s^{-1}

MSSM Higgs world

- In the MSSM, 5 Higgs bosons: $\phi(h, H, A)$ and H^+, H^- by at least two parameters, m_A and $\tan\beta$
- Neutral Higgs, ϕ
  - Production is enhanced by $\tan\beta^2$
  - Another factor of 2 due to degeneracy of two Higgs bosons
  - Coupling to *b* quark is increased by $\tan\beta$: greatly enhanced $\sigma(bb \rightarrow H)$

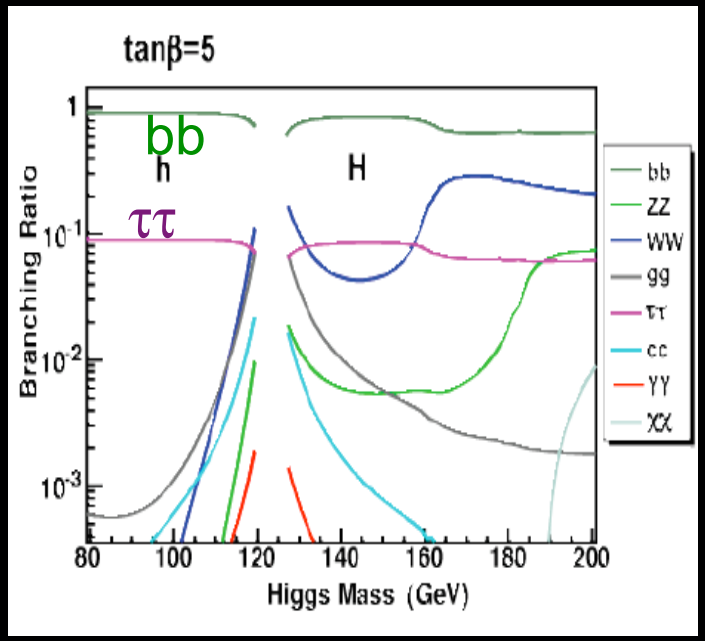




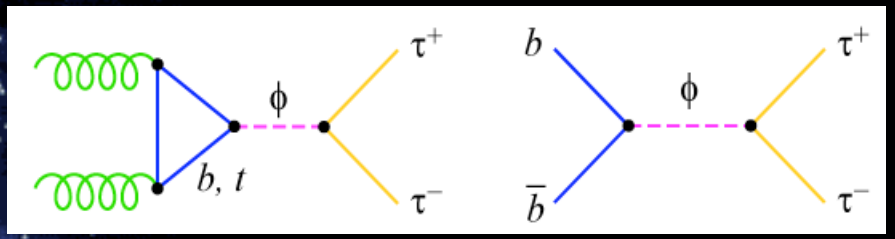


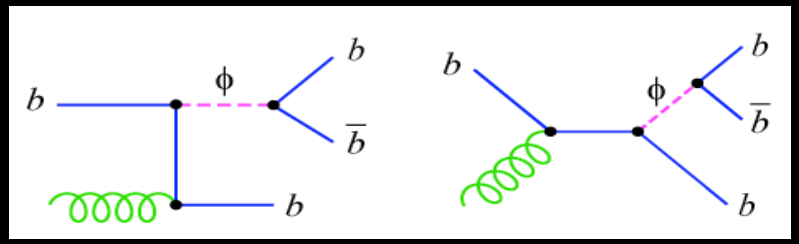
Search Modes

- At high tan β , for all m_A:
  - Br(bb) ~ 90 % (but large bkgds)
  - Br(ττ) ~ 10 % (but distinct signature)



- Three searches:
  - $\phi \rightarrow \tau\tau$,
  - $b\phi \rightarrow bbb$
  - $b\phi \rightarrow b\tau\tau$,

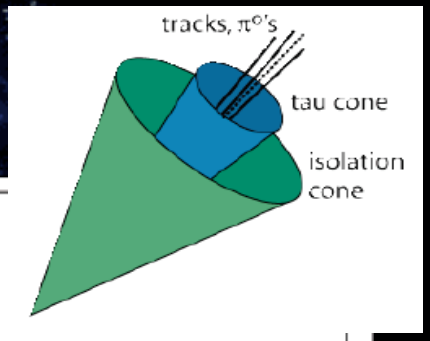


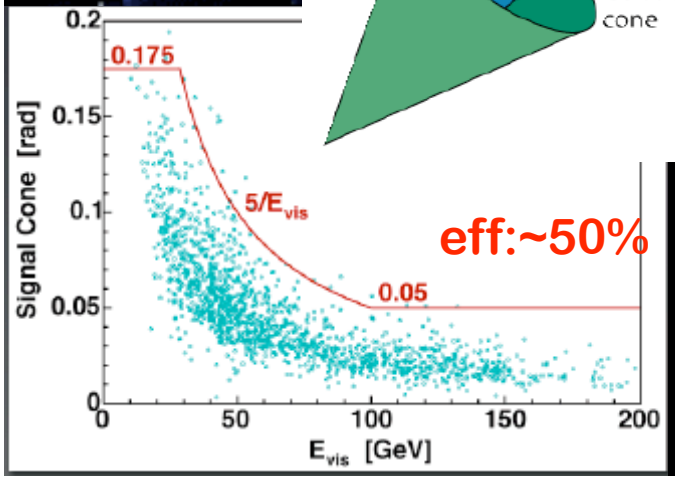


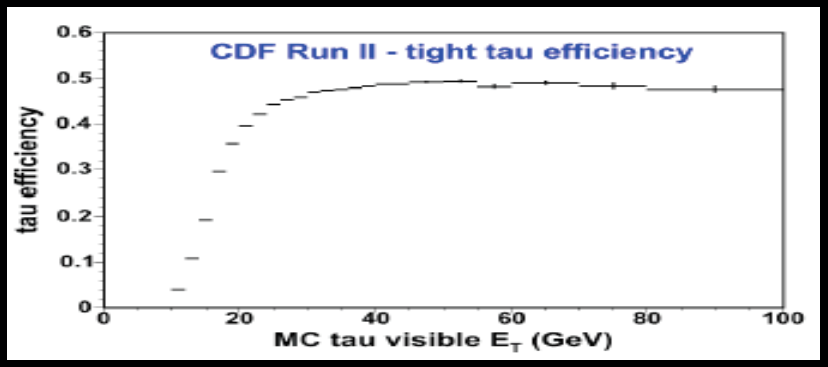
- Good *b*-jet and τ identification are essential!

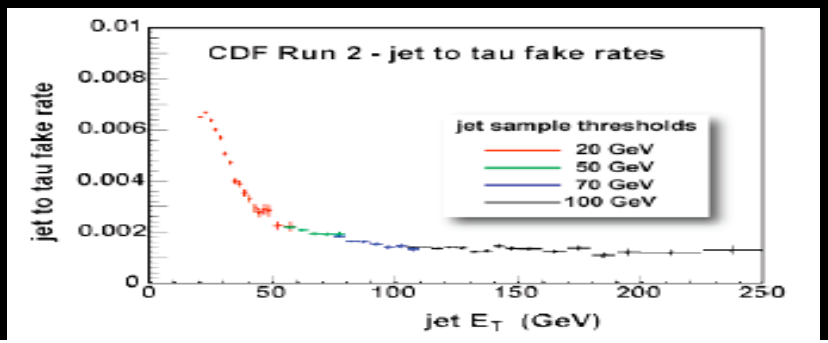
MSSM Higgs : $\phi \rightarrow \tau^+\tau^-$

- Searches in three different channels: $\tau_e\tau_{had}, \tau_\mu\tau_{had}, \tau_e\tau_\mu$
  - At least one lepton(e/μ), but only eμ dileptons (no *ee*, $\mu\mu$)
  - Main background*: Z* production ($\tau^+\tau^-$)
  - Challenge: hadronic τ reconstruction and ID (eff./fake):
  - narrow cal. clusters matched to low mul. Trks
  - CDF: define signal & isolation cone (as a function of Evis)
  - D$\varnothing$: define 3 types ($\pi^+, \pi^+\pi^0, \pi^+\pi^-\pi^+$) and use NN: eff~70%





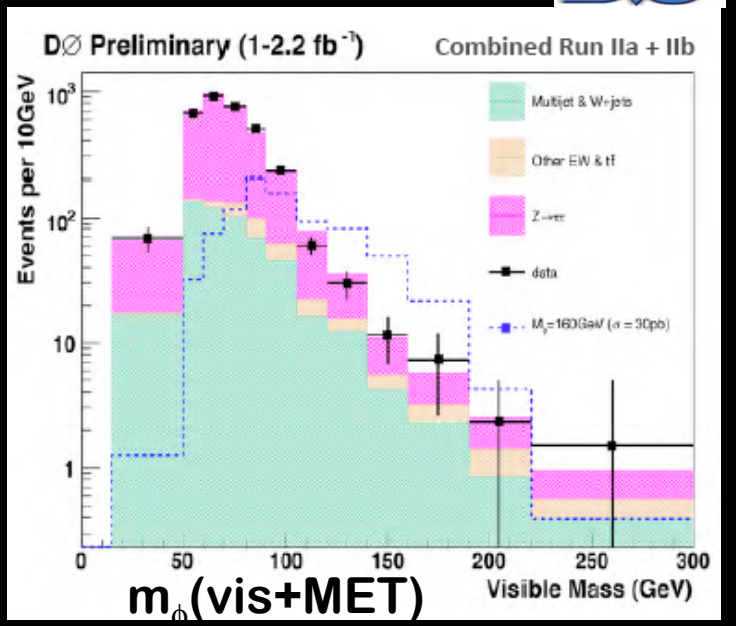


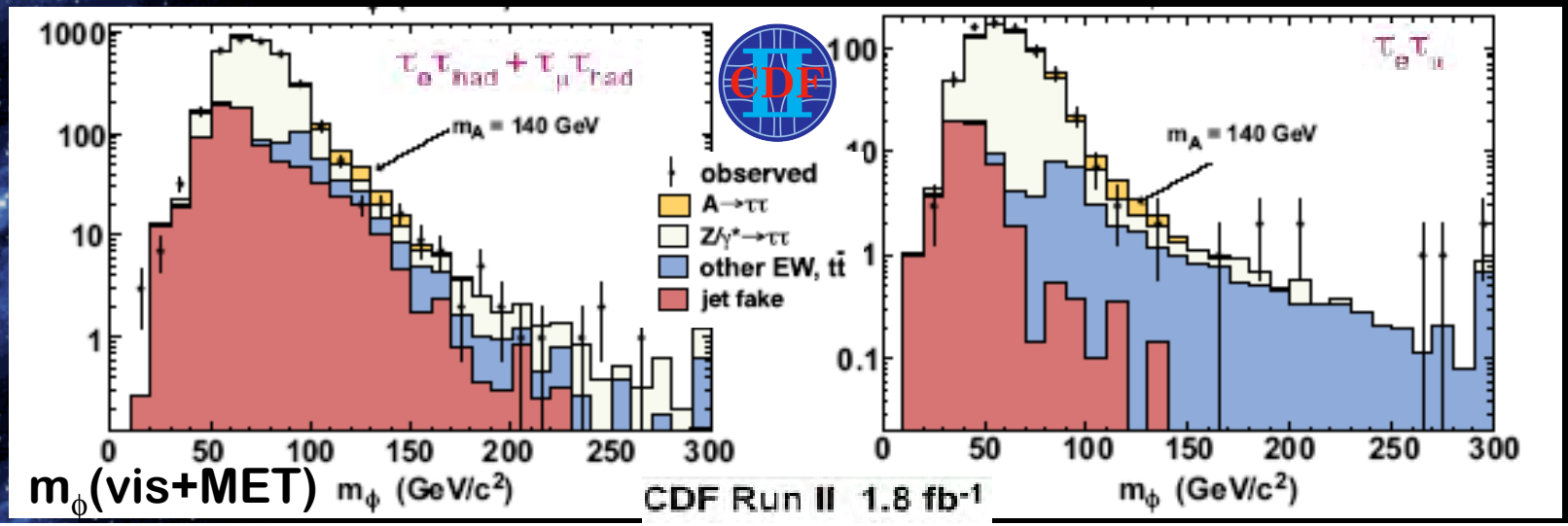


$\phi \rightarrow \tau^+\tau^-$ search

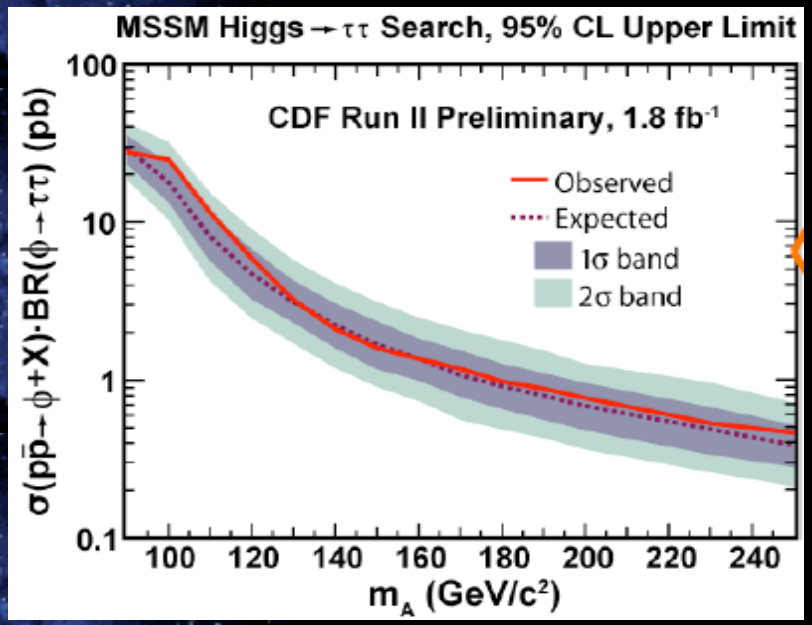
- Dominant backgrounds:
  - Irreducible $Z \rightarrow \tau\tau$ (MC)
  - W+jet fake (data)
    - ✓ DØ: $M_T < 40$ GeV
    - ✓ CDF: use relative directions of visible τ and MET

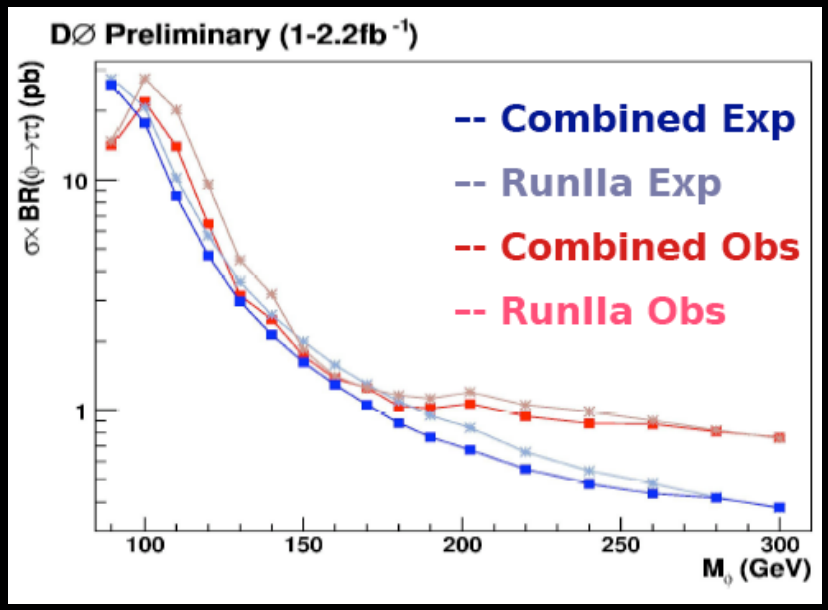
- τ-id is a main systematic
- No excess over the prediction

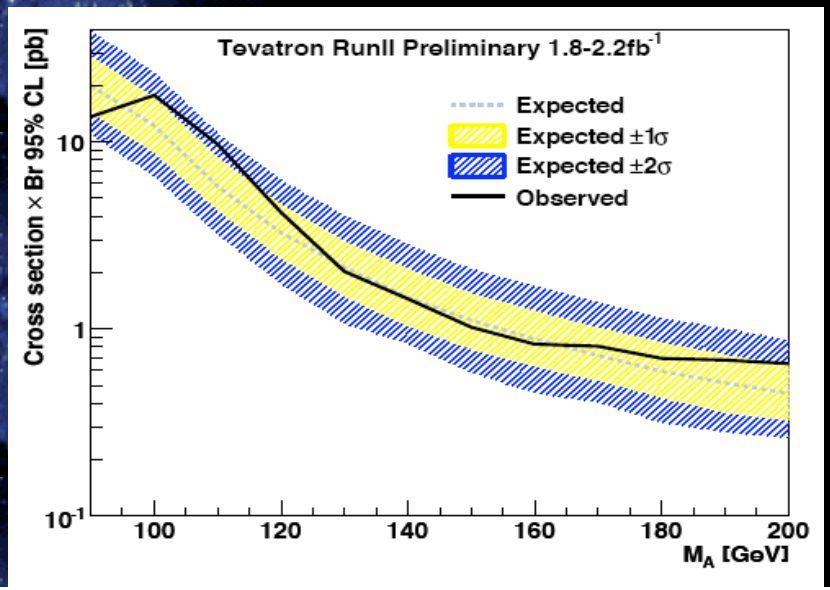


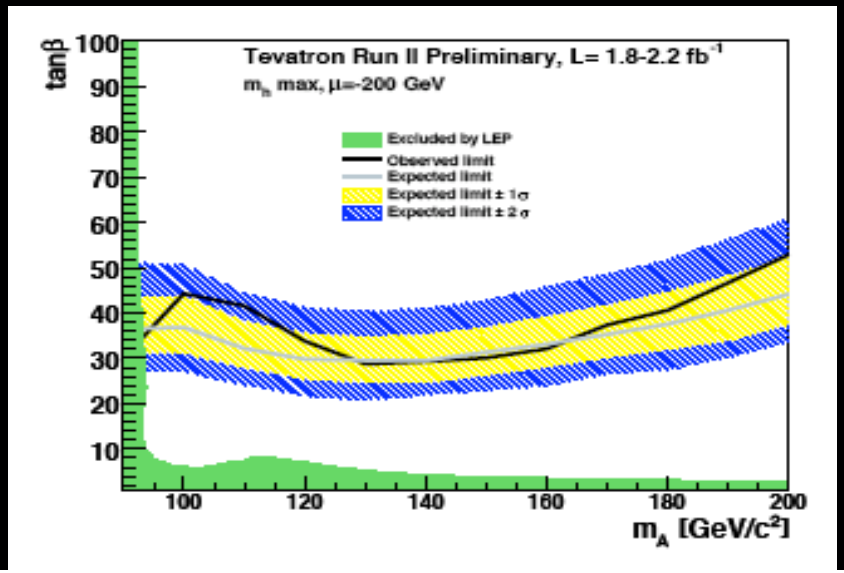


CDF and DØ comb. limits



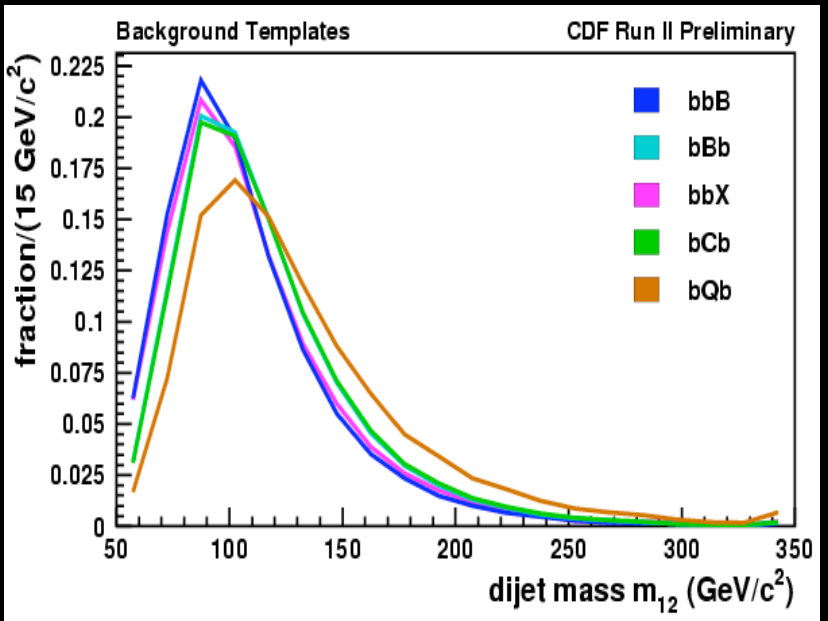


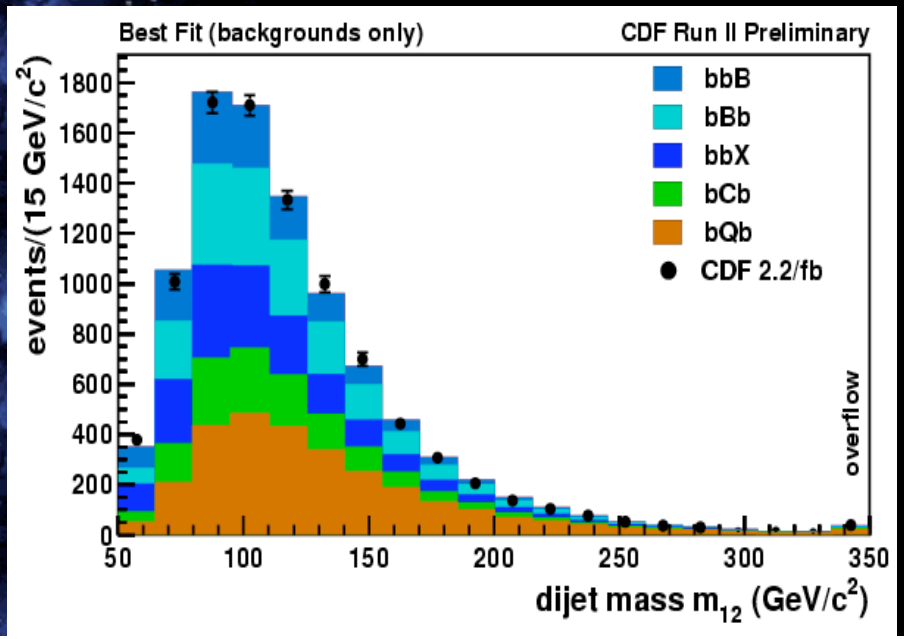


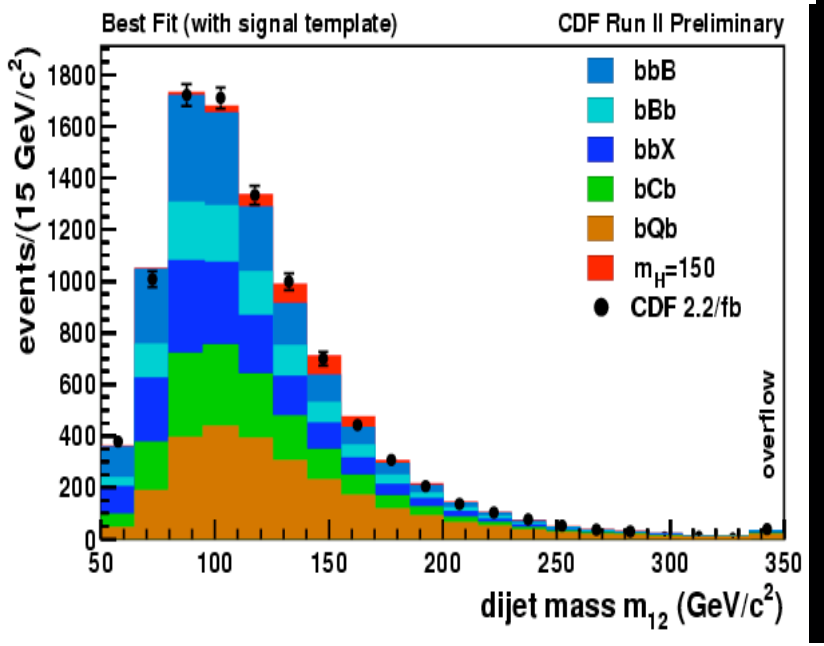


MSSM Higgs : $\phi b \rightarrow bbb$

- 3 b-tag events to reduce bkgds selected with SVT trigger
- Di-jet mass, m_{12} of the leading 2 jets
- Fully data-driven bkgds: use 2 b-tagged events to model bb+(b,c, mistag) with flavor separation using tag properties

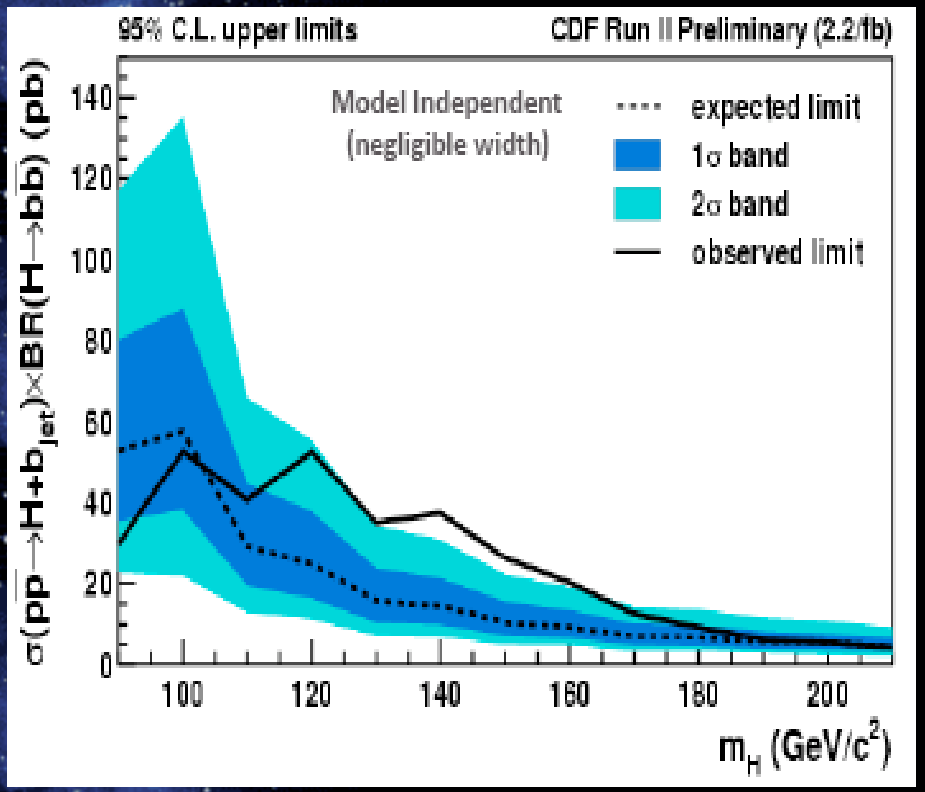


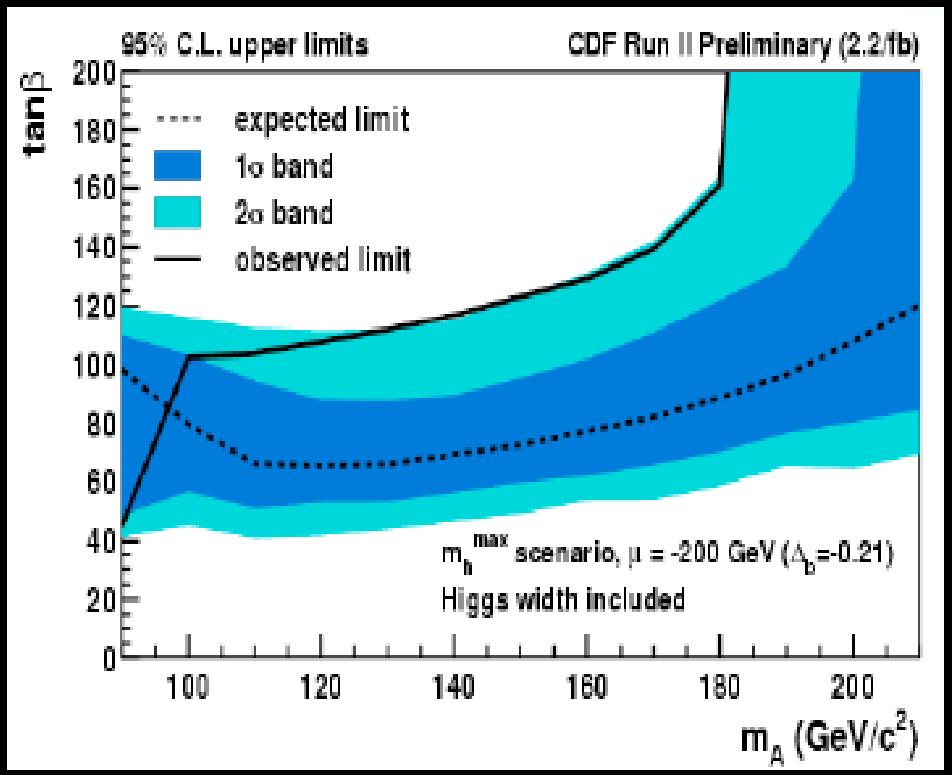




MSSM Higgs : $\phi b \rightarrow bbb$

- Set σ x BR @95% C.L.
- MSSM exclusion in m_A vs tanβ

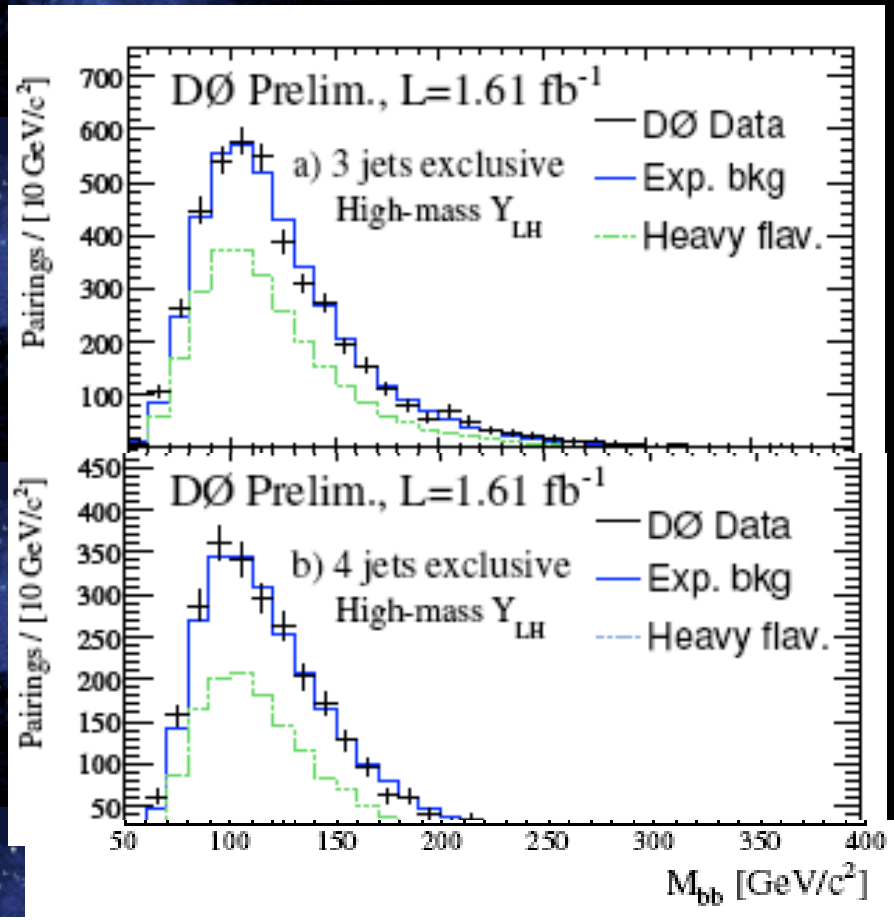


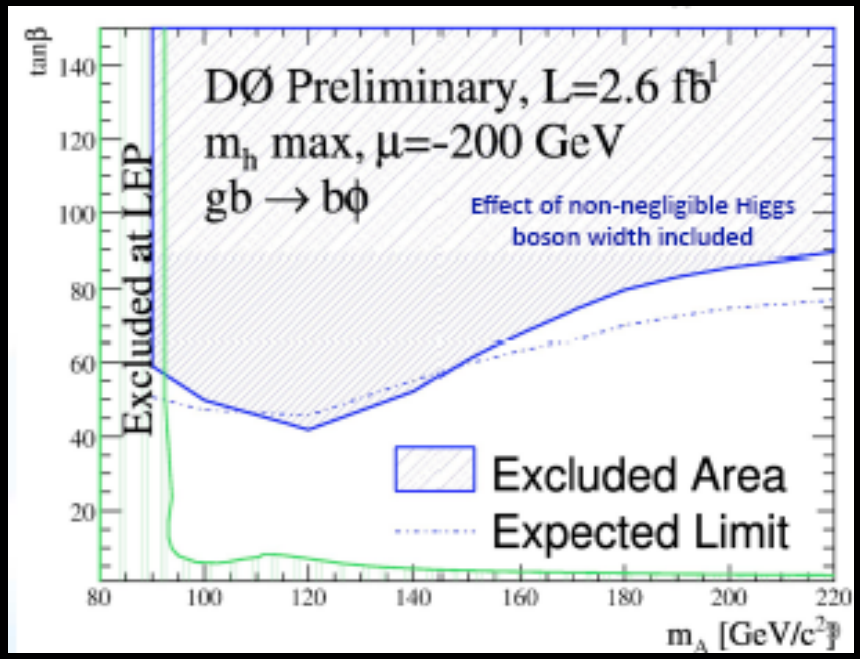


- Interesting deviation at ~140 GeV with p-value=0.9%

MSSM Higgs : $\phi b \rightarrow bbb$

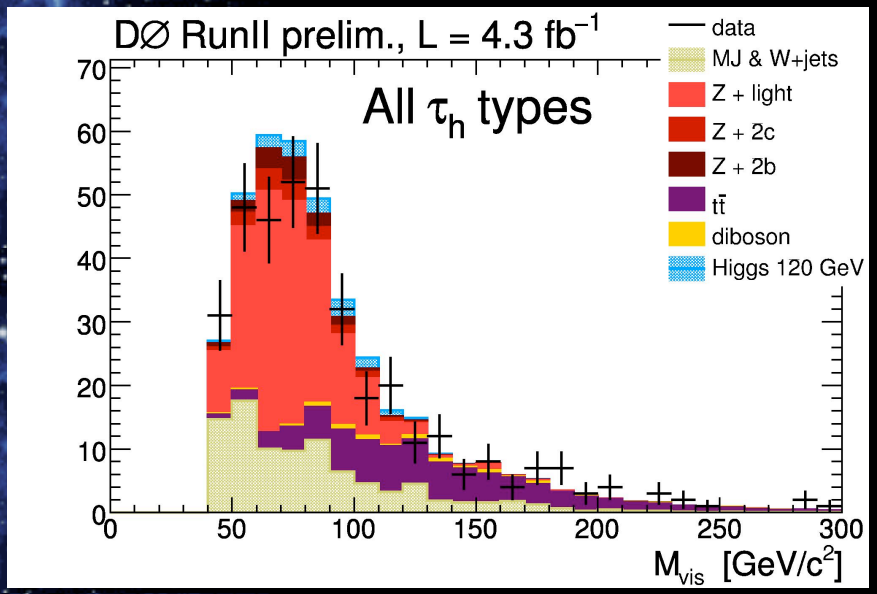
- 3 b-tagged events using NN tagger (implemented in trigger)
- Use the di-jet mass of the leading 2-jets
- Bkgds shape, M_{bb} from 2 b-tag data tuned by a 3-tag/2-tag correction from MC (exclusive 3-jets, 4-jets, 5-jets)
- Use the likelihood discriminant to separate signals from bkgds

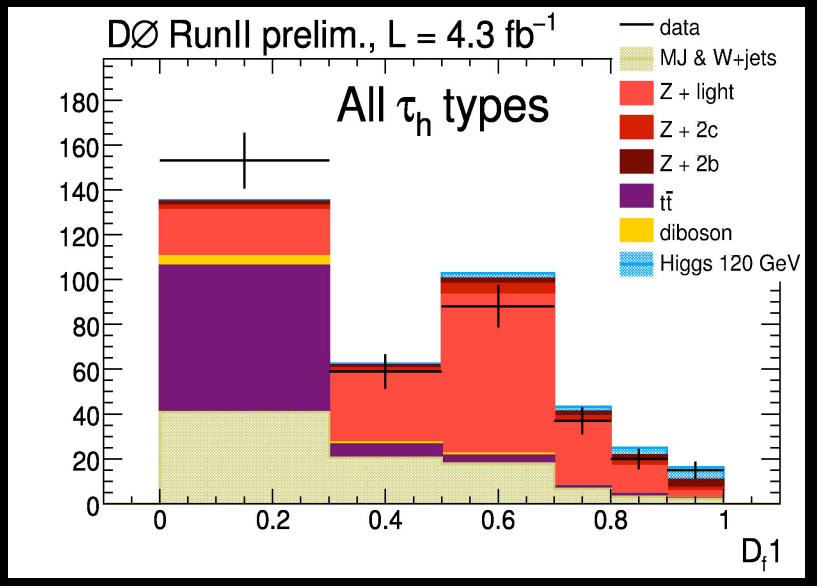




MSSM Higgs : $\phi b \rightarrow b\tau^+\tau^-$

- **Search in $b\tau_\mu\tau_{had}$ channel with 4.3 fb^{-1} data**
  - Isolated $\mu + \tau_{had}$ using NN tagger + b-jet
- **The b-tagging enhances the sensitivity**
  - NN b-tagger
  - Improve signal to bkgds using NN based discriminant
  - Dominant bkgds: Z+jets, tt, multi-jets

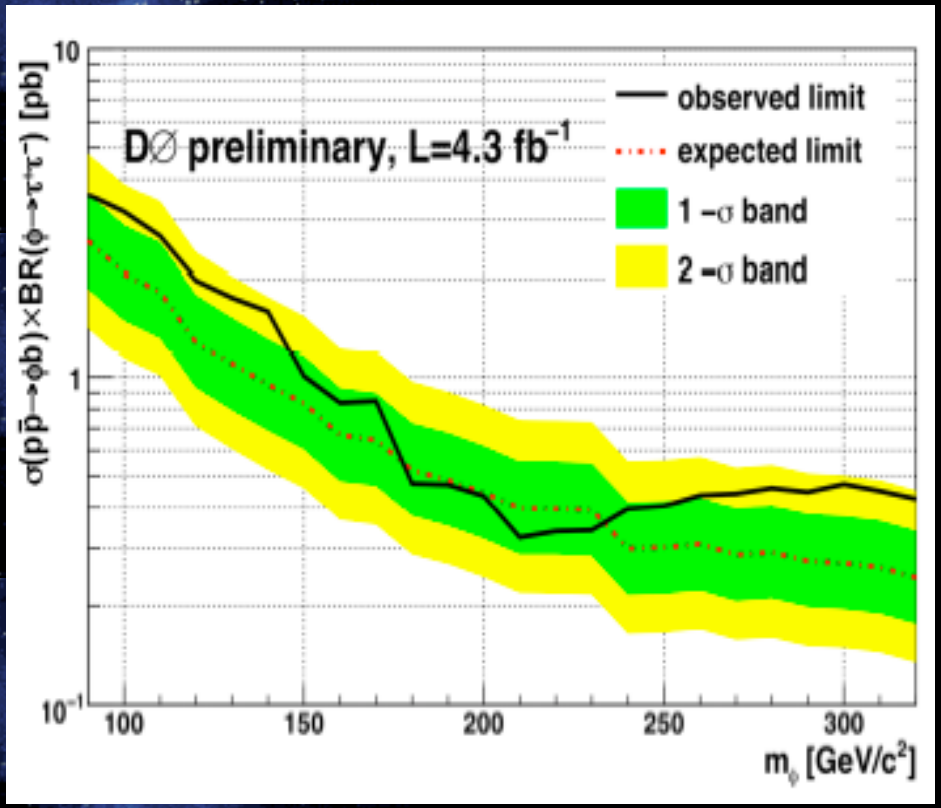


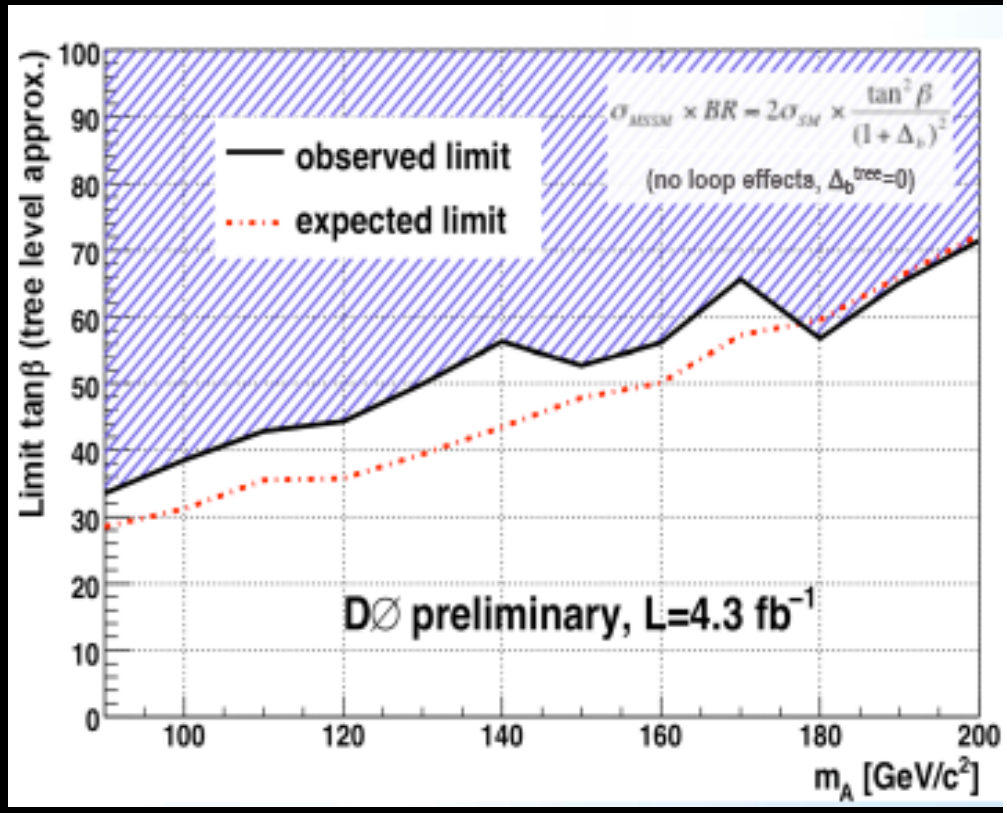


Data are consistent with bkgds

MSSM Higgs : $\phi b \rightarrow b\tau^+\tau^-$

- Set σ x BR @95% C.L.
- MSSM exclusion in m_A vs. tanβ

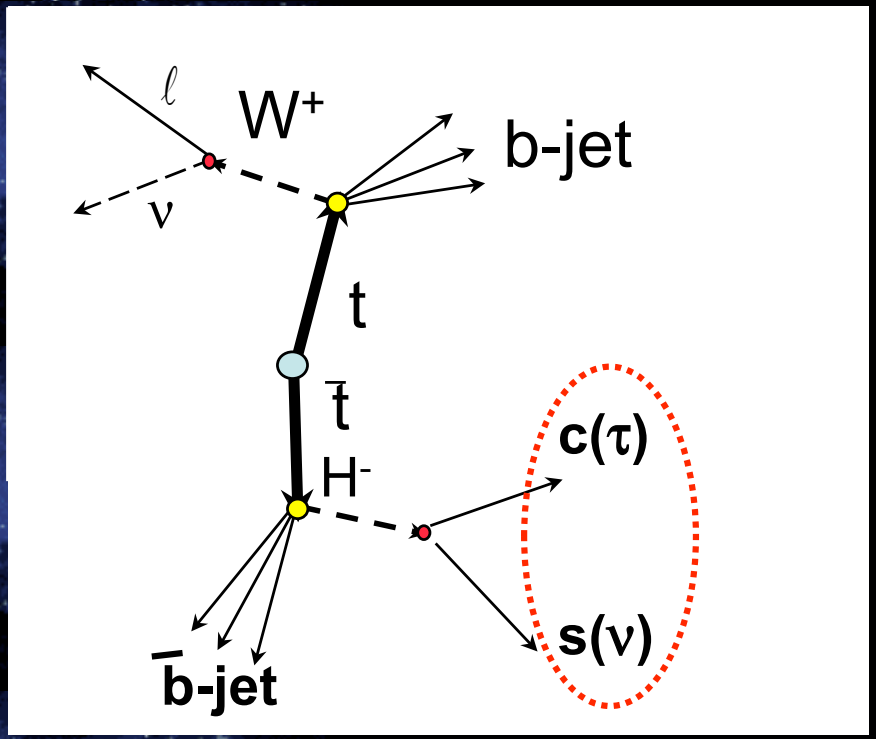


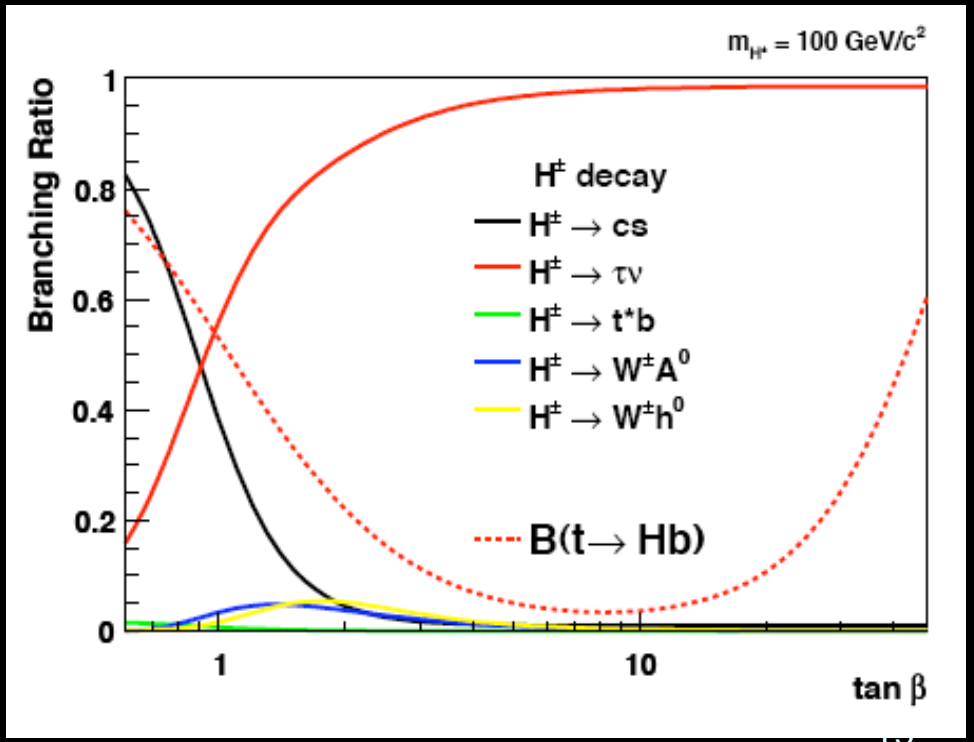


- Comparable to DØ comb. limit from $\tau\tau$, bbb,b$\tau\tau$ (1-2.6fb^{-1})

Charged Higgs: H^+

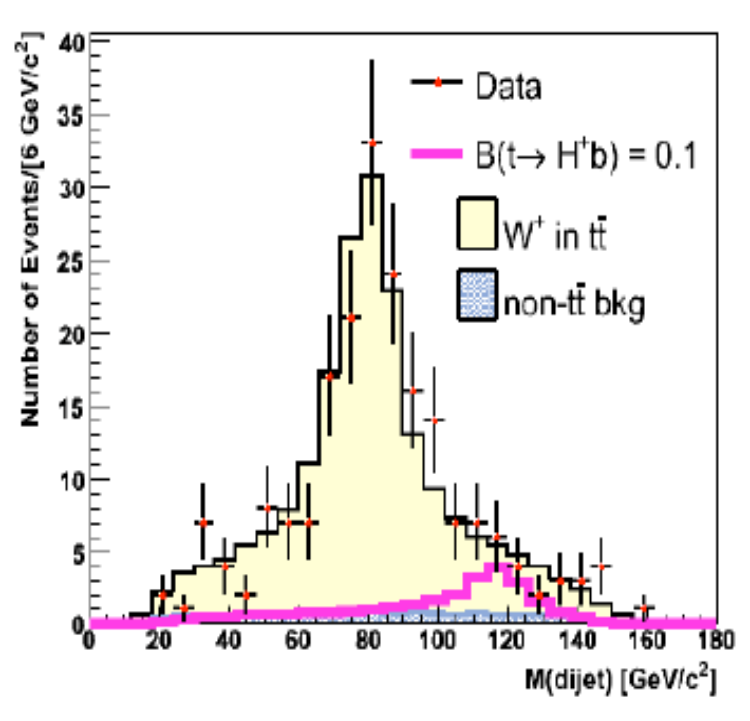
- Only exists in the BSM : direct evidence of new physics
- If $m_H < m_t$: search in top events for $t \to H^+ b$ decay
  - Two main decays; $H^+ \to \tau\nu$ (high tanβ), cs (low tanβ)
  - H(cs) dijet shape and counting experiments
- If $m_H > m_t$: search in top events for $H^+ \to tb$ decay

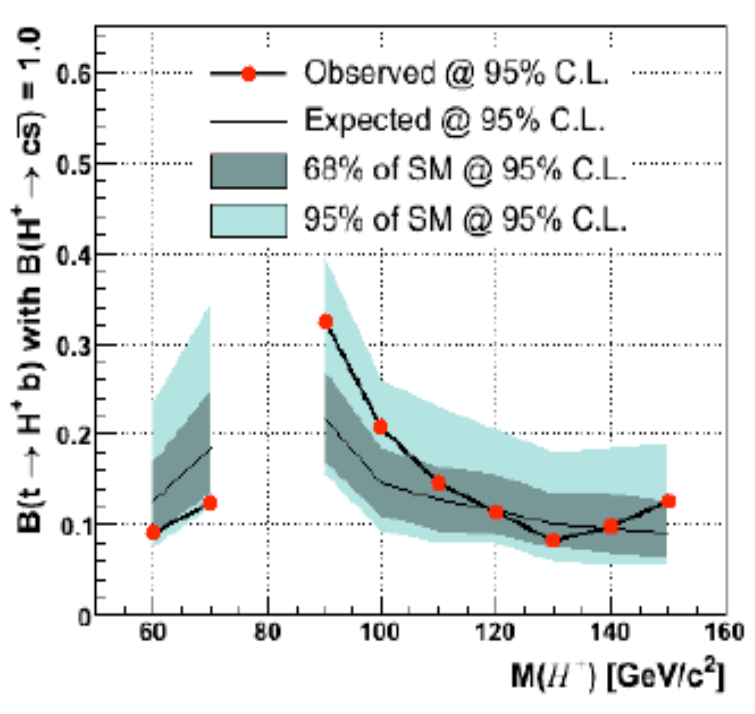




Light H^+ Search: $H^+ \rightarrow cs$

- Search for a second bump in the di-jet mass (W/H^+) from top decays
- Lepton (e/μ)+4jets with loose 2 *b*-tag jets, MET
- Understanding of the tail in the di-jet mass: essential

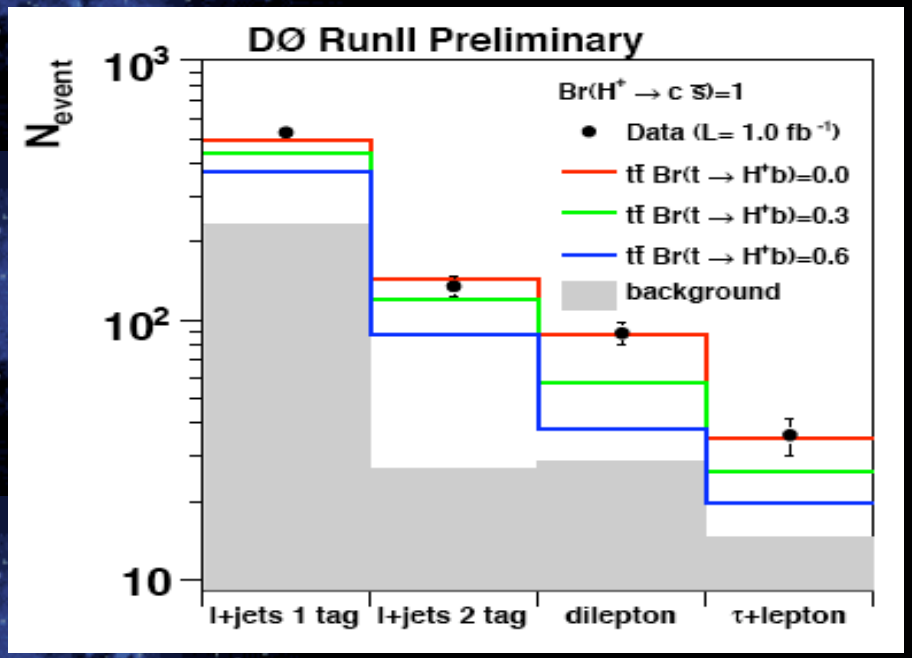


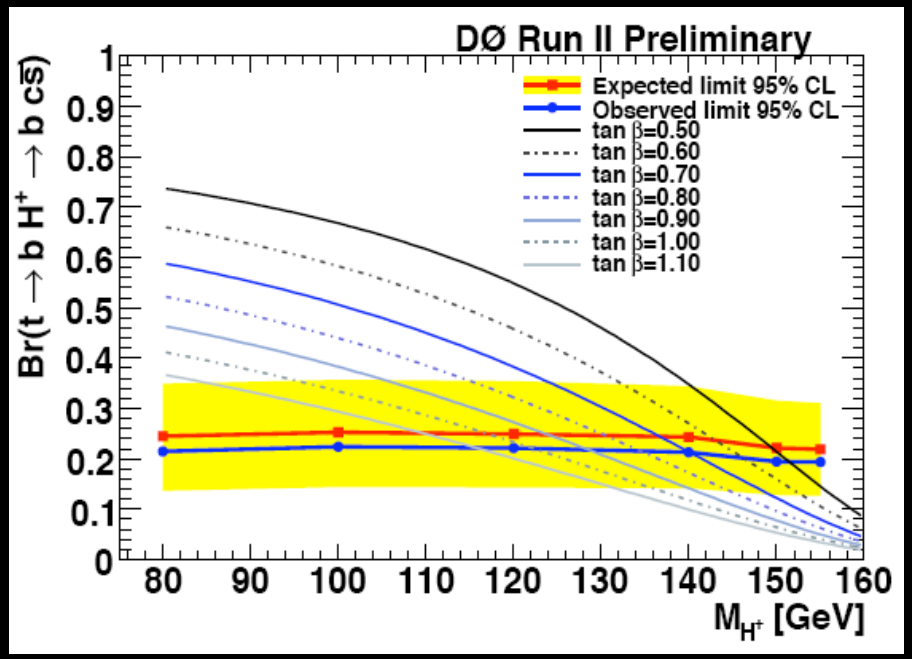


- 10% better limit for $H^+ \rightarrow ud$

H^+ Searches: $H^+ \to \tau\nu$,cs

- Counting exp.: dilepton, lep+jets, lep+τ: data vs. expected assuming leptophobic (100% cs) and tauonic (100%) scenarios
- Fit to BR($t \to H^+b$) with the NLO σ(tt), 7.3±0.7pb

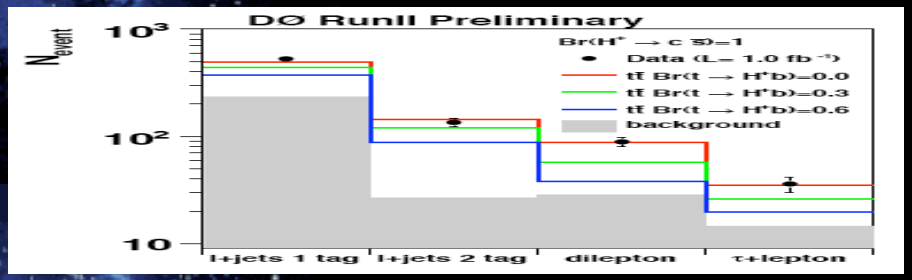


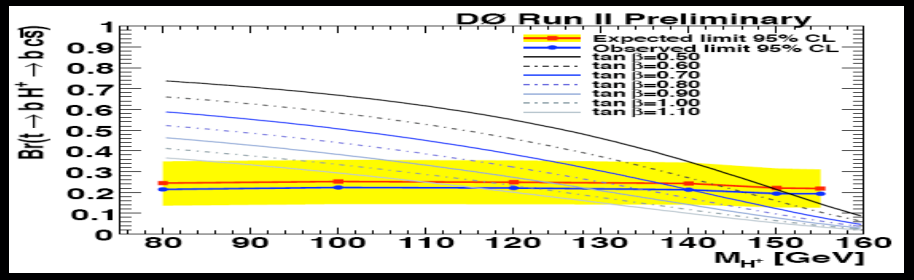


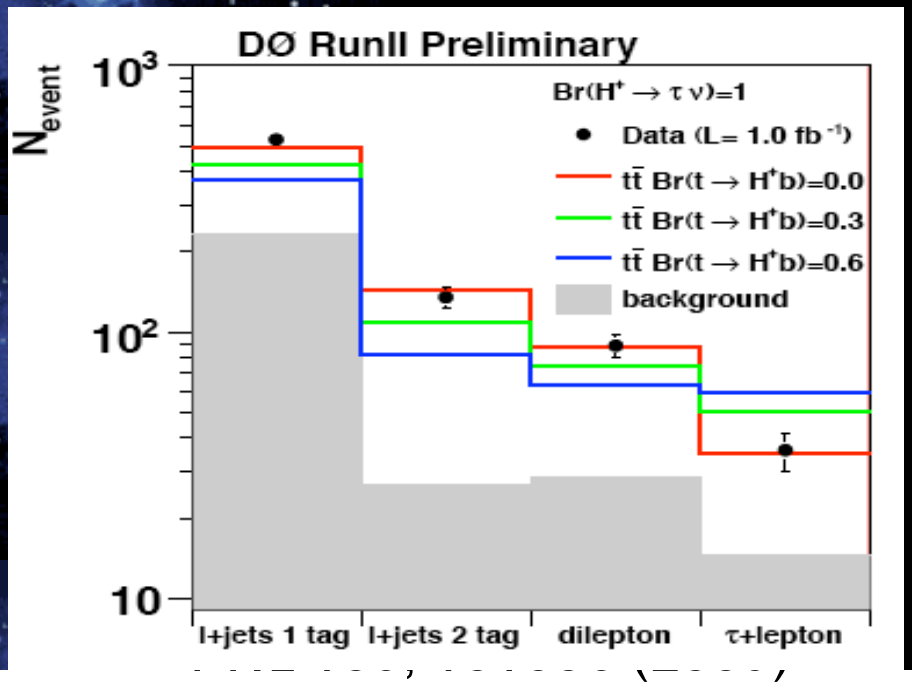
PRL

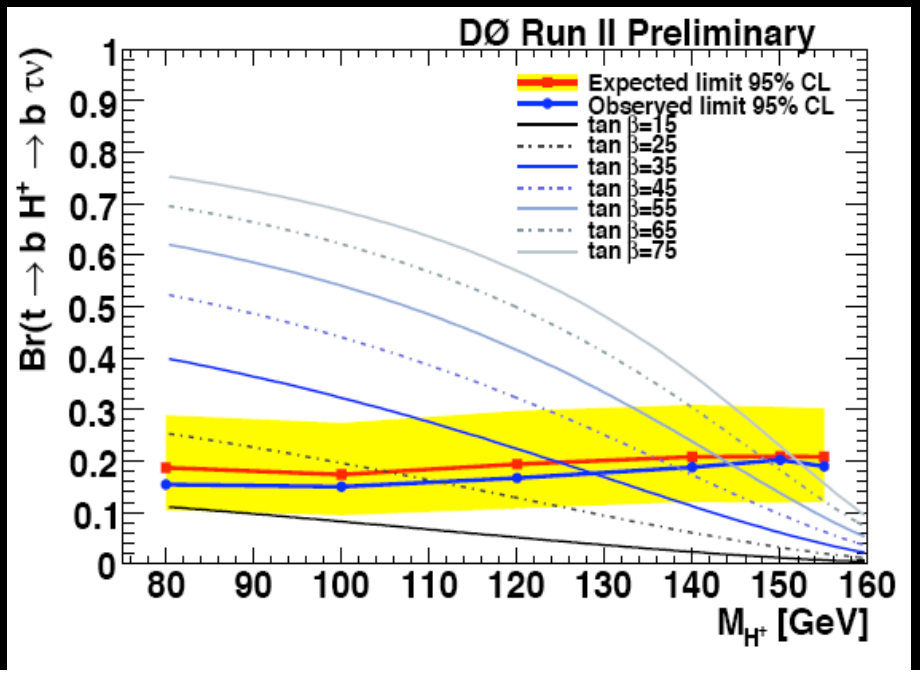
H^+ Search

- Counting exp.: dilepton, lep+jets, lep+τ: data vs. expected assuming leptophobic (100% cs) and tauonic (100%) scenarios
- Fit to BR($t \to H^+ b$) with the NLO σ($t\bar{t}$), 7.3±0.7pb



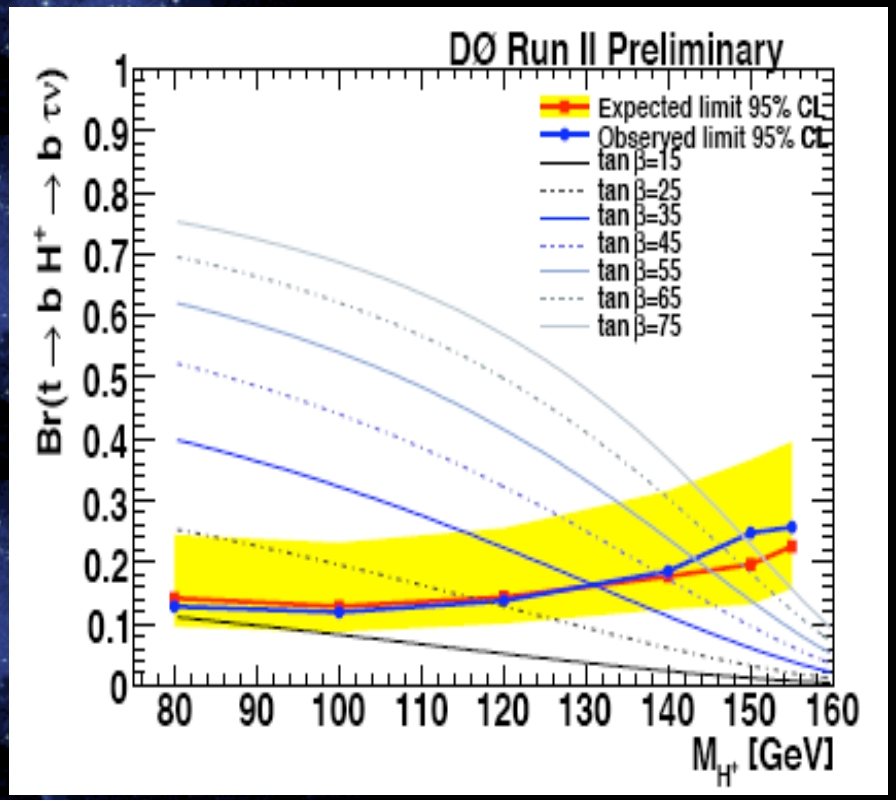


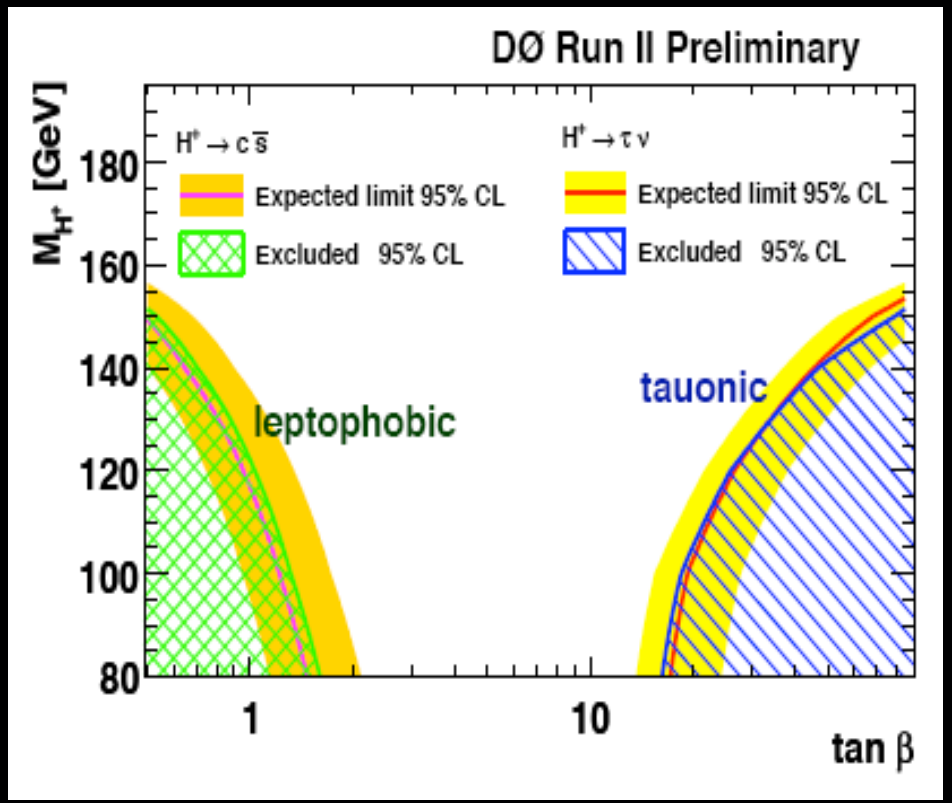




H^+ Search

- 2-D fits to BR & $\sigma(tt)$ together: 30% improvement
- MSSM exclusion limit in m_A vs $\tan\beta$ plane for leptophobic (100% cs) and tauonic (100% $\tau\nu$)



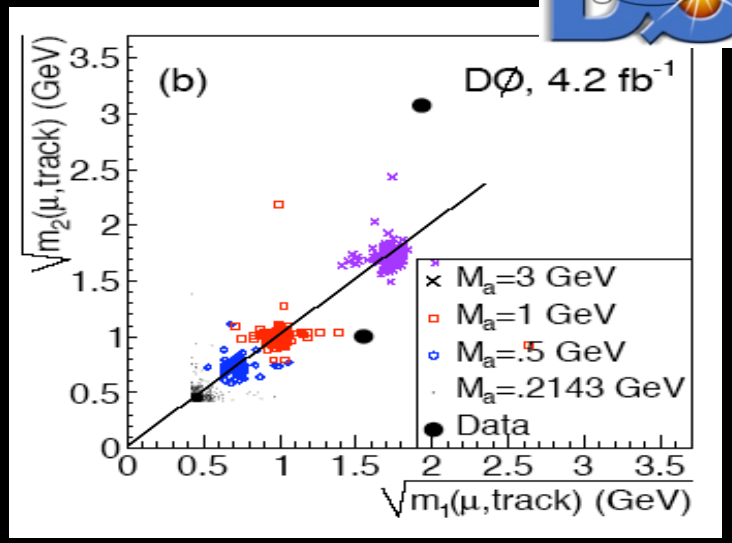


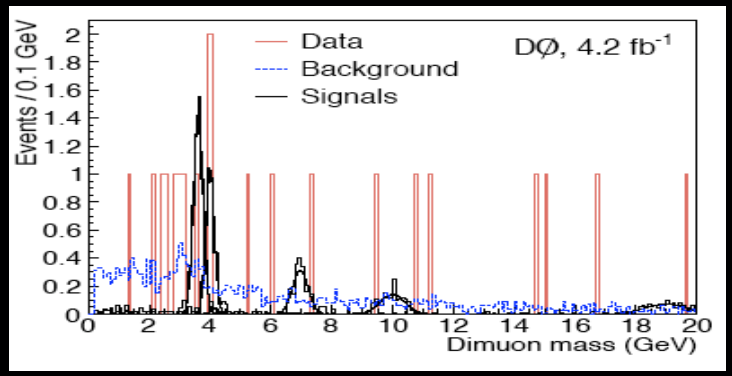
NMSSM Higgs

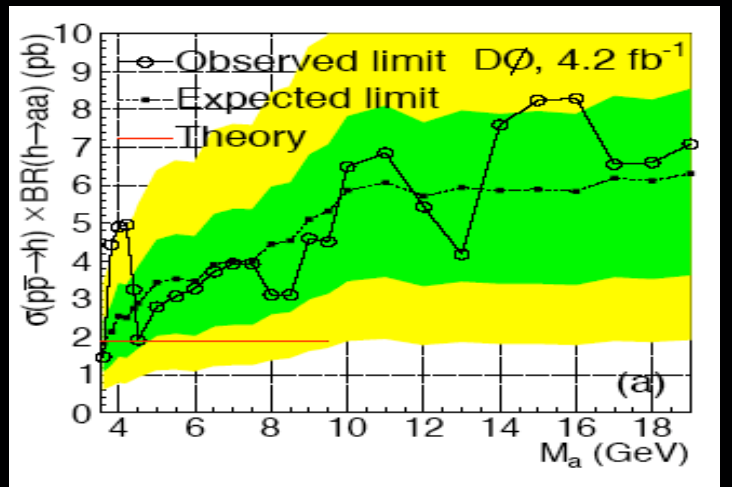
- The Next-to-MSSM adds singlet superfield to the MSSM
  - Two additional Higgs: CP-even and CP-odd (*a*)
  - The CP-odd *a* (pseudo-scalar) can be the lightest Higgs
  - The SM-like Higgs: $h \to aa$ (dominant decay), $h \to bb$ (suppressed)
  - It can avoid the LEP direct limit, $M_h > 114$ GeV, the most general LEP limit, $M_h > 82$ GeV
- $2m_\mu < M_a < 2m_\tau$: $a \to \mu\mu$ (dominant decay)
  - $h \to aa \to 4\mu$, search for two pairs of the very collinear muons
- $2m_\tau < M_a < 2m_b$: $a \to \tau\tau$ (primary decay)
  - 4τ final states challenging, search for $h \to aa \to \mu\mu\tau\tau$
  - $H^+ \to aW \to \tau\tau W$, search for H^+ from top decays in top pair events

NMSSM Searches

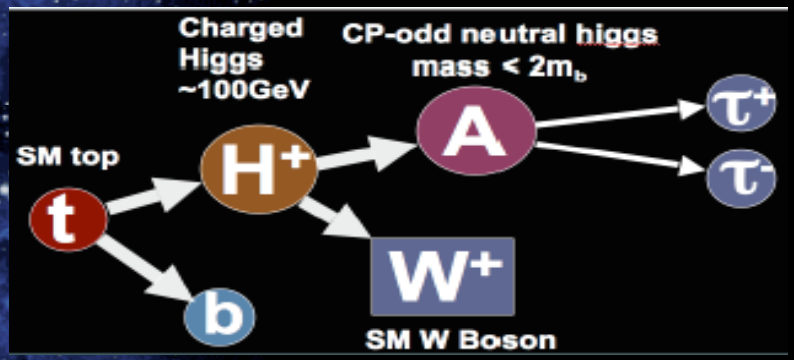
- Search for $h \to aa \to 4\mu$
  - Two muons $\Delta R(\mu,\mu)>1$, different isolation cut
  - Two companion tracks $\Delta R(\mu,\text{track})>1$
  - Counts events in 2D Higgs (a) mass windows
  - 2 exp. evts against 2.2±0.5 bkgds
- Search for $h \to aa \to \mu\mu\tau\tau$
  - $\Delta R(\mu,\mu)<0.5$ & MET>25 GeV
  - $\Delta R(\text{MET},\mu\mu)>2.5$
  - Looking in dimuon mass windows



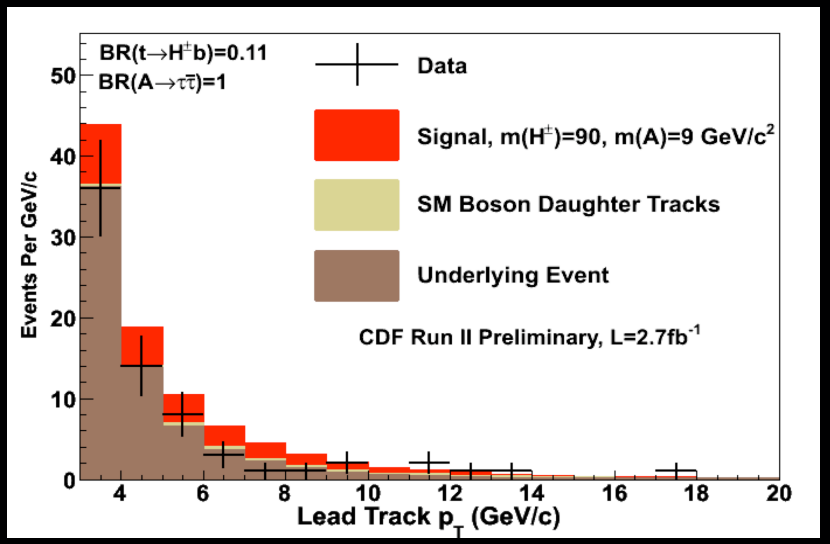


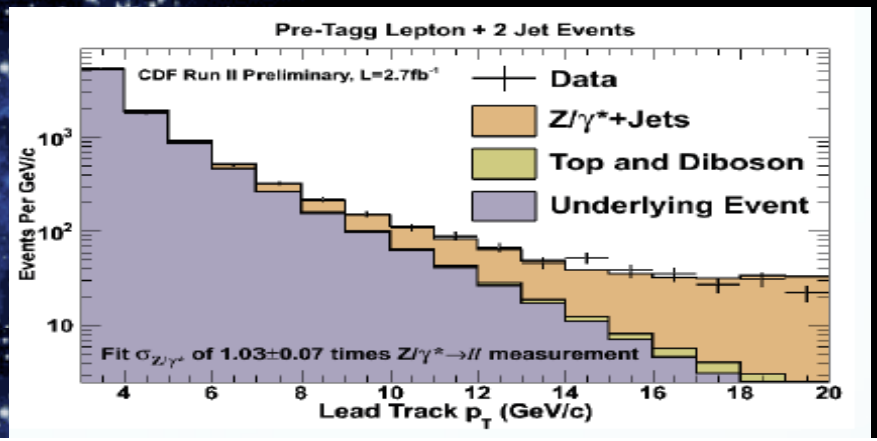


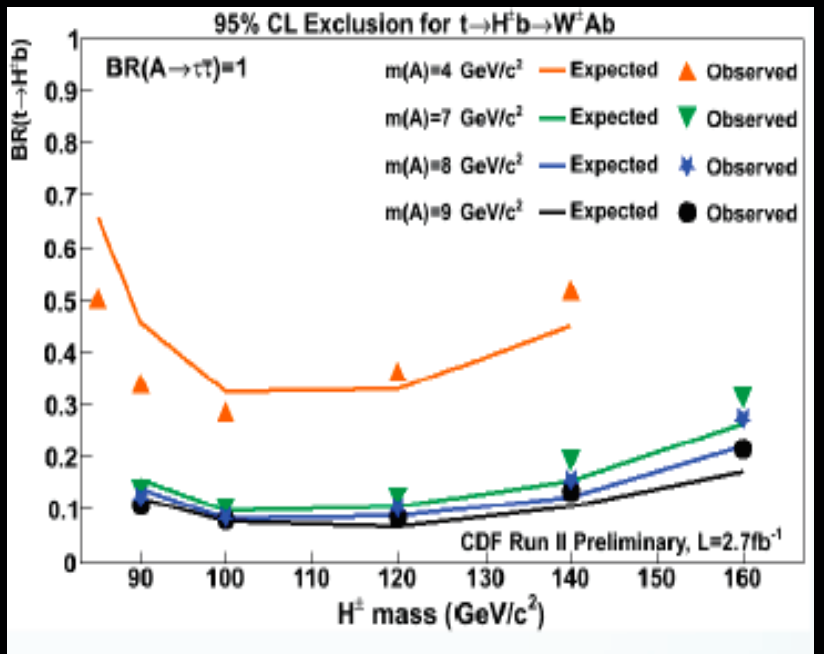
NMSSM Search: $H^+ \rightarrow AW \rightarrow \tau\tau W$



- Br($H^+ \rightarrow AW \rightarrow \tau\tau W$); up to 50%
- **Lepton+3 jets with one b-jet, one isolated track**
- In SM: one isolated track mostly from underlying evt

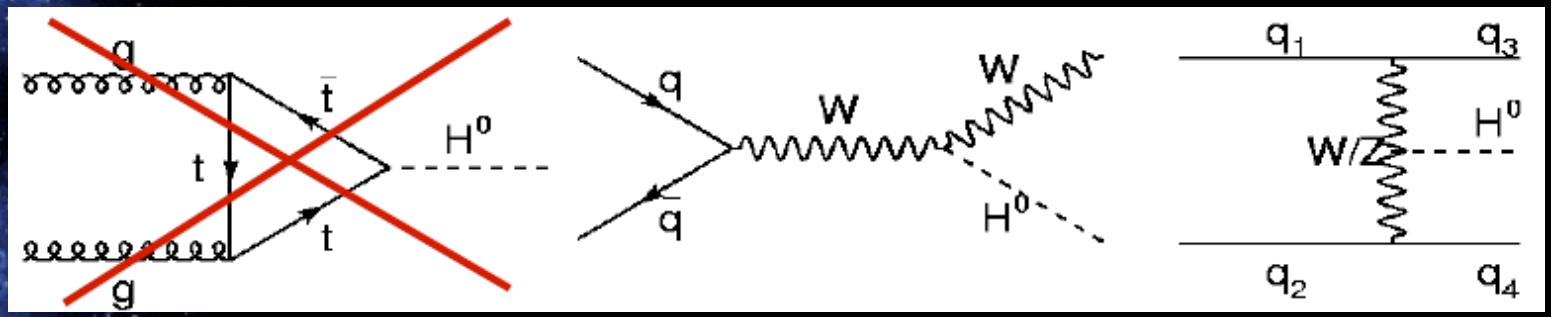




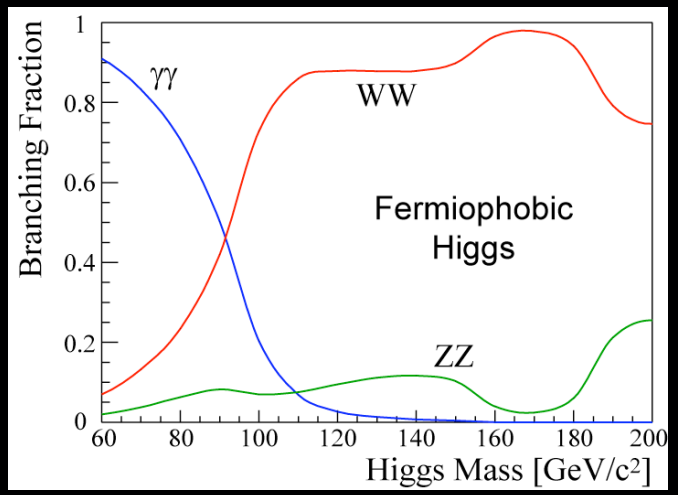


Fermiophobic Higgs

- In 2-D Higgs Doublet Model, Higgs couples only to boson when mixing angle $\alpha \rightarrow \pi/2$: different origin of mass for fermions and bosons

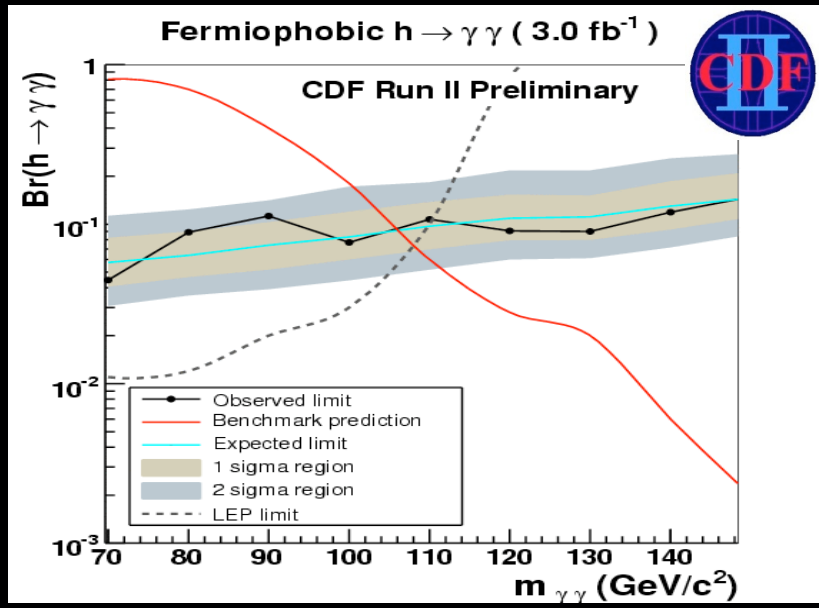


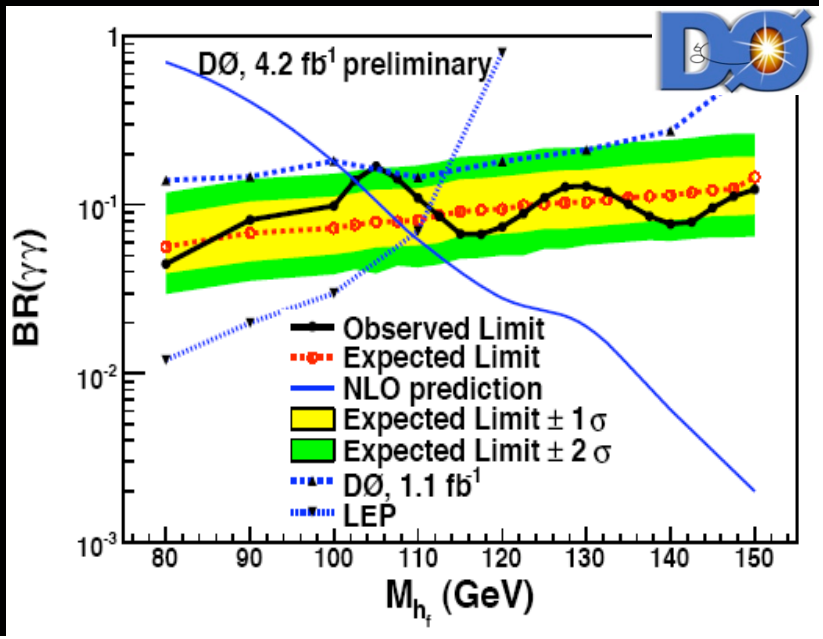
- Two promising channels
  - $H \rightarrow \gamma\gamma$ at low mass: large BR due to no bb decay)
  - $WH \rightarrow WWW^*$ at high mass see M. Kirby's talk



$H \rightarrow \gamma\gamma$

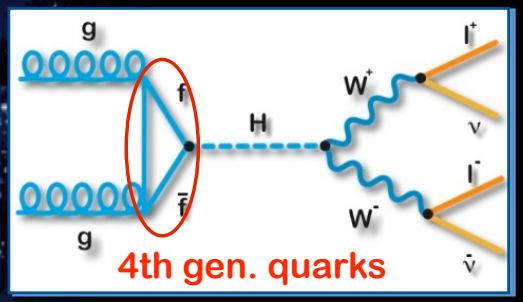
- Search for a diphoton mass resonance
  - Much better energy resolution than jets (<3%)
  - Large recoil against H
- CDF:
  - $P_T(\gamma\gamma)$>75 GeV
  - Bkgd shape from sideband
  - Excluded M_h<106 GeV @95% CL
- DØ:
  - $P_T(\gamma\gamma)$>35 GeV
  - Bkgd shape from data and MC
  - Excluded M_h<102.5 GeV @95% CL

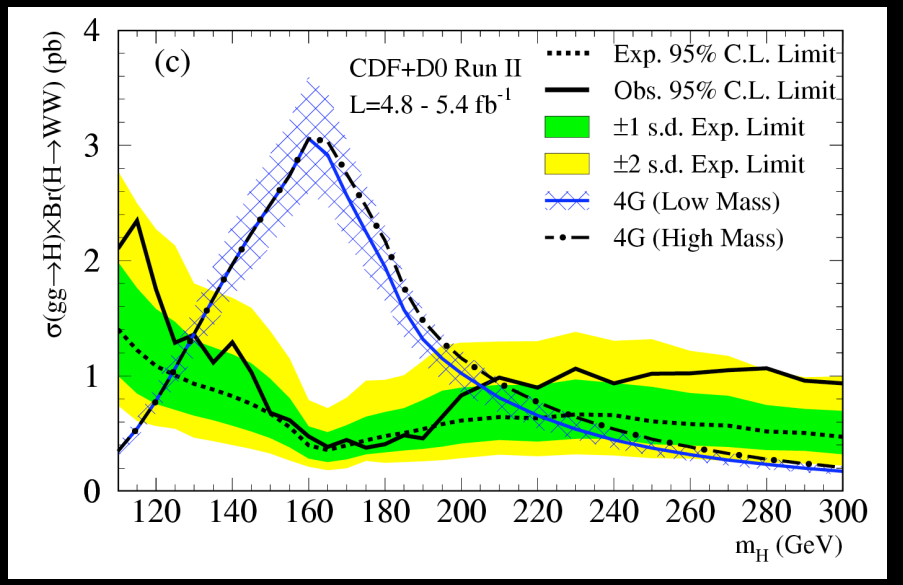




4th gen. model: gg→H→WW

- With 4th generation of fermions;
  - Precision EWK fit results are consistent with a heavy Higgs boson up to mH=300 GeV at 68% CL, m(4th ν)>45 GeV
  - ggH coupling by a factor of 3 larger, but no change for WWH, ZZH
  - Focus on gg→H→WW: 2 OS leptons with MET
  - Combined analysis of the WW CDF (4.8 fb^{-1}) and DØ (5.4 fb^{-1}) results





- Exclude a SM-like Higgs boson for 131<m_H< 204 GeV @95% CL

Summary

- BSM Higgs boson hunting effort at the Tevatron are diverse and vigorous, looking for every corners even not allowed by the SM
- No evidence of BSM Higgs in up to 5.4fb^{-1} of data
- The Tevatron is running extremely well
- With >10 fb^{-1} data, we hope to make significant statements about BSM Higgs