BSM Higgs and other bump searches at the Tevatron

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on behalf of the CDF and DØ collaborations

CEA Saclay / Irfu / SPP

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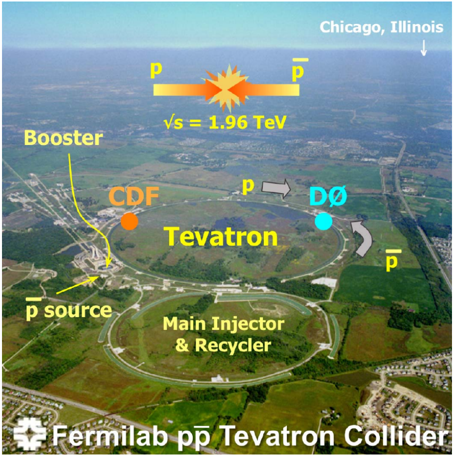
Outline

1. MSSM
   - $\phi \to \tau\tau$ (incl.)
   - $b\phi \to b\bar{b}b$
   - $b\phi \to b\tau\tau$
   - Combination
2. Extended Higgs Sector Models
   - Hidden Valley
   - Doubly-Charged Higgs Boson
3. Fermiophobic Higgs search
4. Dijet Mass Spectrum in $W + jj$ Events

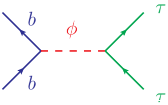


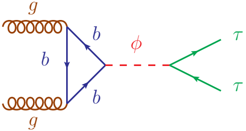
Many thanks to the Tevatron

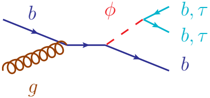
$11.9\,\mathrm{fb}^{-1}$ of $p\bar{p}$ collisions delivered between April 2002 and September 30$^{\text{th}}$ 2011!

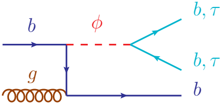
The Higgs Sector in the MSSM

- Two Higgs doublets (coupling to resp. up- and down-type quarks, with vevs resp. v_u and v_d). $\tan\beta = \frac{v_u}{v_d}$
  - $\tan\beta \approx \frac{m_t}{m_b} \approx 35$ (large $\tan\beta$) looks natural.
- Five physical Higgs bosons:
  - Three neutral A, h, H (collectively denoted ϕ),
  - Two charged H^+, H^-.
- Hbb coupling enhanced by $\tan\beta$
  - Enhanced production cross-section $\sigma(p\bar{p} \to \phi)$ compared to the SM.
  - h/A or H/A degenerate in mass: $\sigma \times 2$
  - $\mathcal{B}(\phi \to b\bar{b}) \approx 90\%$, $\mathcal{B}(\phi \to \tau^+\tau^-) \approx 10\%$
- MSSM Higgs sector fully described by $\{m_A, \tan\beta\}$ at tree level.
  - Radiative corrections make it more model-dependent for $\phi \to b\bar{b}$.





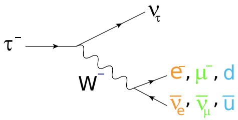




τ identification at the Tevatron

Analyses with τ leptons:

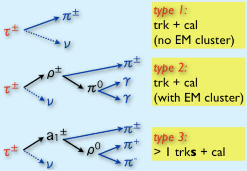
- Several channels to combine.
- Missing energy (information) from neutrinos.
- τ_{had}: multijet background.



DØ

Neural network NN_τ.

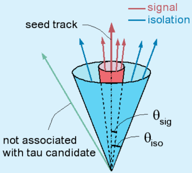
- Use isolation, shower shape, trk-cal consistency variables
- eff. $= 65\%$, fake rate $= 2.5\%$



CDF

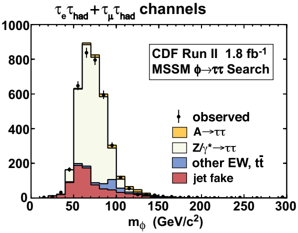
Cut-based.

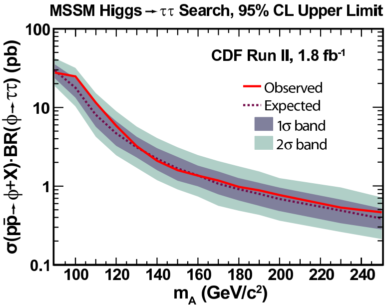
- Signal / isolation cones, π^0 reconstruction
- eff. $= 50\%$, fake rate $< 1\%$

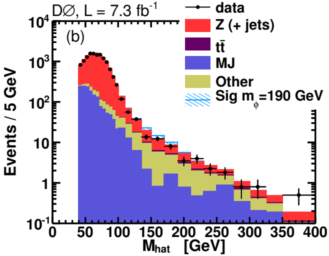


$\phi \to \tau\tau$ (incl.) (DØ, CDF)

- CDF:
  - $\tau_\mu\tau_{had}$, $\tau_e\tau_{had}$, $\tau_e\tau_\mu$ ($1.8\,fb^{-1}$, PRL 103, 201801 (2009))
- DØ:
  - $\tau_e\tau_\mu$, $\tau_\mu\tau_{had}$ ($5.4\,fb^{-1}$, PLB 707, 323 (2011)),
  - $\tau_\mu\tau_{had}$ ($7.3\,fb^{-1}$, Accepted by PLB, 2012).
- Look for an excess in the visible mass spectrum:
  $M_{vis} = \sqrt{(P_{\tau_h} + P_{\tau_\mu} + \not{E}_T)^2}$

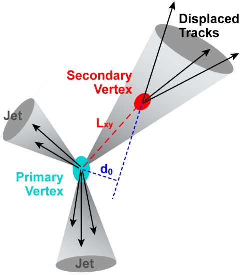


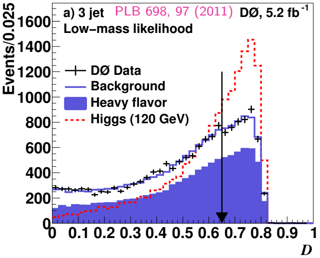


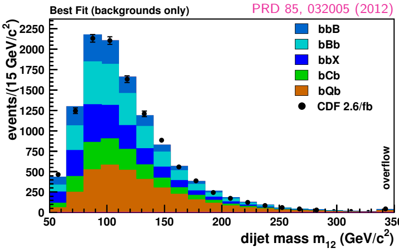


$b\phi \to b\bar{b}b$ (DØ, CDF)

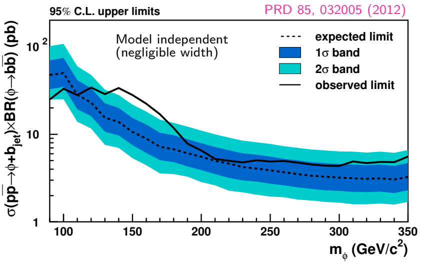
- $\mathcal{B}(\phi \to b\bar{b}) \approx 90\%$ at high $\tan\beta$
- Selection: 3-4 high-p_T jets, ≥ 3 b-jets.
  - CDF *b*-tagging: displaced vertices, vertex mass separation.
  - DØ *b*-tagging: multivariate discriminant.
- Challenging multijet background:
  - Fit the flavor composition from data.
- Use $M_{b\bar{b}}$ distribution to set limits.
  - CDF: use two leading jets.
  - DØ: jet pair with highest likelihood.

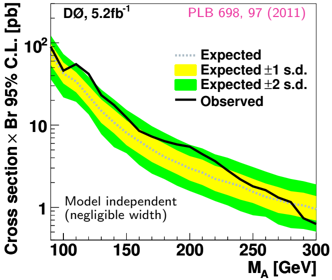






$b\phi \to b\bar{b}b$: limits



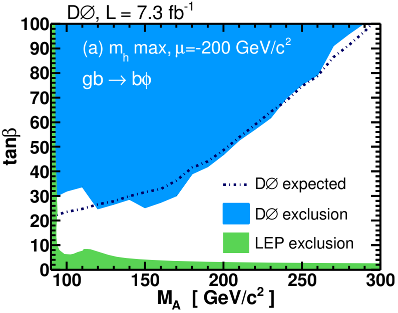


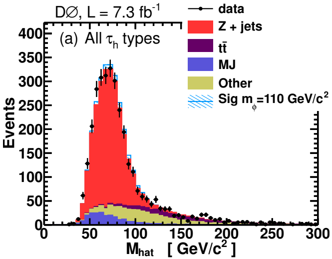
- Both experiments see some excess.
  - DØ: $\approx 2.5\sigma$ at 120 GeV ($\approx 2.0\sigma$ after LEE)
  - CDF: $\approx 2.8\sigma$ at 150 GeV ($\approx 1.9\sigma$ after LEE)
  - A Tevatron $b\phi \to b\bar{b}b$ combination is in progress.
- Translate limits in MSSM benchmarks scenarios:
  - Big dependence on sign(μ).
  - Large $\tan\beta$: enhanced *bbH* coupling, increased Higgs width.

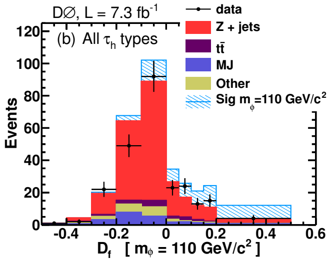
$b\phi \to b\tau\tau$ (DØ)

Final states: $\tau_e\tau_{\text{had}}$ ($3.7\,\text{fb}^{-1}$, Preliminary), $\tau_\mu\tau_{\text{had}}$ ($7.3\,\text{fb}^{-1}$, PRL 107, 121801 (2011))

- Little sensitive to model parameters (compared to $b\phi \to b\bar{b}b$).
- Less $Z \to \tau\tau$ compared to $\phi \to \tau\tau$ (incl.)
  - Thanks to the use of b-tagging.
- Multijet and $t\bar{t}$ discriminants.
- Limits set on a final discriminant.





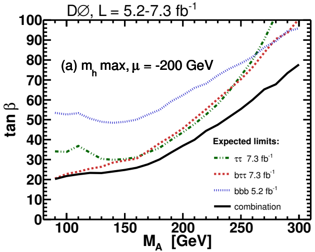


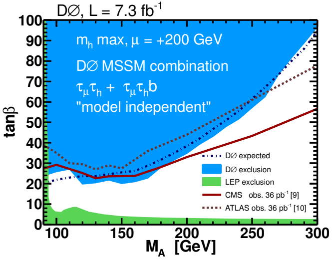
MSSM combination (DØ)

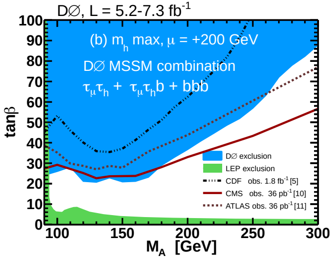
Combined limits on MSSM neutral Higgs production using:

- $b\phi \to b\bar{b}b$ (5.2 fb^{-1}),
- $b\phi \to b\tau_\mu\tau_{\text{had}}$ (7.3 fb^{-1}),
- $\phi \to \tau_\mu\tau_{\text{had}}$ (7.3 fb^{-1}, re-analyzed with b-jet veto).

Accepted by PLB.

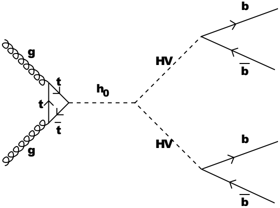


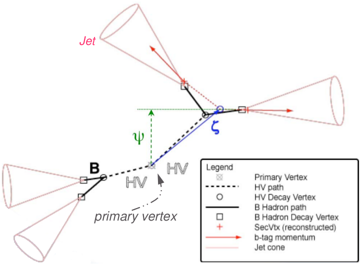


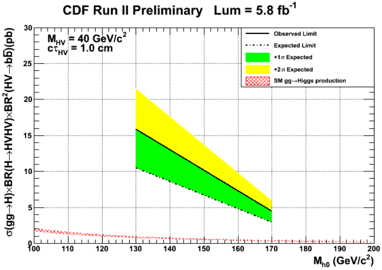


Hidden Valley (CDF)

- Search for long-lived heavy particles ($c\tau \approx 1\,\mathrm{cm}$).
- Decay mode HV $\rightarrow b\bar{b}$
- Look at displaced vertex variables: ψ, ζ

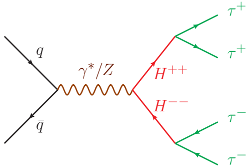


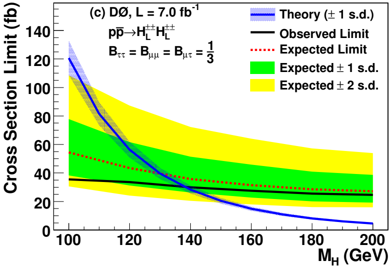


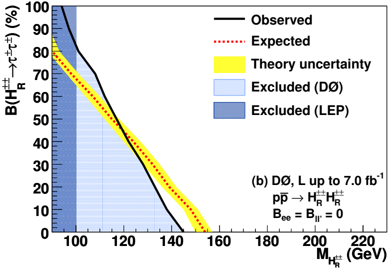


Doubly-Charged Higgs Boson (DØ)

- Models with two Higgs triplets (branching ratios depend on the model).
- Final state: two hadronic taus and one muon.
- Four channels (nature of the two same-sign leptons, presence of additional leptons).
- First search for $H^{\pm\pm} \to \tau_{\text{had}}\tau_{\text{had}}X$ at a hadronic collider.

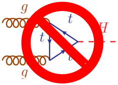


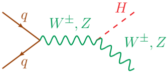


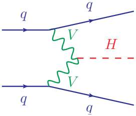


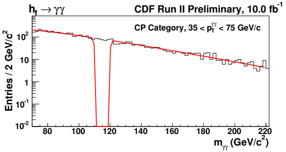
Fermiophobic Higgs search (DØ, CDF)

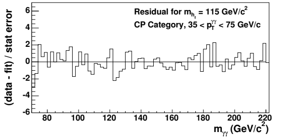
- No coupling to fermions
- $gg \to H_f$ forbidden: only VH_f and VBF.
- $H_f \to ff$ forbidden.
  - $H_f \to \gamma\gamma$ greatly enhanced and dominates the exclusion.
- $H_f \to \gamma\gamma$ analysis strategy:
  - DØ: Decision tree. Background estimated from MC.
  - CDF: $M_{\gamma\gamma}$ distribution in 3 independent $p_T^{\gamma\gamma}$ bins. Background estimated from sideband fitting (sliding window).

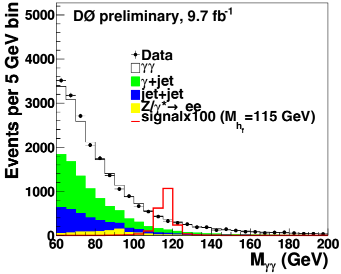






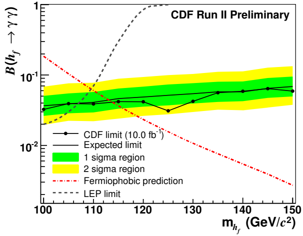


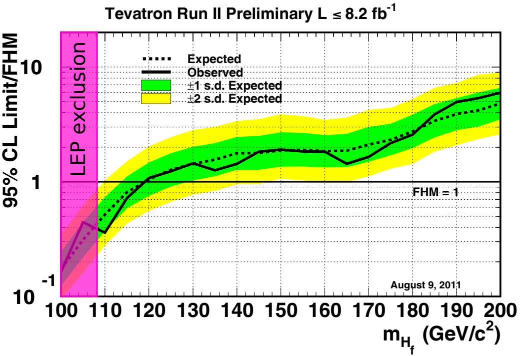


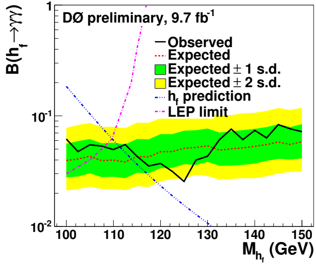


Fermiophobic Higgs (limits)

- $H_f \to \gamma\gamma$:
  - limits on $\mathcal{B}(H_f \to \gamma\gamma)$ converted into limits on $\sigma \times \mathcal{B}(H_f \to \gamma\gamma)$ using the fermiophobic Higgs benchmark scenario.
- Combine $H_f \to \gamma\gamma$ and $H_f \to W^+W^-$ from CDF and DØ ($\mathcal{L} \leq 8.2\,\mathrm{fb}^{-1}$)
  - $m_{H_f} > 119\,\mathrm{GeV}/c^2$ at 95% C.L.







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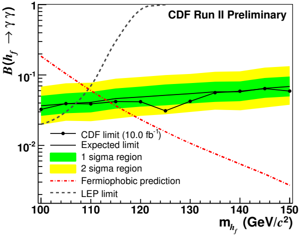
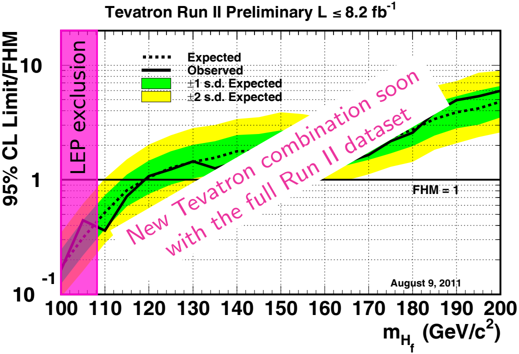
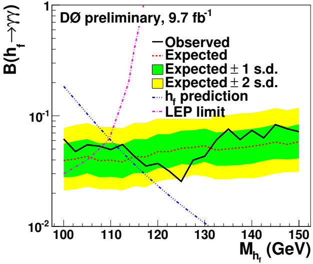




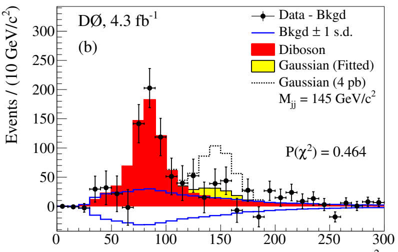


Dijet Mass Spectrum in $W + jj$ Events

CDF and DØ disagree... CDF is performing several independent analyses with the full dataset to make a final statement on the subject.

DØ ($4.3\,\text{fb}^{-1}$)

- No excess seen.
- $\mathcal{P}(M_{jj} = 145\,\text{GeV}, \sigma \times \mathcal{B} = 4\,\text{pb}) = 8 \times 10^{-6}$.

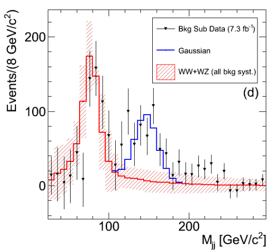


PRL 107, 011804 (2011)

CDF ($7.3\,\text{fb}^{-1}$, $4.3\,\text{fb}^{-1}$ published)

- Data is 4.1 standard deviations from expectation.
- $\sigma \times \mathcal{B} = 3.1 \pm 0.8\,\text{pb}$

Updated from PRL 106, 171801 (2011)



Summary

- The Higgs sector is a good place too for new physics.
    - Reported CDF and DØ results with up to the full Run II Tevatron dataset.
    - Also $H^{\pm}$ and NMSSM searches (not reported here).
- MSSM Higgs searches:
    - Look for $\phi \to b\bar{b}$ and $\phi \to \tau^+\tau^-$.
    - Different channels with similar sensitivity: combine!
- Extended Higgs Sector and other exotic models.
    - Hidden Valley (long-lived heavy particle).
    - Doubly-charged Higgs.
    - Fermiophobic Higgs.
- $W + jj$ di-jet mass spectrum.
    - CDF and DØ agree to disagree...

These are legacy results from the Tevatron

Upcoming: $b\phi \to b\bar{b}b$ update, Fermiophobic Higgs Tevatron combination with the full Run II dataset.

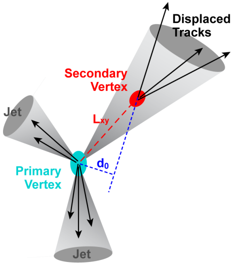
Additional material

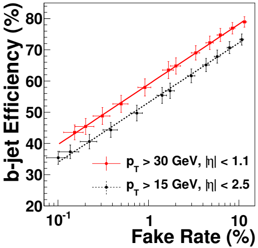
Higgs bosons branching ratios depend only on m_A and $\tan\beta$ at tree level in the MSSM.
However radiative corrections make them much more model-dependent, hence the need for additional assumptions (benchmark scenarios):

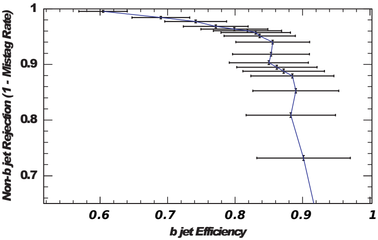
Parameter	$m_h^{\max}$ scenario	No-mixing scenario
X_t	2 TeV	0 TeV
μ	$\pm$ 0.2 TeV	$\pm$ 0.2 TeV
M_2	0.2 TeV	0.2 TeV
$m_{\tilde{g}}$	0.8 TeV	1.6 TeV
M_{SUSY}	1 TeV	2 TeV

Note the need to test both signs of the μ parameter, which has a big impact on radiative corrections (for $\mathcal{B}(\phi \to b\bar{b})$).

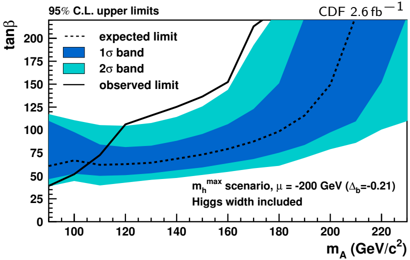
- *B* hadrons travel in the detector before they decay.
- Information used in *b*-tagging:
  - Secondary vertex,
  - Impact parameters of tracks,
- DØ: Multivariate discriminant.
- CDF: Displaced vertices, L_{xy}/σ cut, vertex mass separation.

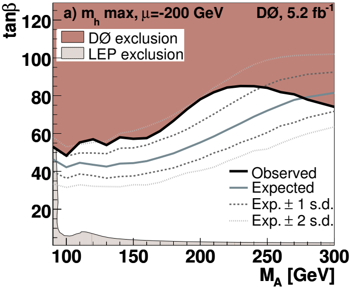




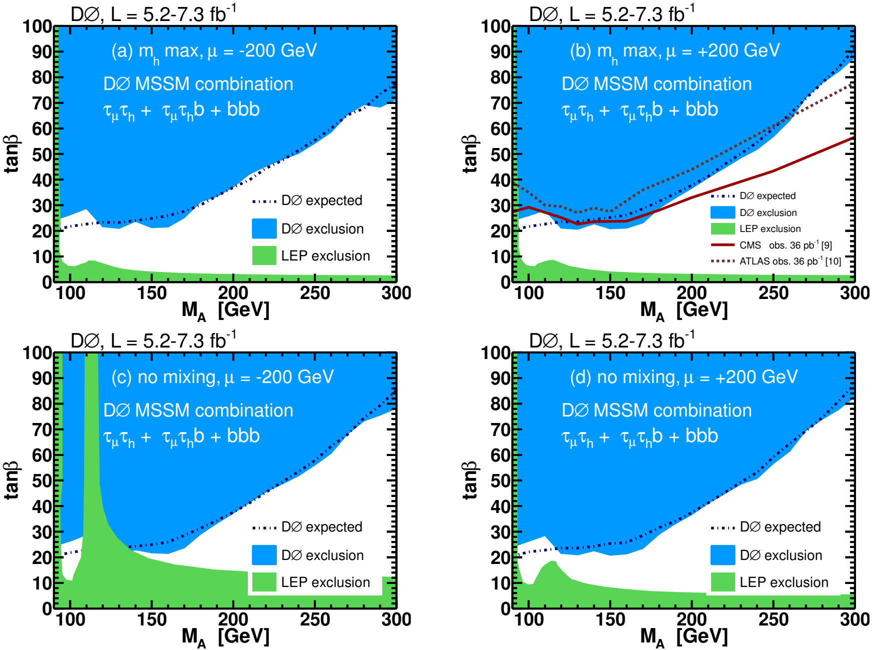


$b\phi \to b\bar{b}b$: limits (CDF, DØ)



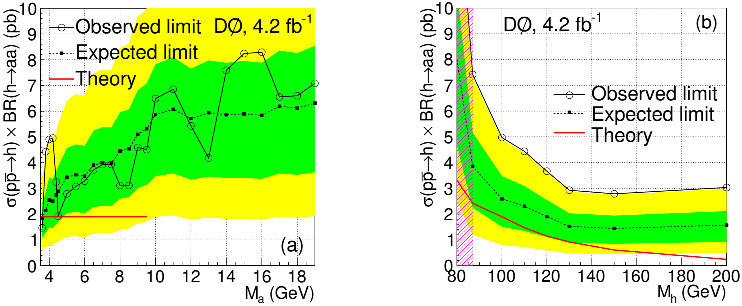


MSSM combination (DØ)



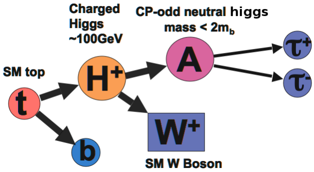
NMSSM $h \to aa$ (DØ)

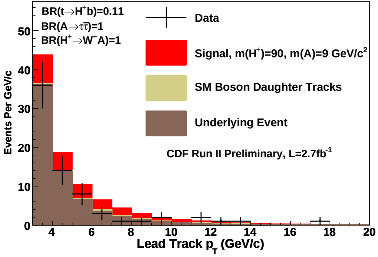
- PRL 103, 061801 (2009)
- Model with reduced $\mathcal{B}(h \to b\bar{b})$.
- The dominant decay becomes $h \to aa$ where a is a light pseudo-scalar Higgs.
- General LEP search limit: $M_h > 82\,\text{GeV}$.
- For $2m_\mu < M_a <\sim 2m_\tau (\sim 3.6\,\text{GeV})$: $aa \to \mu\mu\mu\mu$
  - Two pairs of extremely collinear muons (because of the low M_a).
  - $\mathcal{B}(a \to \mu\mu) < 7\%$ assuming $\mathcal{B}(h \to aa) \sim 1$.
- For $2m_\tau < M_a < 2m_b (\sim 9\,\text{GeV})$: $aa \to \mu\mu\tau\tau$
  - One pair of collinear muons and large $\not{E}_T$ from $a \to \tau\tau$ decay.

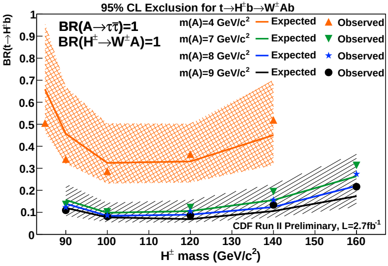


NMSSM Charged Higgs (CDF)

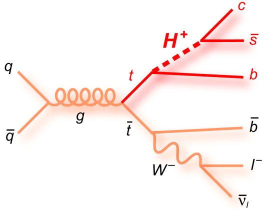
- Search for a light (mass $< 2m_b$) NMSSM pseudo-scalar Higgs boson A in top decays, with $A \to \tau\tau$.
- $t \to H^{\pm} b \to W^{\pm(*)} A b$
- Use the isolated track p_T spectrum to derive limits.

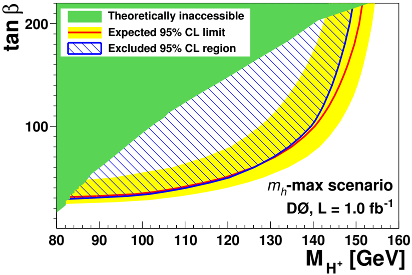


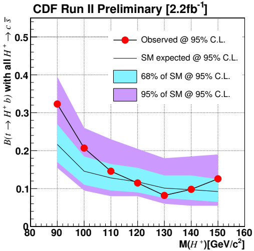




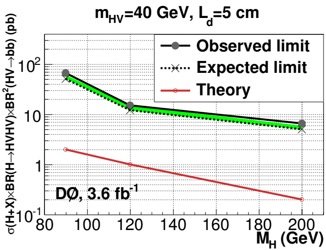
- If $M_{H^{\pm}} < m_{\text{top}}$, $t \to H^{\pm} b$ is allowed.
- CDF: PRL 103, 101803 (2009) (2.2 fb^{-1}).
- DØ: PLB 682, 278 (2009) (1.0 fb^{-1}).
- Two scenarios:
  - $H^{\pm} \to \tau\nu$ (high $\tan\beta$),
  - $H^{\pm} \to c\bar{s}$ (low $\tan\beta$).
- Look at l + jets (CDF+DØ), dilepton and $l\tau_{\text{had}}$ events (DØ).

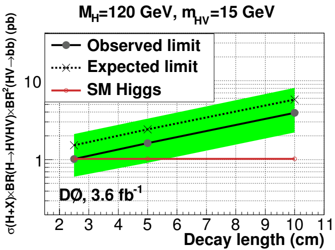




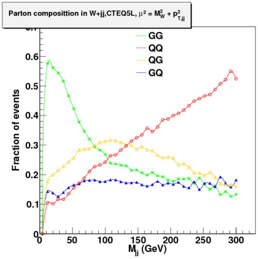


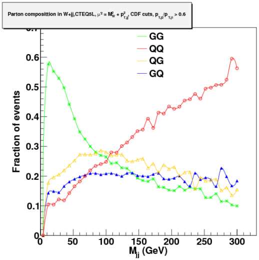
PRL 103, 071801 (2009) (3.6 fb^{-1})

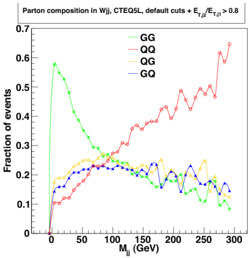




$W + jj$: quark vs. gluon jets (CDF)



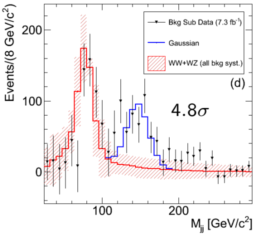


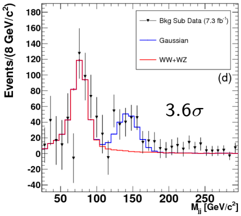


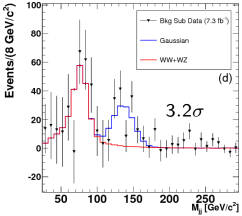
No cut (less qq)

$E_T^{j1}/E_T^{j2} > 0.6$

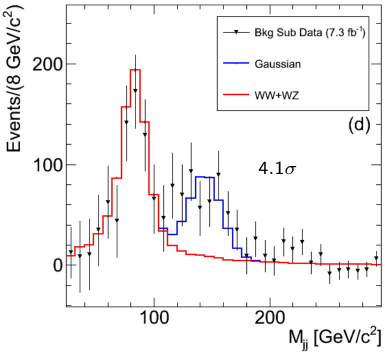
$E_T^{j1}/E_T^{j2} > 0.8$ (more qq)



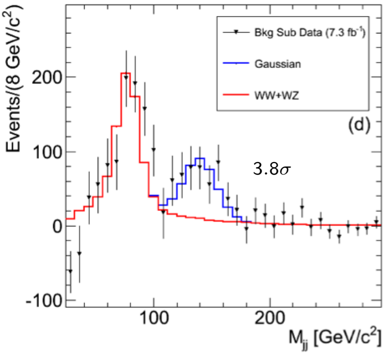




$W + jj$: other tests (CDF)



JES shifted by +7% (twice the systematic uncertainty)



W+jets modeled by SHERPA (instead of ALPGEN)

For more information

http://www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html