Searches for the Higgs Boson and Supersymmetry at the Tevatron

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On Behalf of the DØ and CDF Collaborations

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Outline

Searches for:

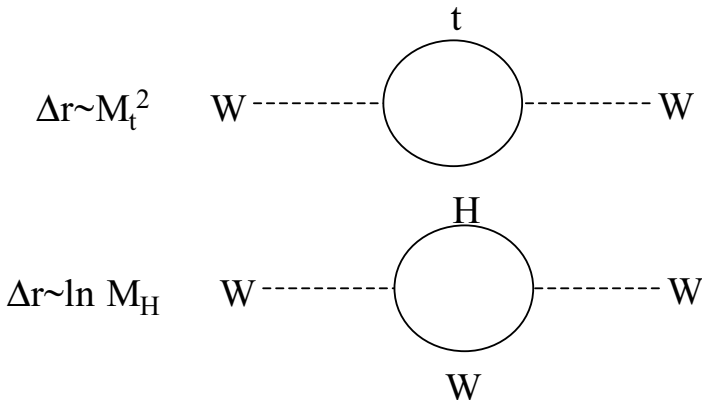
- Standard Model Higgs boson
- SUSY Higgs boson
- chargino-neutralino pair-production
- scalar quark and gluino production
  - inclusive production
  - scalar b quarks, $\tilde{b}$
  - scalar t quarks, $\tilde{t}$

with focus on recent measurements/updates

Note: all limits reported here are at 95% C.L.

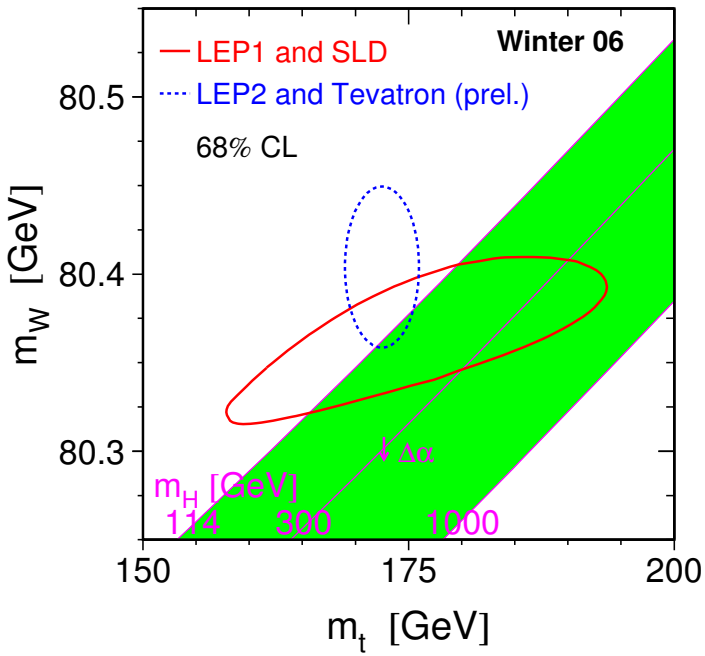
SM Higgs Constraints from EW Theory

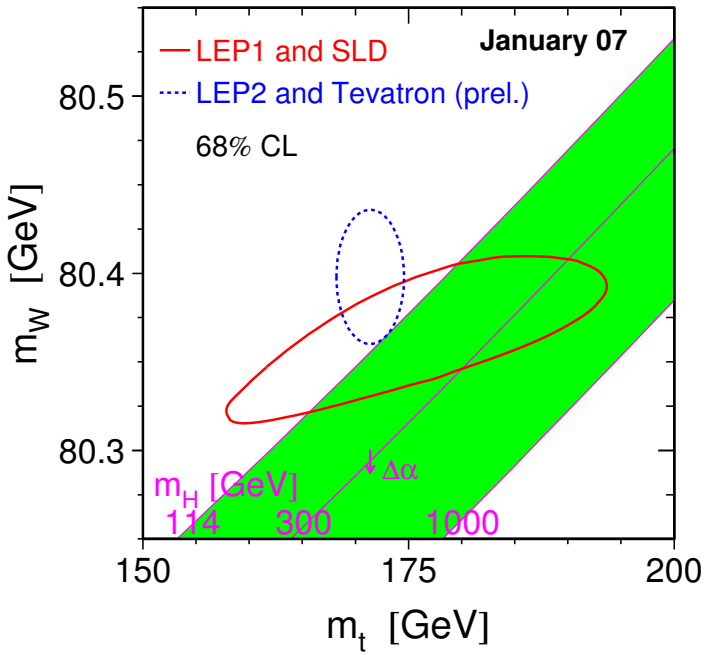
- SM: M_H constrained by radiative corrections to M_W



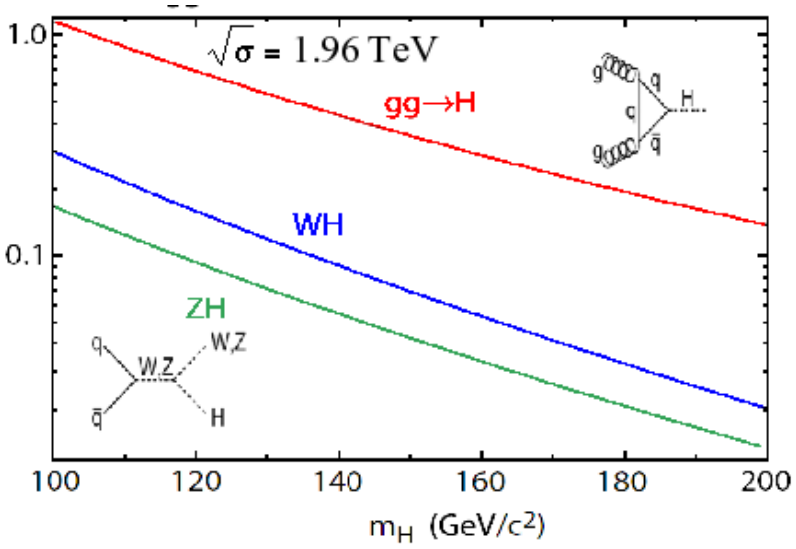
- new precision measurements of M_W and M_t from Tevatron
  $\longrightarrow$ see talks by C. Hays, P.M. Fernandez

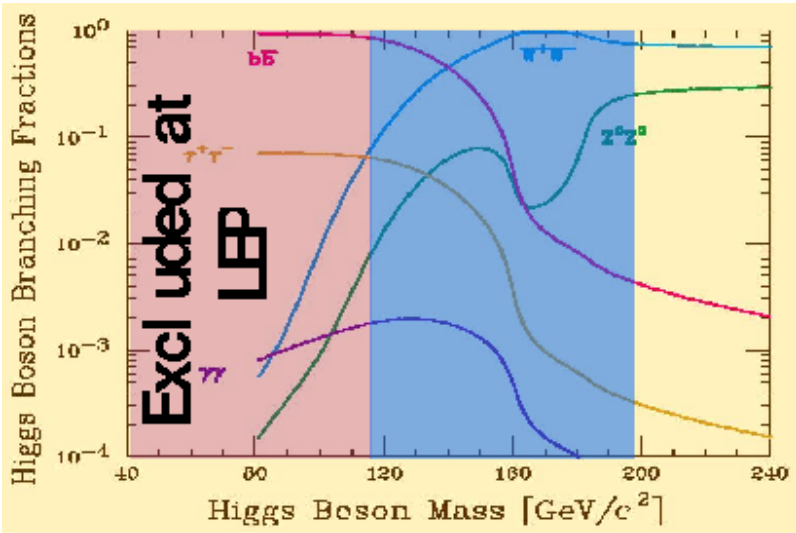
$\Rightarrow$ A light SM Higgs boson is favored!





SM Higgs Production and Decay



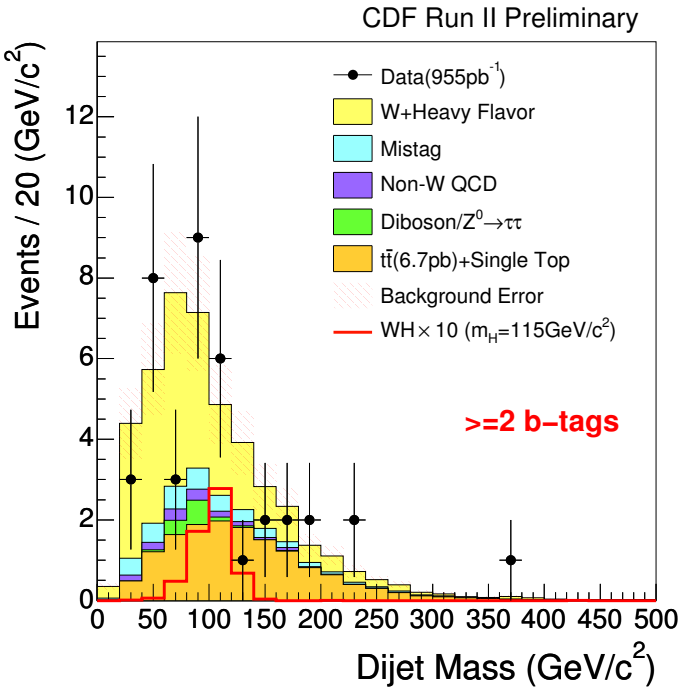


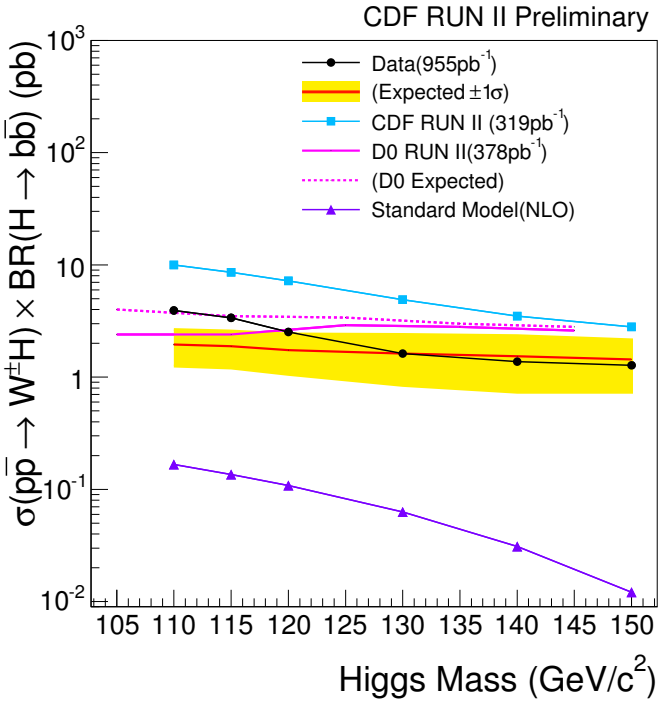
Search strategy:

- $M_H \lesssim 135\,\mathrm{GeV}$: associated production WH, ZH with $H \to b\bar{b}$
  - backgrounds: $Wb\bar{b}$, $Zb\bar{b}$, W/Zjj, top, WZ, QCD
  - additional sensitivity from $WH(\to WW^*)$, $H \to WW^*$
- $M_H \gtrsim 135\,\mathrm{GeV}$: $gg \to H \to WW^{(*)}$
  - backgrounds: WW, WZ, $W + \mathrm{jet}/\gamma$, $t\bar{t}$, Z/DY, QCD
  - additional sensitivity from WH, ZH

$WH \to l^{\pm}\nu b\bar{b}$

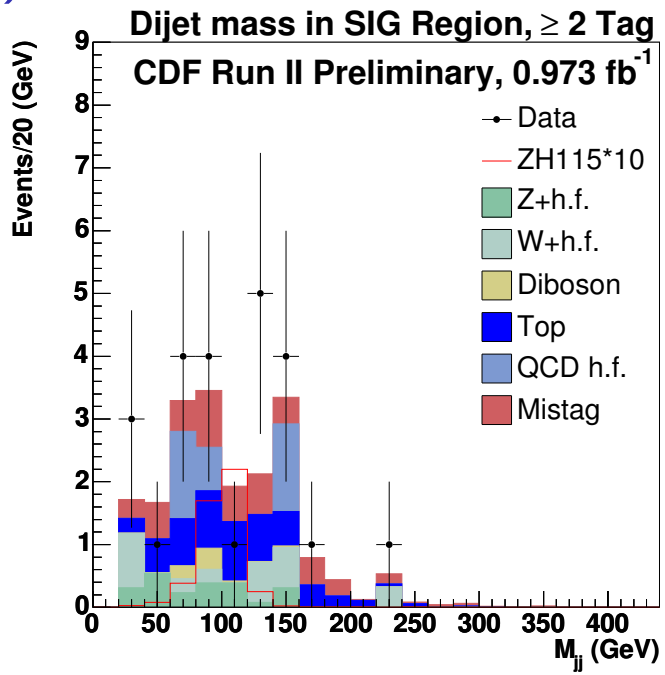
- recent CDF measurement based on $L = 1\,\mathrm{fb}^{-1}$
- selection:
  - e or μ with high transverse momentum $p_T > 20\,\mathrm{GeV}$
  - large missing E_T, $\not\!\!E_t > 20\,\mathrm{GeV}$
  - two jets, $E_T > 15\,\mathrm{GeV}$ (with b-tags)
- b-tagging:
  - secondary vertex (SVT)
  - neural network (NN)
  - best sensitivity: 1 SVT w/ NN && $\geq$2 SVT
- search for resonant peak in m_{jj}
- for $M_H \sim 115\,\mathrm{GeV}$: $\sigma_{\mathrm{excl}}/\sigma_{\mathrm{SM}} \sim 20$ (single measurement)

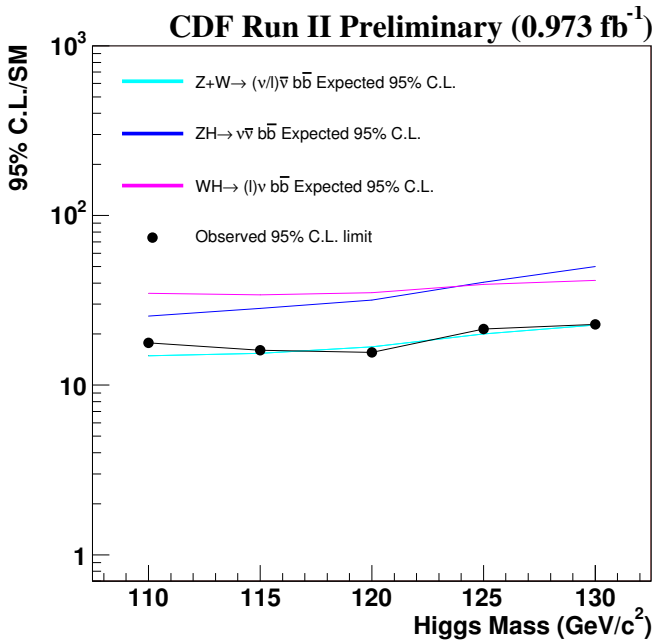




$ZH \to \nu\bar{\nu}b\bar{b}$, $WH \to (l^{\pm})\nu b\bar{b}$

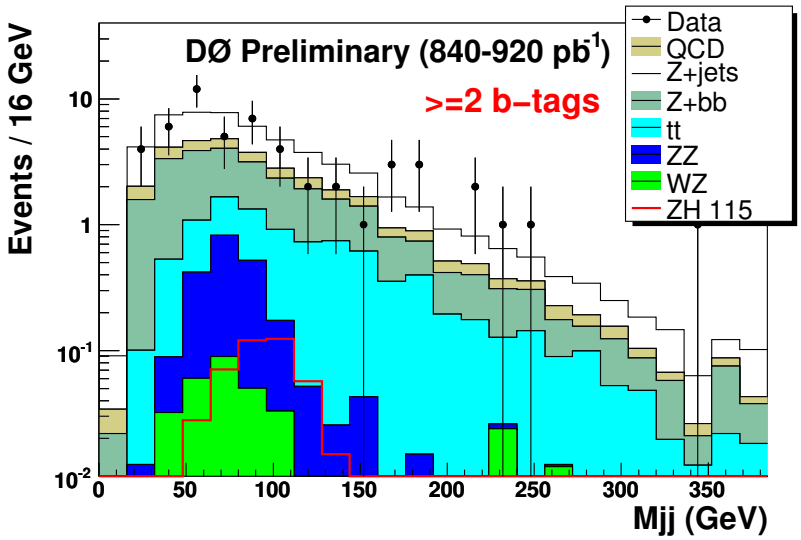
- analysis includes $WH \to (l^{\pm})\nu b\bar{b}$, where $l^{\pm}$ is undetected
- selection:
  - large $\not\!\!E_t > 75\,\mathrm{GeV}$
  - 2 jets with ≥ 1 b-tag
  - topological cuts
- large bgd. from QCD multi-jet and Zjj with mistag
- sensitivity at $M_H \sim 115\,\mathrm{GeV}$:
  - ZH, WH: each $\sigma_{\mathrm{excl}}/\sigma_{\mathrm{SM}} \sim 30$
  - combined: $\sigma_{\mathrm{excl}}/\sigma_{\mathrm{SM}} \sim 16$

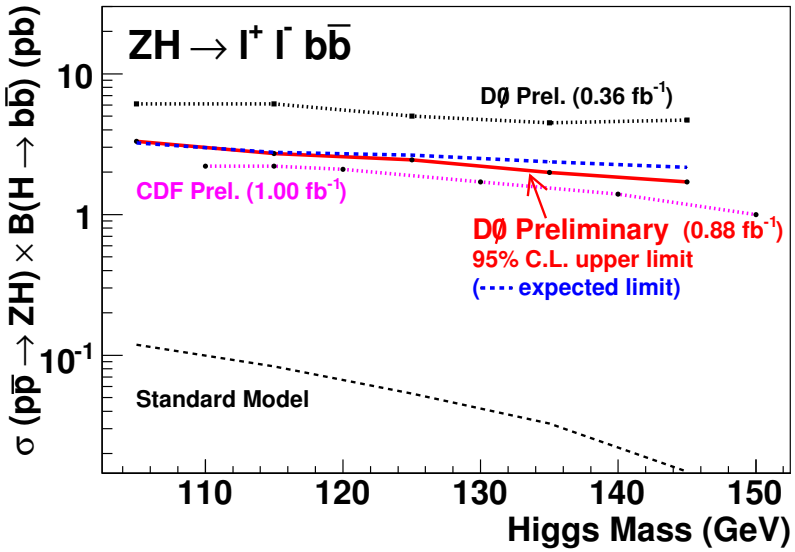




$ZH \to l^+l^- b\bar{b}$

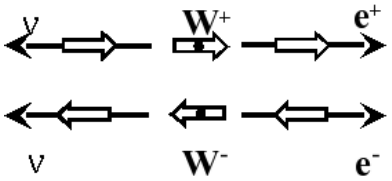
- new (Nov. 06) DØ result
- selection:
  - ee or $\mu\mu$ with $m_{ll} \sim M_Z$
  - ≥ 2 jets, both b-tagged
- NN b-tagger: 72% b-tagging efficiency at 4% light-jet fake rate ($|\eta| < 1.5$)
- background: mostly $Zb\bar{b}$, Zjj
- CDF: improved sensitivity with NN selection
- sensitivity at $M_H \sim 115\,\mathrm{GeV}$: $\sigma_{\mathrm{excl}}/\sigma_{\mathrm{SM}} \sim 25 - 30$
  $\Rightarrow$ similar sensitivity as $Z(\to \nu\bar{\nu})H$ despite low $Z \to l^+l^-$ Br





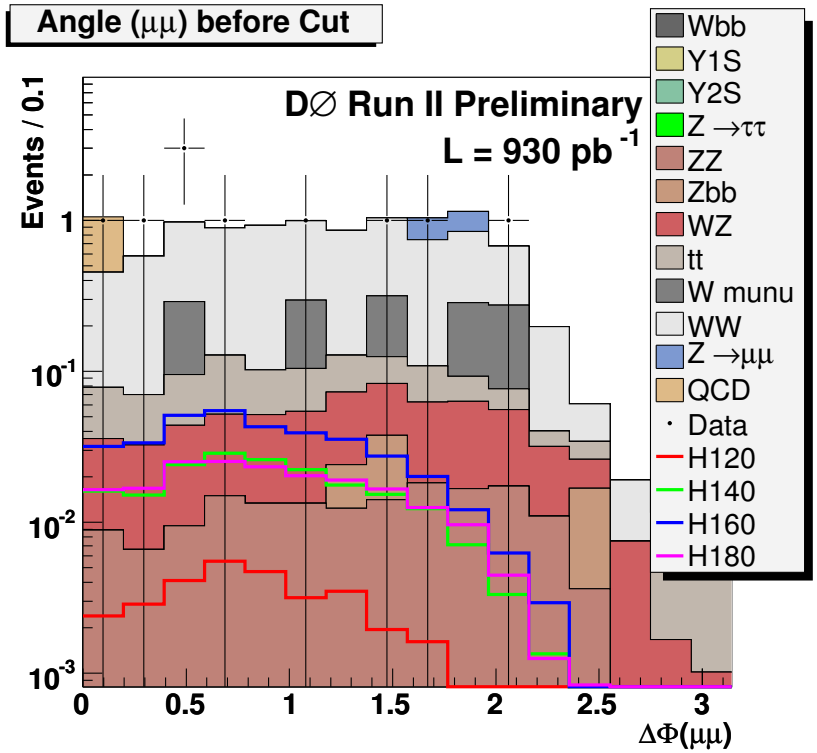
$H \to WW^{(*)} \to l\nu l'\nu$

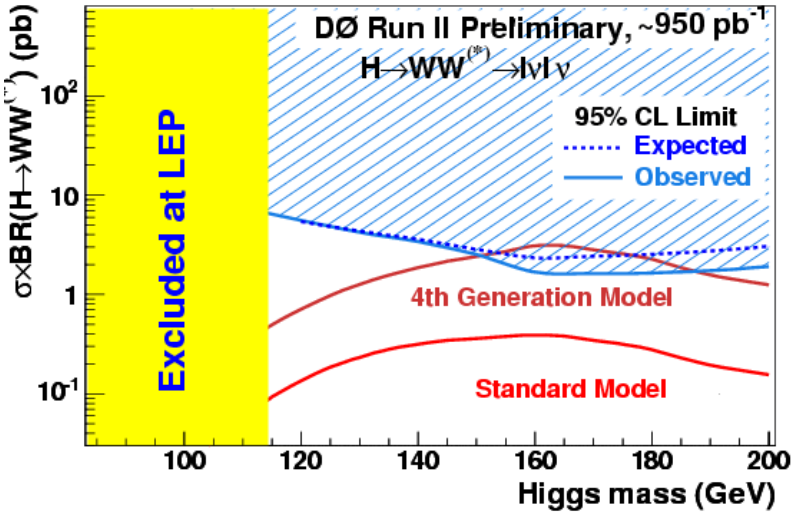
- selection:
  - ee, $e\mu$ or $\mu\mu$
  - $\not\!\!E_t$ and $\not\!\!E_t$ significance (cf. jet E_T resolution)
  - kinematic cuts
- spin correlation



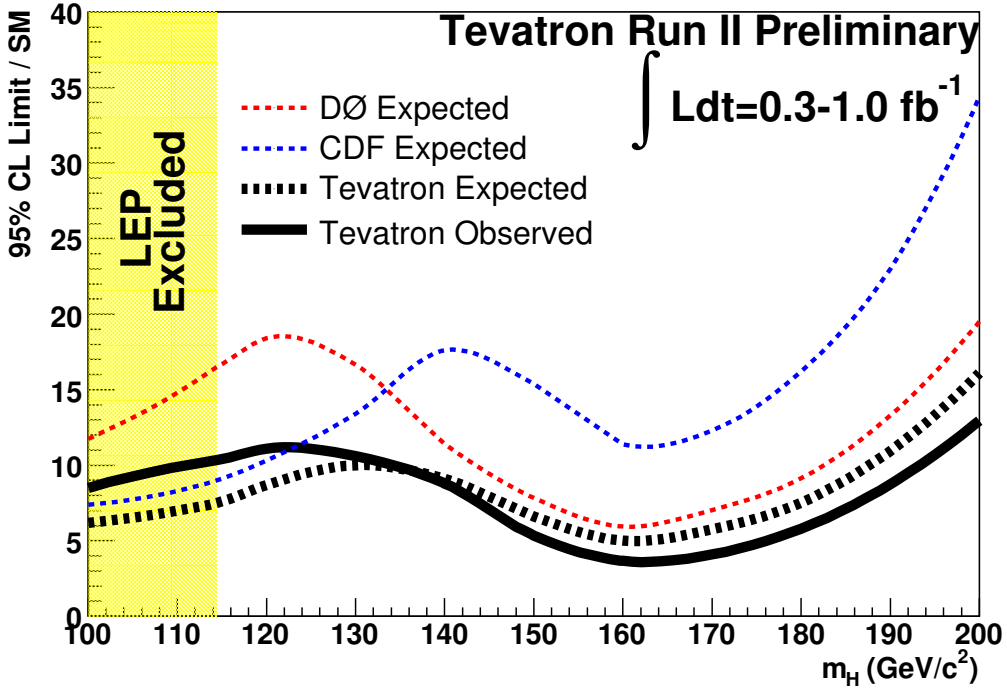
$\to$ di-lepton opening angle $\Delta\phi_{ll'}$ to discriminate against dominating WW background

- sensitivity at $M_H \sim 160\,\mathrm{GeV}$: $\sigma_{\mathrm{excl}}/\sigma_{\mathrm{SM}} \sim 4$ $\Rightarrow 4^{th}$ gene. model already excl. for $M_H = 150 - 185\,\mathrm{GeV}$!
- CDF: new results (not shown)





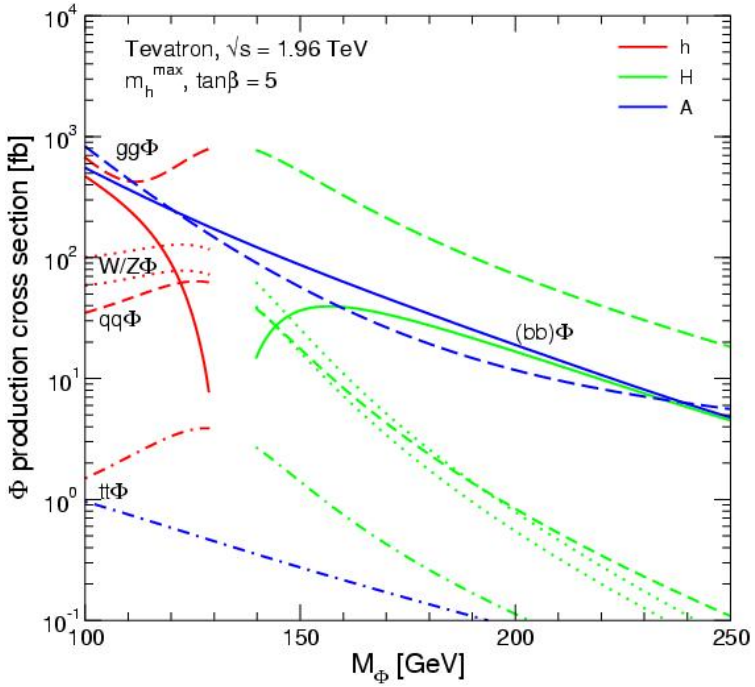
Combined Tevatron SM Higgs Limits

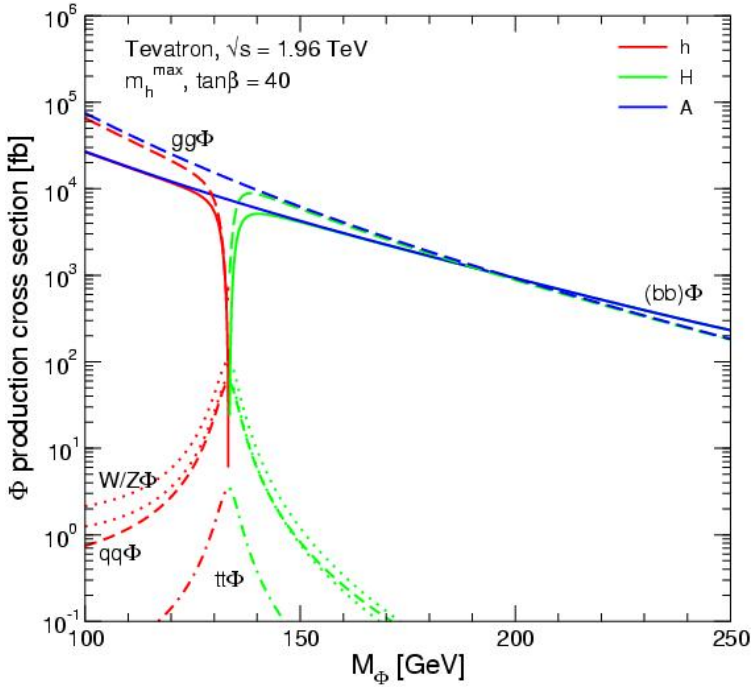


- first CDF and DØ combined limits (status: Summer 06)
  - ZH, WH (low mass): only CDF's $1\,\mathrm{fb}^{-1}$ results included
  - $H \to WW^{(*)}$ (high mass): only DØ's $1\,\mathrm{fb}^{-1}$ results included
- new measurements with $1\,\mathrm{fb}^{-1}$ not yet in combination:
  - CDF: $H \to WW^{(*)}$, DØ: $ZH \to l^+l^-b\bar{b}$
- new updates to be released within the next weeks
- prospects: $L = 4 - 8\,\mathrm{fb}^{-1}$ (by 2009), improved b-tagging (NN) and selections

SUSY Higgs

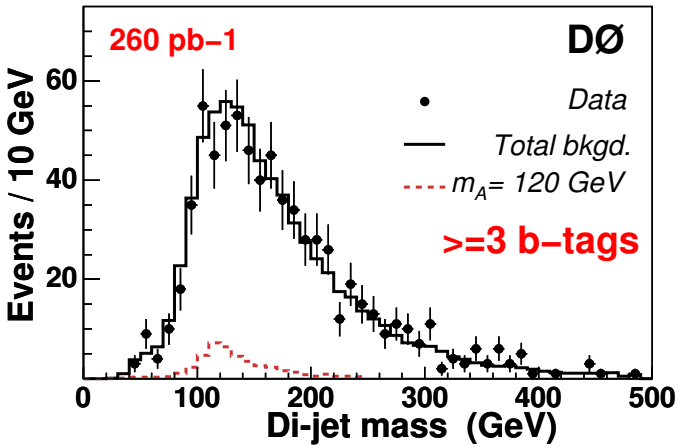
- MSSM: 2-Higgs-doublet model:
  - 5 H-bosons: h^0, H^0, A^0, $H^\pm$
  - all $^0 = \phi^0$
  - prediction: $m_h \lesssim 135\,\mathrm{GeV}$
- Higgs v.e.v.'s v_u, v_d: ratio $\tan\beta = v_u/v_d$
  $\rightarrow$ $\sigma(gg \rightarrow H)$ and $\sigma(b\bar{b}H)$ enhanced at large $\tan\beta$
- at large $\tan\beta$: A nearly mass-degenerate with h or H, $\sigma(A) \sim \sigma(h/H)$
- decays at large $\tan\beta$:
  - $Br(\phi \rightarrow b\bar{b}) \sim 90\%$
    $\Rightarrow b\bar{b}\phi \rightarrow b\bar{b}b\bar{b}$
  - $Br(\phi \rightarrow \tau^+\tau^-) \sim 10\%$
    $\rightarrow \phi \rightarrow \tau^+\tau^-$

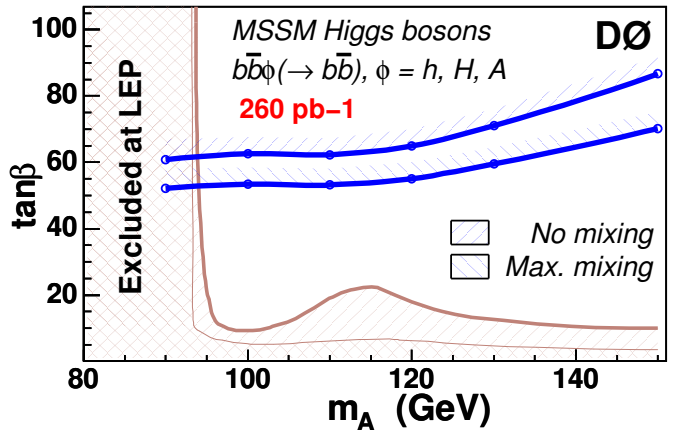


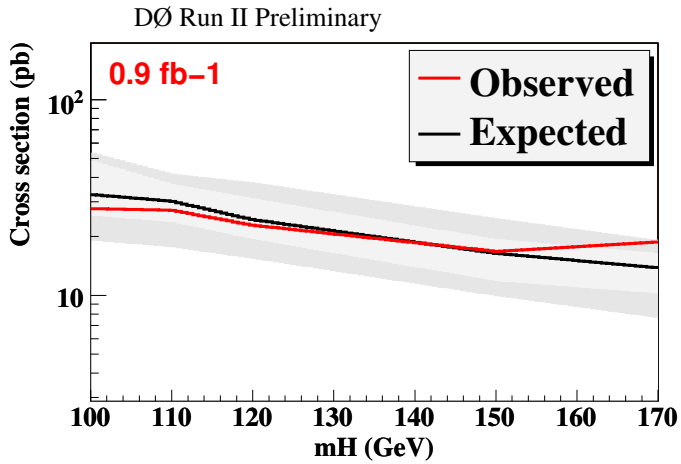


MSSM $b\bar{b}\phi \to b\bar{b}b\bar{b}$

- selection:
  - 3 b-tagged jets
  - search for peak in $m(j_1, j_2)$
- backgrounds:
  - $b\bar{b}j(j)$, $b\bar{b}b\bar{b}$, $Z(\to b\bar{b})j$, $t\bar{t}$
  - shape: $2b$-tagged $\times$ (mis-)tag
  - normalized to $3b$-tagged outside signal region
- sensitivity at $M_A \sim 120\,\mathrm{GeV}$:
  $\tan\beta >\sim 50 - 60$
  (depending on $\tilde{t}$ mixing param. X_t)
- update based on $0.9\,\mathrm{fb}^{-1}$
  - NN b-tagger: $\epsilon(b\text{−tag}) = 49\%$ at $\epsilon(\mathrm{mis-tag}) = 0.33\%$
  - σ(excl.) improved by $\sim 1/3$

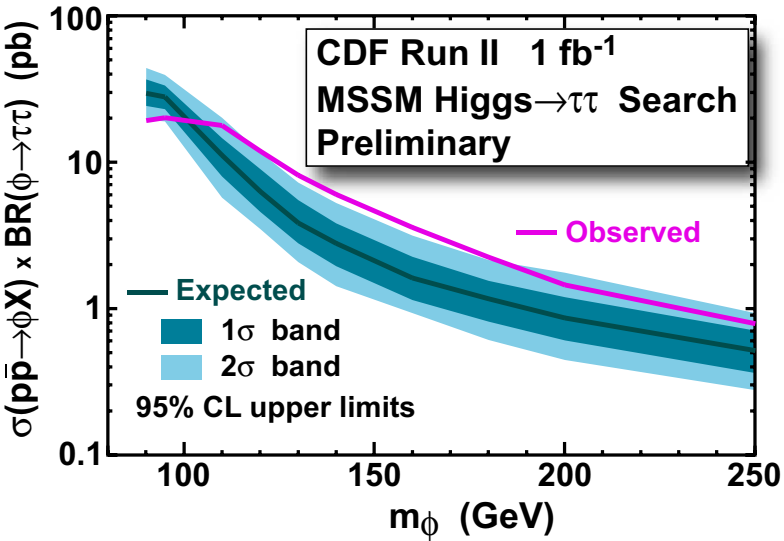




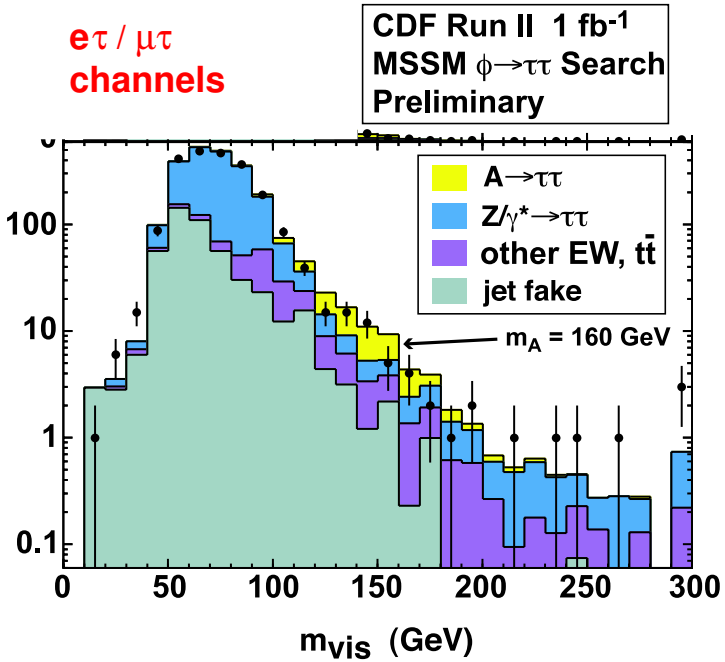


MSSM $\phi \to \tau\tau$

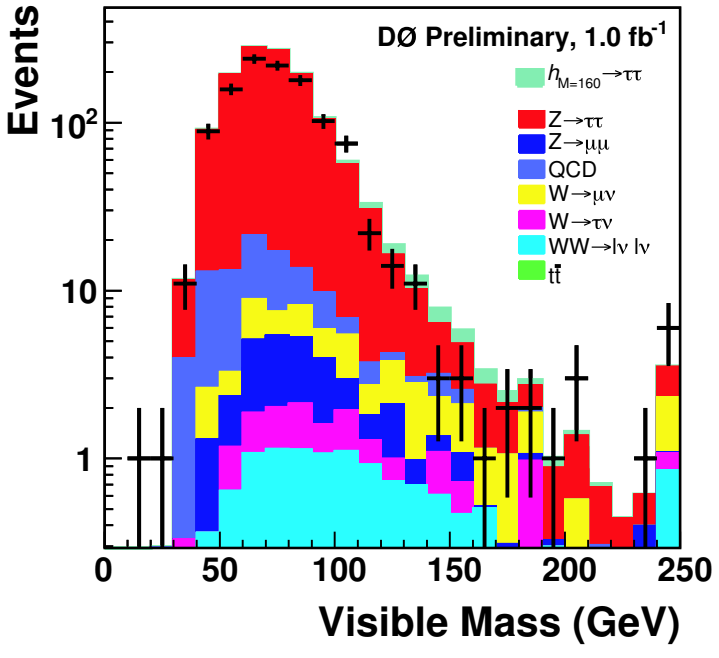
- 2 new results based on $1\,\mathrm{fb}^{-1}$
  - CDF: $e\mu$, $e\tau$, $\mu\tau$
  - DØ: $\mu\tau$ selection
- partial reconstruction of M_ϕ:
  $m_{\mathrm{vis}} = |P^{\mathrm{vis}}_{\tau_1} + P^{\mathrm{vis}}_{\tau_2} + \not{P}_t\,|$
  - CDF: some excess seen (only $e\tau$, $\mu\tau$), but significance $< 2\sigma$
  - DØ: no excess, (limits from NN analysis)



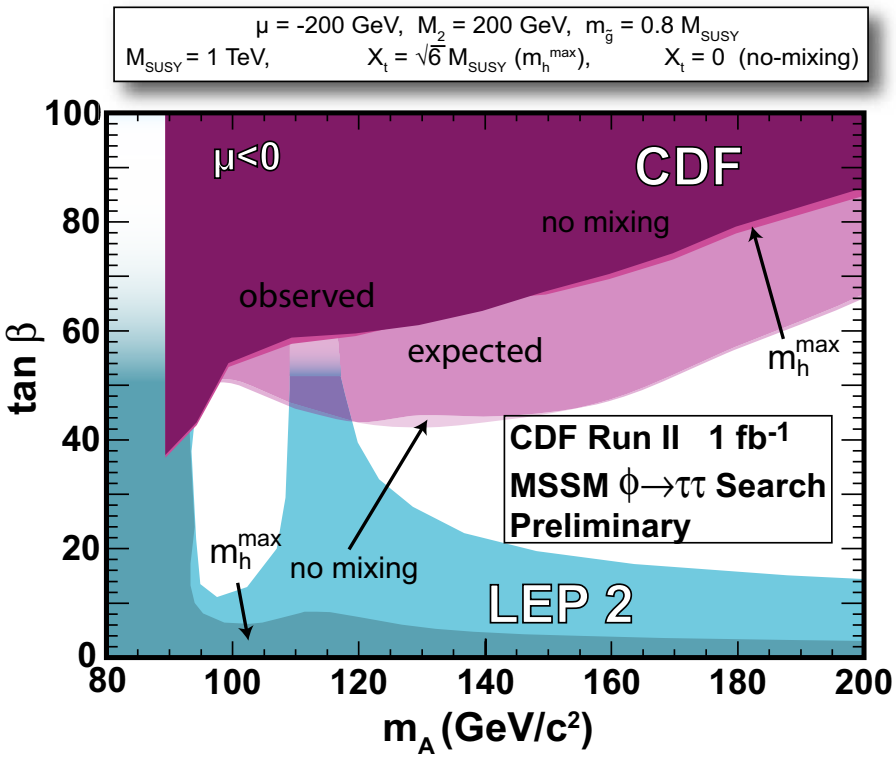
eτ / μτ channels

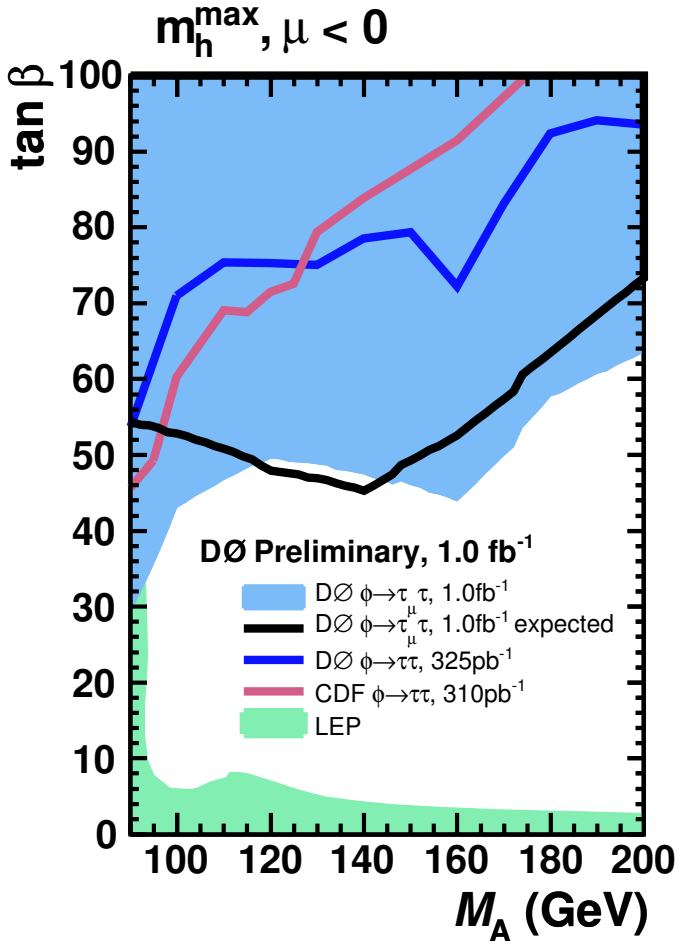


$\mu\tau$ channel



MSSM $\phi \to \tau\tau$: Exclusion Regions

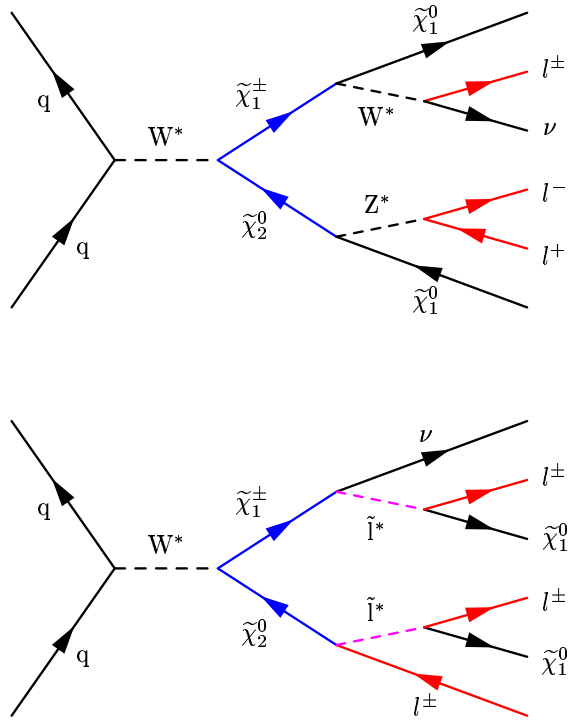


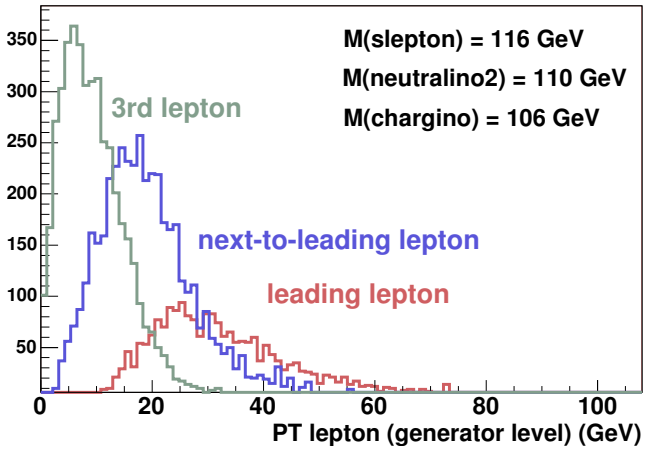


- only minimal change in excluded region for different model assumptions
  - $\tilde{t}$-mixing: no-mixing and $m_h^{\max}$ (parameters that maximize M_h)
  - $\mu > 0$ or $\mu < 0$ (Higgs mass term)

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ Production: Tri-Lepton Signature

- chargino-neutralino ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$) pair-production with 3-lepton signature
- searches within mSUGRA (inspired) models
  - R-parity conservation
  - $\tilde{\chi}_1^0$ LSP $\rightarrow \not{E}_t$
  - vary models by relaxing constraints on $\tilde{l}$-mixing and m_0 unification
- clean signature with low background, but:
  - low cross section and branching fractions Br in leptons
  - leptons with small p_T
  - large tan β: enhanced coupling to τ



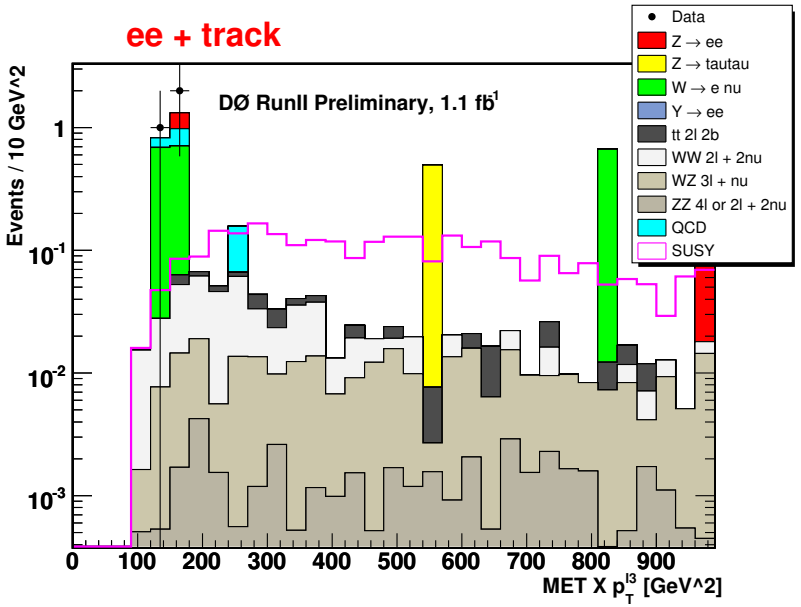


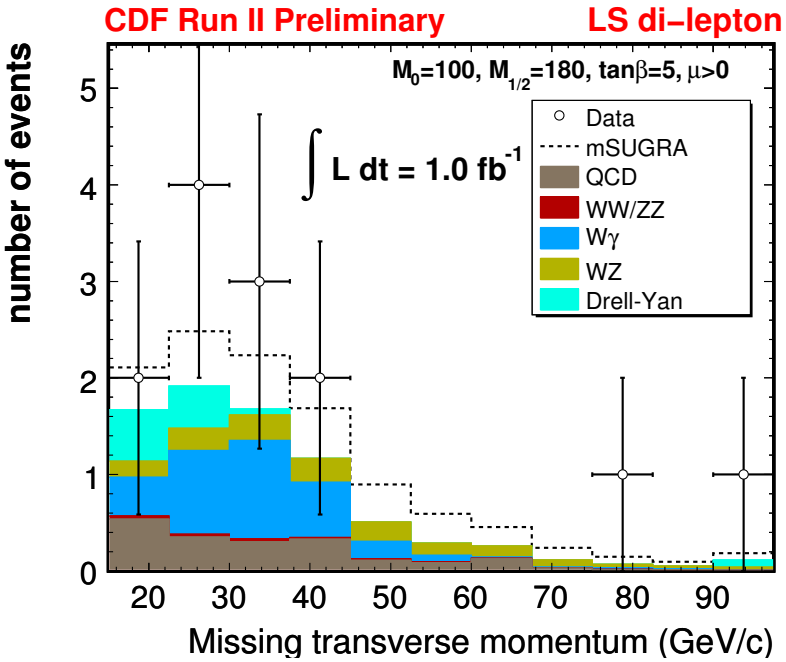
Tri-Lepton/Like-Sign $l^{\pm}l^{\pm}$ Searches

- DØ: 6 analyses
  - $ll(e,\mu)$+track
  - $e/\mu + \tau_h$+track
  - $\mu^{\pm}\mu^{\pm}$

  $\rightarrow$ increase sensitivity by not requiring explicit l-ID for 3^{rd} l
- CDF: 14 analyses:
  - lll
  - ee+track
  - $l^{\pm}l^{\pm}$

  $\rightarrow$ dedicated analyses for high/low p_T trigger, e at high η
- backgrounds: WZ, WW, $W\gamma$, $Z/\gamma^*(\rightarrow \tau\tau)$, QCD muli-jet



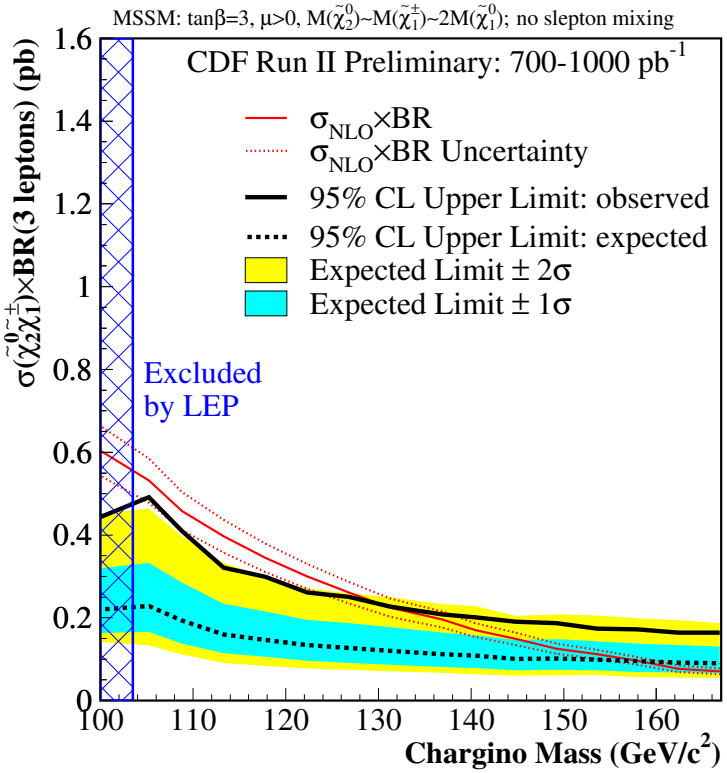


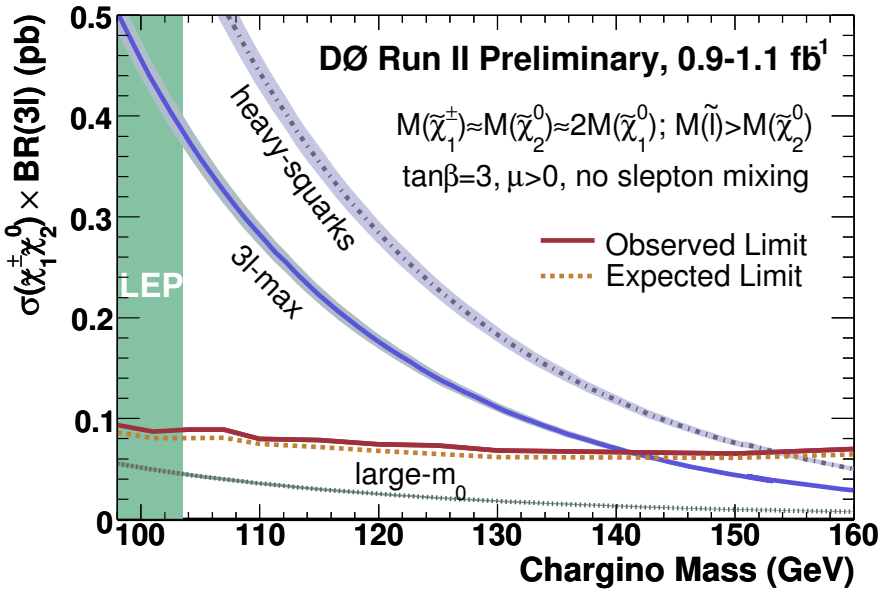
Limits on $M(\tilde{\chi}_1^{\pm})$

mSUGRA (inspired) models

- CDF:
  - no mass limit for mSUGRA with $\tilde{l}$-mixing and when decay via W/Z dominates
  - w/o $\tilde{l}$-mix.: $\sigma \cdot Br \sim 0.2\,\mathrm{pb}$ (exp.: $0.1\,\mathrm{pb}$) $\rightarrow M(\tilde{\chi}_1^{\pm}) > 130\,\mathrm{GeV}$
- DØ:
  - large-m_0: heavy $\tilde{l}$ and $\tilde{q}$ $\rightarrow$ small Br in l
  - heavy $\tilde{q}$: $M(\tilde{l}) \ll M(\tilde{q})$ $\rightarrow$ large σ and Br into l
  - 3l-max: $M(\tilde{l}) \simeq M(\tilde{\chi}_1^{\pm})$ $\rightarrow$ maximal Br into l

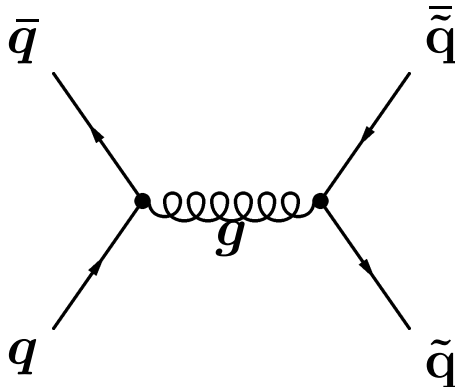
  $\sigma \cdot Br \sim 0.07\,\mathrm{pb}$ $\rightarrow M(\tilde{\chi}_1^{\pm}) > 140\,\mathrm{GeV}$

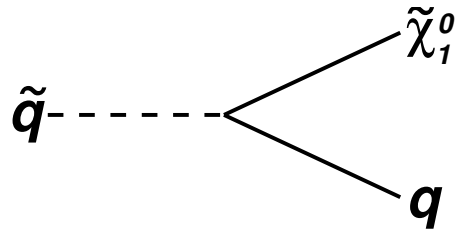


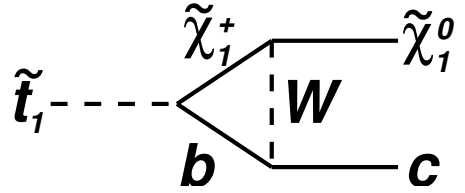


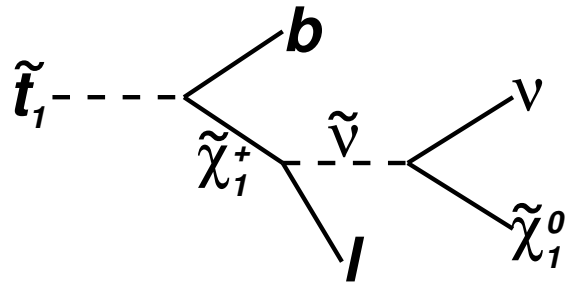
Scalar Quarks, Gluinos: Production and Decay

- strong coupling $\rightarrow$ large σ for pair-production of $\tilde{q}$ and $\tilde{g}$
- large $M(t) \rightarrow$ large mixing of $\tilde{t}_L/\tilde{t}_R$ (and $\tilde{b}_L/\tilde{b}_R$) $\rightarrow$ maybe $M(\tilde{t}_1) \ll M(\tilde{q})$
- $\tilde{q} \rightarrow q\tilde{\chi}_1^0$
  - topology: 2 jets + missing transverse energy ($\not{E}_t$)
- $\tilde{b} \rightarrow b\tilde{\chi}_1^0$
  - efficient background suppression by requiring b-tag
- $\tilde{t}$ decays
  - two-body decays $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^+$ kinematically forbidden (in interesting parameter region)
  - $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$, loop induced
  - $\tilde{t}_1 \rightarrow bl\tilde{\nu}$, $M(\tilde{\nu}) > 43.7\,\text{GeV}$ (LEP)



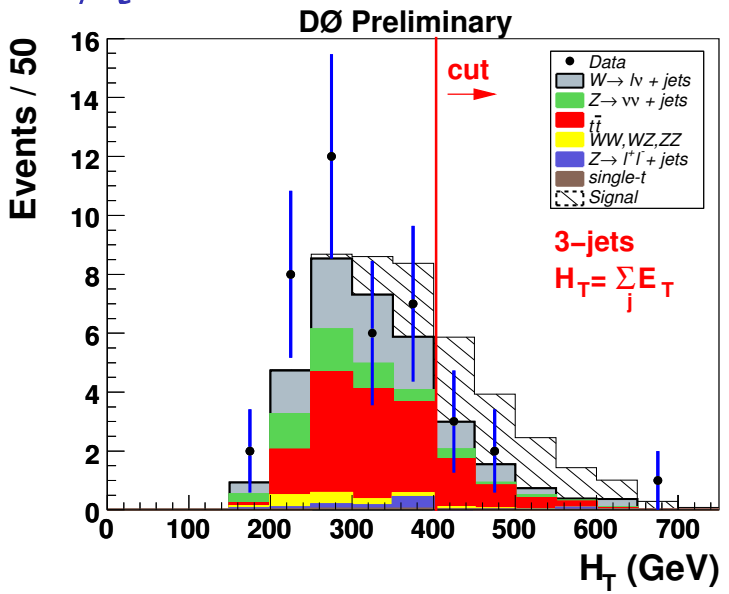


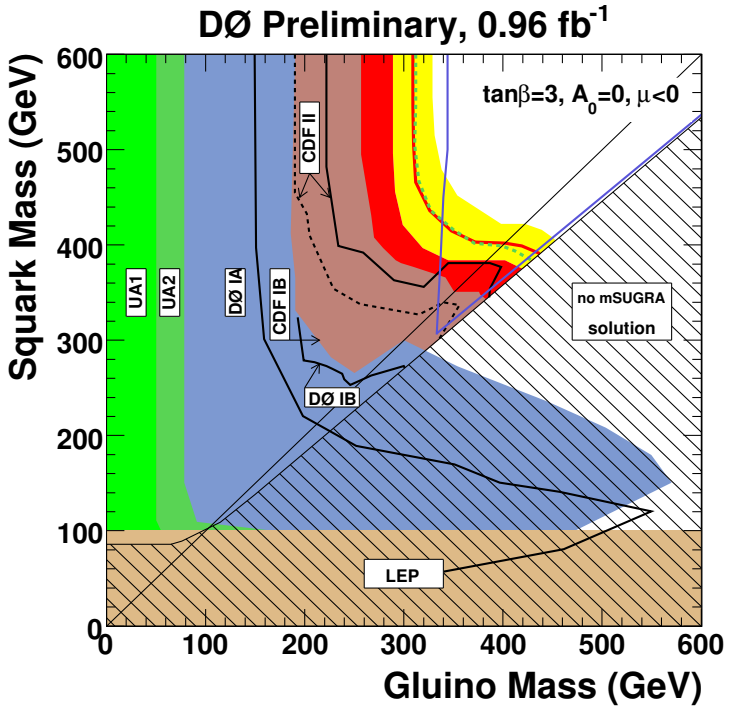




Search $\tilde{q}$, $\tilde{g}$ in Jets + $\not\!\!E_t$

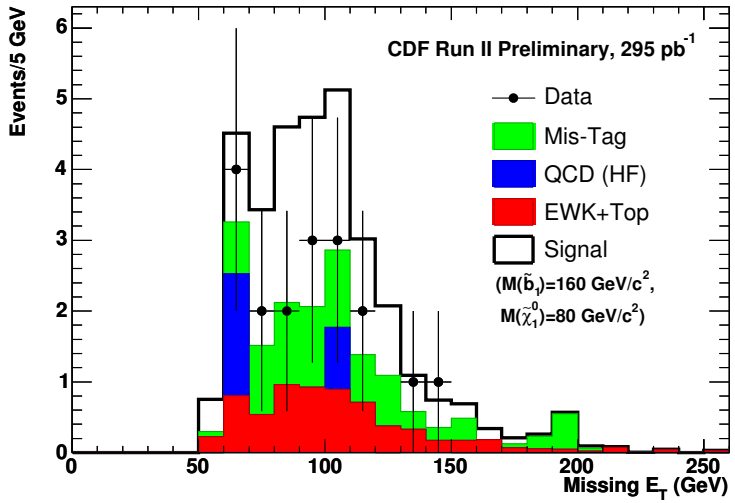
- new update with $L = 1\,\mathrm{fb}^{-1}$
- 3 analyses:
  - $M_{\tilde{q}} < M_{\tilde{g}}$: $\tilde{q}\bar{\tilde{q}} \rightarrow q\tilde{\chi}_1^0\bar{q}\tilde{\chi}_1^0$
    $\Rightarrow$ 2 jets, $\not\!\!E_t$
  - $M_{\tilde{q}} \sim M_{\tilde{g}}$: $\tilde{q}\tilde{g} \rightarrow q\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$
    $\Rightarrow$ 3 jets, $\not\!\!E_t$
  - $M_{\tilde{q}} > M_{\tilde{g}}$: $\tilde{g}\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$
    $\Rightarrow$ 4 jets, $\not\!\!E_t$
- most conservative limits
  (for $\tan\beta = 3, A_0 = 0, \mu < 0$):
  $M_{\tilde{g}} > 289\,\mathrm{GeV}$
  $M_{\tilde{q}} > 375\,\mathrm{GeV}$
- interpretation within mSUGRA:
  improved limits w.r.t. LEP for
  $m_0 \sim 75 - 250\,\mathrm{GeV}$ and
  $m_{1/2} \sim 125 - 165\,\mathrm{GeV}$

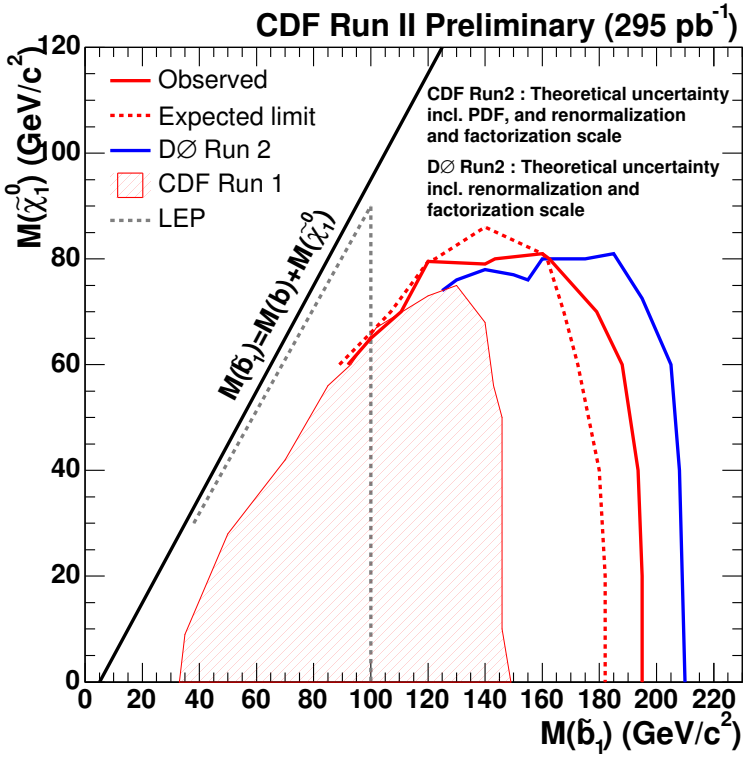




Search for $\tilde{b}_1\bar{\tilde{b}}_1$: $\tilde{b} \to b\tilde{\chi}_1^0$

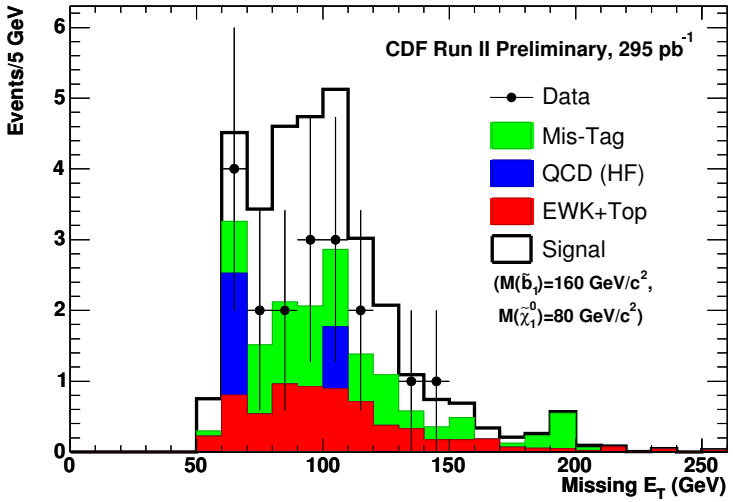
- signal: generic MSSM,
  vary $M(\tilde{b})$, $M(\tilde{\chi}_1^0)$
  assume $Br(\tilde{b} \to b\tilde{\chi}_1^0) = 100\%$
- selection:
  - 2 or 3 jets, $\not\!\!E_t$
    cuts depending on $M(\tilde{b})$
  - 1 b-tag
- main backgrounds:
  - QCD multi-jet (HF+mis-tag)
  - W/Z+jets
- previous DØ result ($310\,\mathrm{pb}^{-1}$):
  - higher sensitivity at large $M(\tilde{b})$

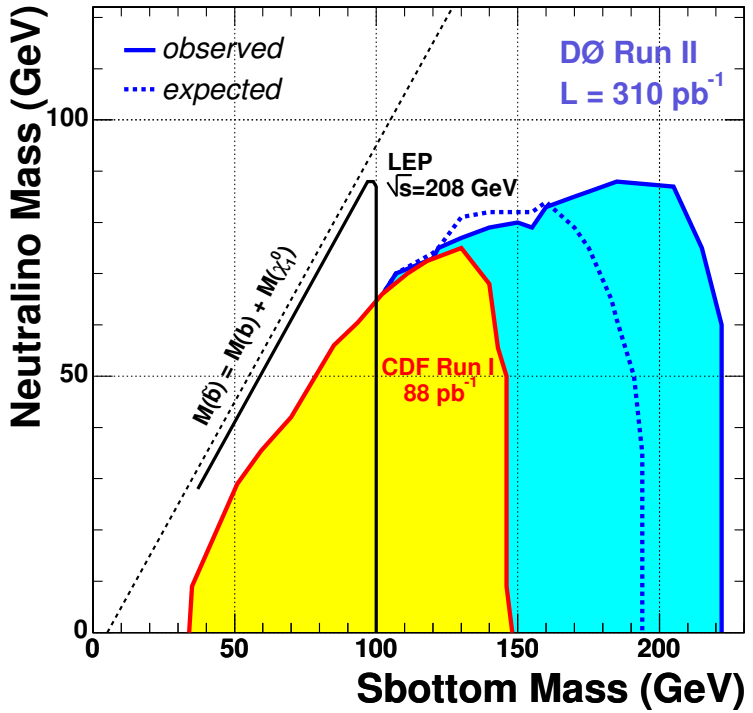




Search for $\tilde{b}_1\bar{\tilde{b}}_1$: $\tilde{b} \to b\tilde{\chi}_1^0$

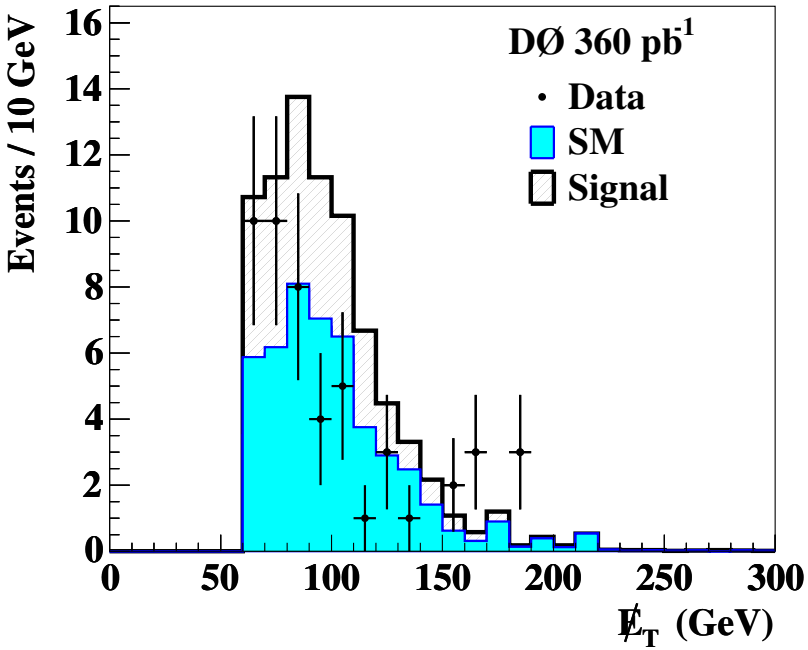
- signal: generic MSSM,
  vary $M(\tilde{b})$, $M(\tilde{\chi}_1^0)$
  assume $Br(\tilde{b} \to b\tilde{\chi}_1^0) = 100\%$
- selection:
  - 2 or 3 jets, $\not\!\!E_t$
    cuts depending on $M(\tilde{b})$
  - 1 b-tag
- main backgrounds:
  - QCD multi-jet (HF+mis-tag)
  - W/Z+jets
- previous DØ result ($310\,\mathrm{pb}^{-1}$):
  - higher sensitivity at large $M(\tilde{b})$
  - now published

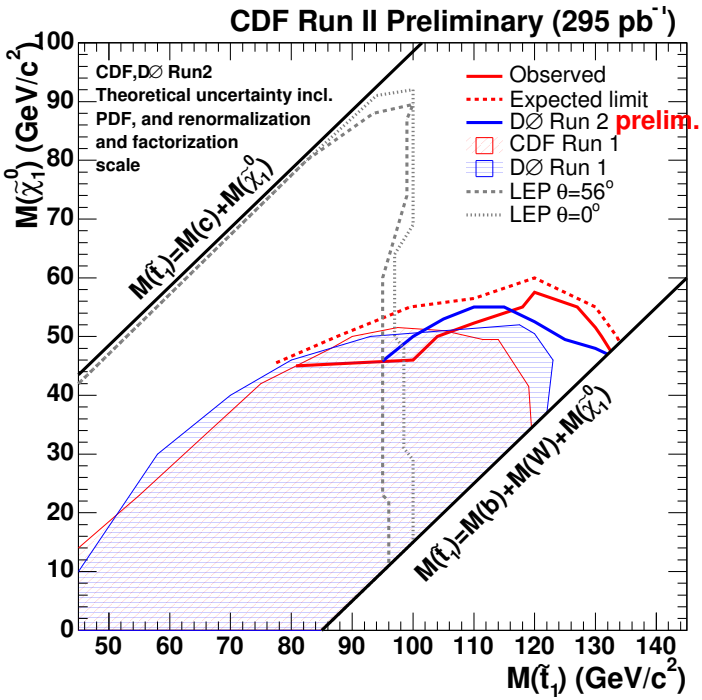


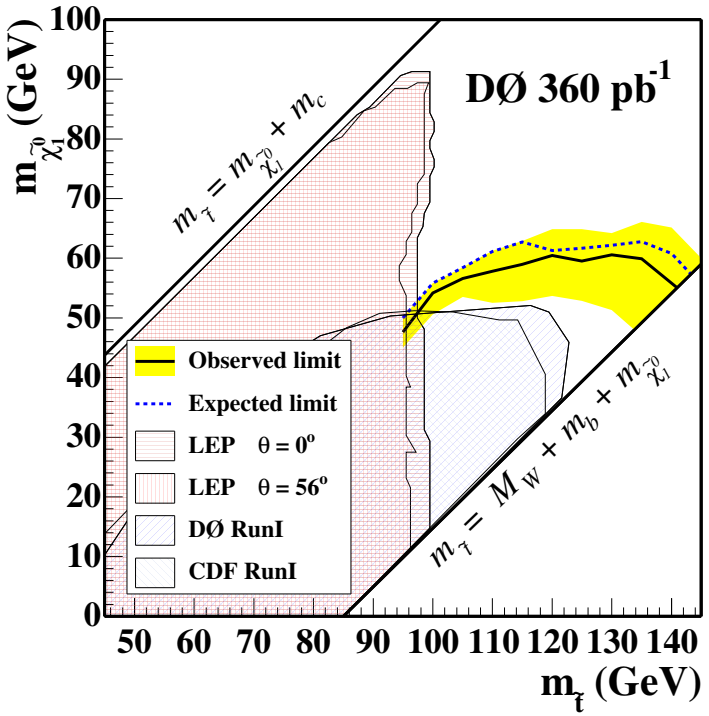


$\tilde{t}_1\bar{\tilde{t}}_1$: $\tilde{t}_1 \to c\tilde{\chi}_1^0$

- signal: generic MSSM, vary $M(\tilde{t})$, $M(\tilde{\chi}_1^0)$, ass. $Br(\tilde{t}_1 \to c\tilde{\chi}_1^0) = 100\%$
- selection: similar as for $\tilde{b}$ search, but only loose c-tag required
- main background: $Z(\to \nu\bar{\nu})/W(\to l\nu)$ + jets







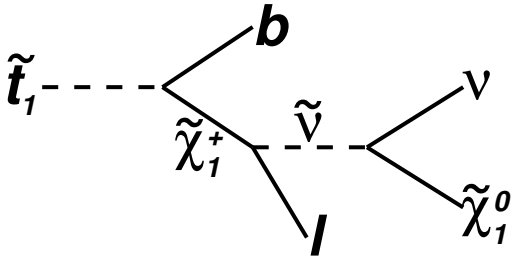
Summary

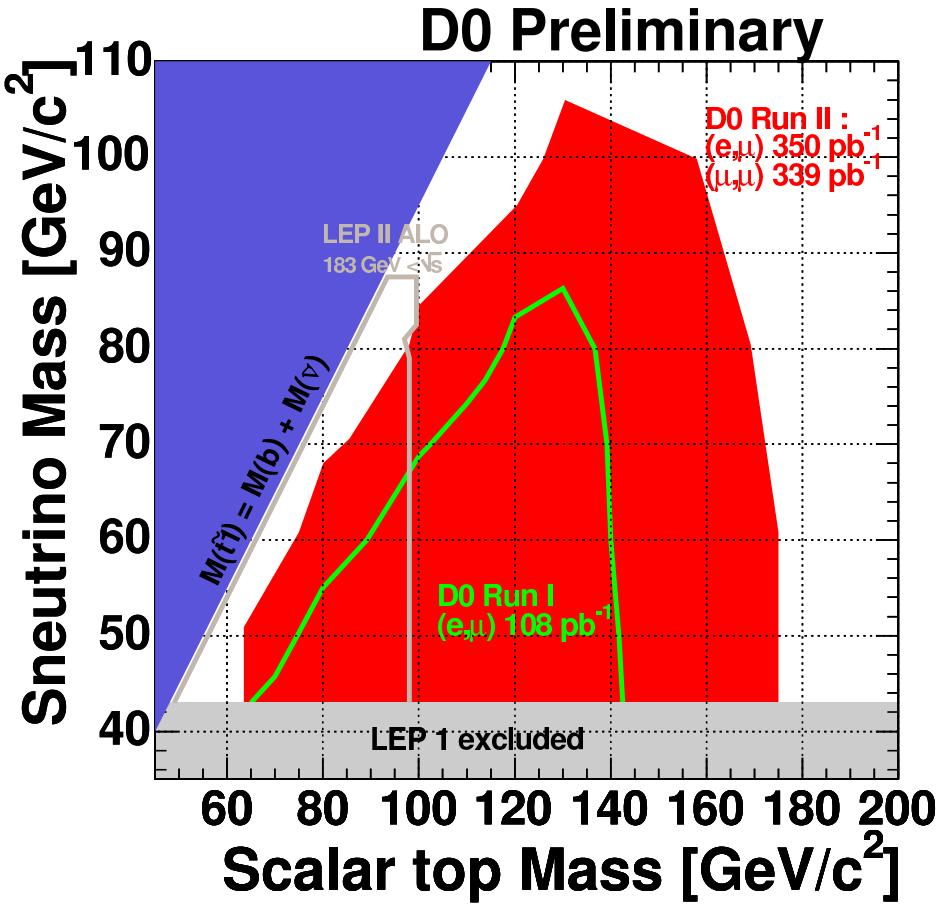
- SM Higgs
  - many updates with $1\,\mathrm{fb}^{-1}$ within the last year
  - first Tevatron combination in Summer 06
    prospects: promising but challenging
- SUSY Higgs
  - large potential if SUSY at large $\tan\beta$ is realized
- searches for SUSY partners
  - large variety of topologies studied although searches for GMSB, ASMB, split SUSY etc. not covered here
  - no indication of new phenomena seen so far, but sensitivity well beyond LEP and Tevatron Run I added.

- for further details see:
  CDF: `http://http://www-cdf.fnal.gov/physics/physics.html`
  DØ: `http://www-d0.fnal.gov/Run2Physics/WWW/results.htm`

Backup

Search for $\tilde{t}_1\bar{\tilde{t}}_1$: $\tilde{t}_1 \to bl\tilde{\nu}$





- selection:
  - $e\mu$ or $\mu\mu$
  - ($+$ b-tagged jet)
- main backgrounds:
  $Z(\to \tau\tau)$, $t\bar{t}$, WW, QCD multi-jet

- challenge for small $M(\tilde{t}) - M(\tilde{\nu})$: leptons and jets with low p_T
  $\to$ $\mu\mu$: $p_T(\mu_2) > 6\,\mathrm{GeV}$, $e\mu$: no jet requirement
- signal model:
  - generic MSSM, vary $M(\tilde{t})$, $M(\tilde{\nu})$
  - assume $Br(\tilde{t} \to bl\tilde{\nu}) = 100\%$

Searches for H and SUSY

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