Search for Higgs Bosons Beyond the Standard Model and Supersymmetry at the Tevatron

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on behalf of the CDF and DØ Collaborations

Les Rencontres de Physique de La Vallée d'Aoste

Results and Perspectives in Particle Physics

La Thuile, 5-11 March 2006

Searches for Higgs Bosons Beyond the Standard Model

Broad spectrum of Higgs bosons searches

- MSSM Higgs, doubly charged Higgs, fermiophobic Higgs
- CDF http://www-cdf.fnal.gov/physics/exotic/exotic.html
- DØ http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

Emphasis on the MSSM model

- 5 Higgs bosons ϕ=(h^0, H^0, A^0, $\mathrm{H}^{\pm}$)
- At tree-level: 2 free parameters ($\mathrm{M_A}$, $\tan\beta$)

Run II results. All limits are given with 95% C.L.

$gg, b\bar{b} \rightarrow \phi(\rightarrow \tau\tau)$

PRL, 96, 011802 (2006)

Motivation:

- Enhancement of the coupling to down-type fermions ($\tan\beta$) over SM
- σ scales as $\tan^2\beta$ (ϕ= A and h/H, simultaneously produced)
- BR($h/H/A \rightarrow \tau\tau$) $\sim$ 10%

Signal: 2 channels, $\tau\tau \rightarrow (\nu_\tau\ \nu_l\ l)\ (\nu_\tau$ hadrons)

Dataset:

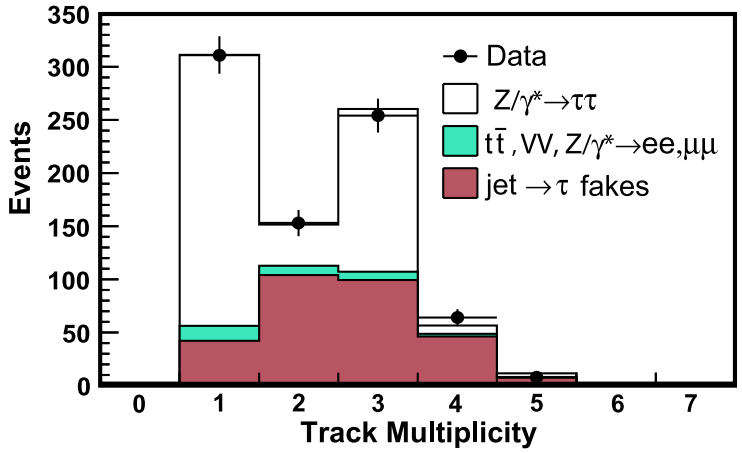
lepton (e or μ) + isolated track, $\mathcal{L}_{int} \sim 310$ pb^{-1}

Background:

$Z \rightarrow \tau\tau$, multi-jet, W+jets, $Z \rightarrow ll$, di-boson, $t\bar{t}$

Selection:

- τ identification: sequential cuts (narrow jets with a few attached tracks)
- E_T^{vis}, angular distributions, Z mass veto
- Combined acc.: 0.8-2.0% (m_ϕ=90-250 GeV)



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Selected events:

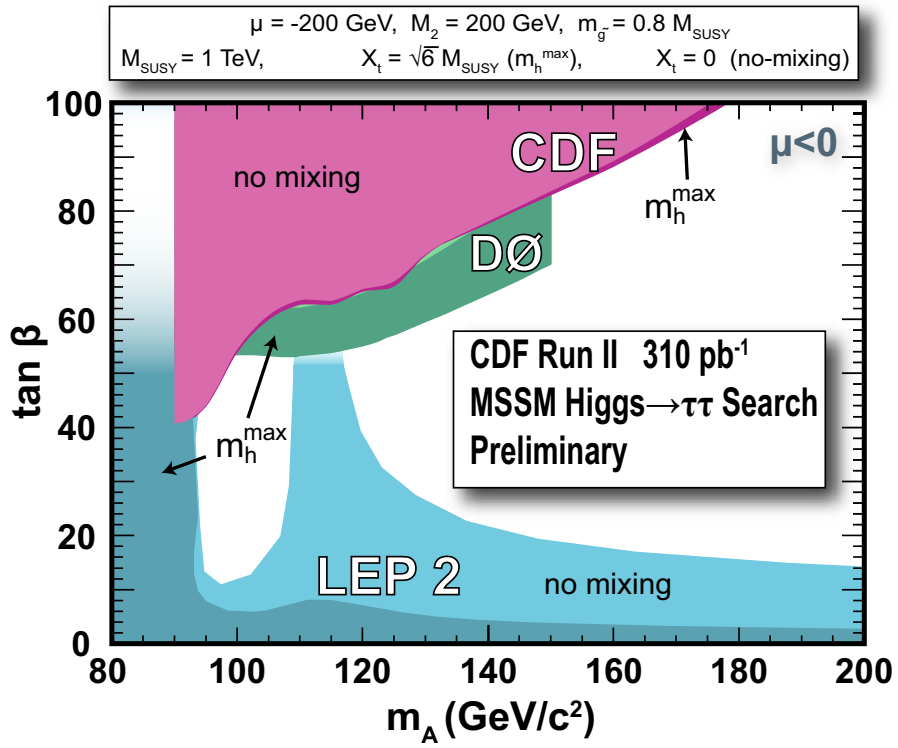
- $N_{SM} = 496 \pm 5(stat) \pm 28(sys) \pm 25(lumi)$, $N_{ob} = 487$
- rather pure sample of real taus ($Z \rightarrow \tau\tau$: 405)

Main systematics:

- jet $\rightarrow \tau$ misidentification: 20%
- signal modelling (PDF): 6%

Limits:

- No evidence for signal.
- Limited extracted from the visible mass of the tau system $m_{vis}(l, \tau_h^{vis}, E_T^{miss})$
- Similar exclusions obtained for $\mu > 0$



$\phi \to \tau\tau$ and combination with $\phi \to b\bar{b}$

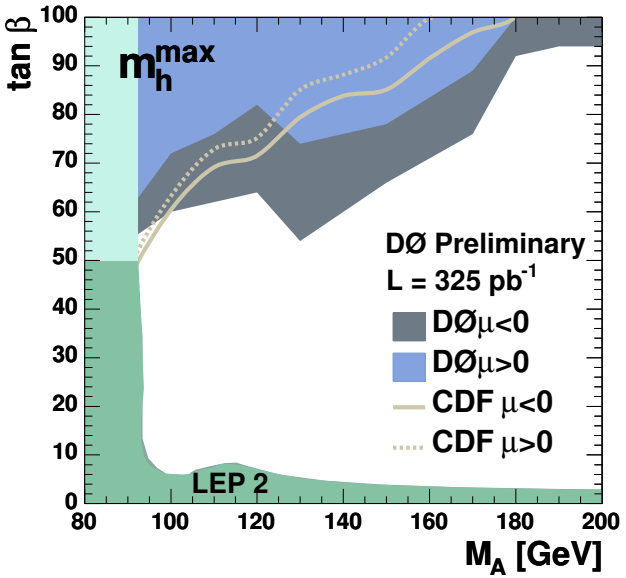
HOT OFF THE PRESS

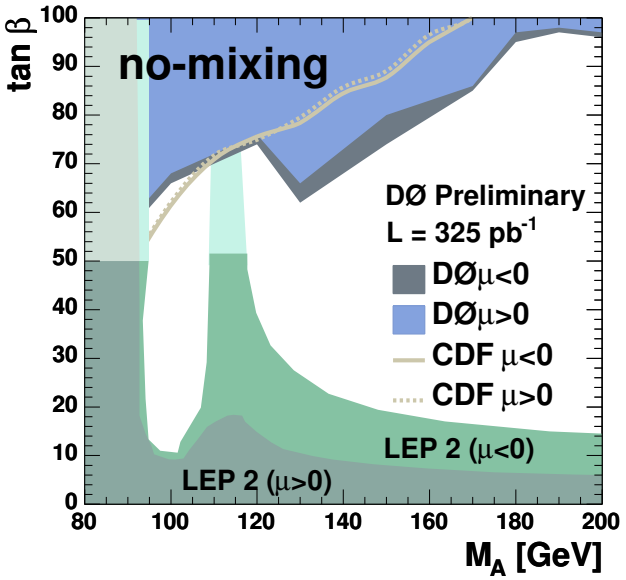
Signal:
- 3 channels: $e\tau_h$, $\mu\tau_h$, $e\mu$

Dataset:
- single em, single μ and $e\mu$ triggers
- 328/299/348 pb^{-1}

Selected events:
- tau identification (NN) and classification
- main backgrounds: $Z \to \tau\tau$, multi-jet (but $e\mu$)
- Acceptances: $\sim$ 1-14% (m_ϕ=100-300 GeV)

Results:
- no excess of signal, upper limits extracted
- discriminating variable: visible mass
- combination with the DØ $\phi \to b\bar{b}$ channel
  PRL, 95, 151801 (2005)





$t \to H^{\pm} b$ in $t\bar{t}$ production

PRL, 96, 042003 (2006)

Motivation:

$t \to H^{\pm} b$ (MSSM) competes with $t \to W^{\pm} b$ (SM)

Method:

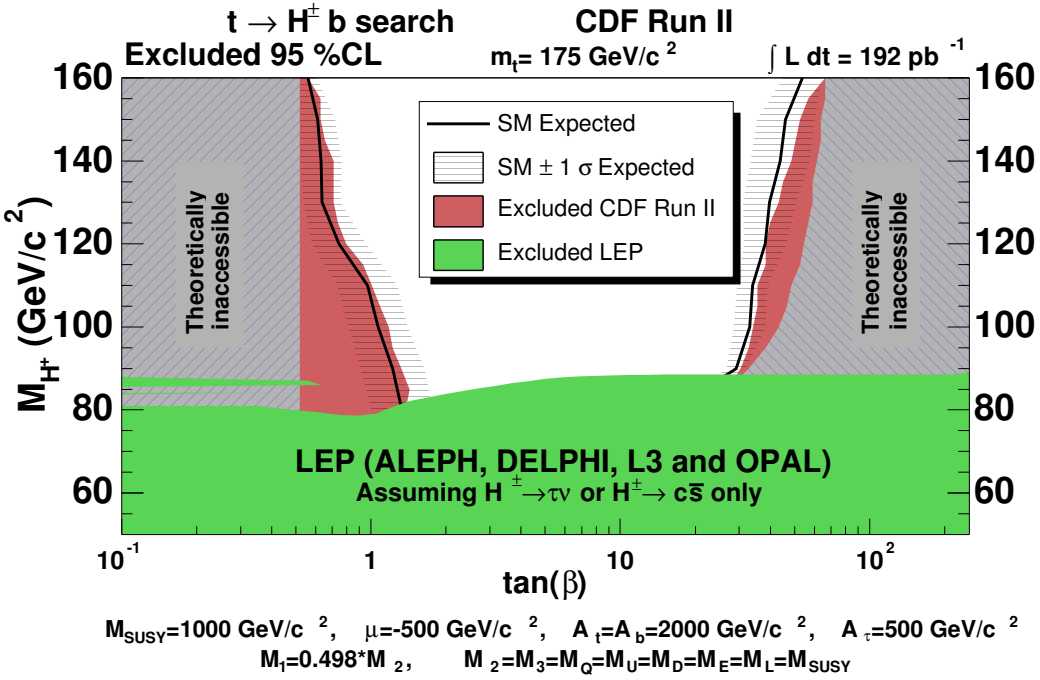
- SM $t\bar{t}$ cross-section measurement reinterpretation
- H^+ decays to: $\bar{\tau}\nu$, $W^+\phi(\to b\bar{b})$, $c\bar{s}$ or $t^{\star}\bar{b}$

channel	B(non $t\bar{t}$)	data	SM_{exp}
dilepton	2.7±0.7	13	10.9±1.4
lep+jets, =1 b-tag	21.8±3.0	49	54.0±4.3
lep+jets, ≥2 b-tag	1.3±0.3	8	10.0±1.0
lep+tau	1.3±0.2	2	2.3±0.3

Dataset: $\mathcal{L}_{int}$ ~200 pb^{-1}

Results:

- no evidence for signal (m_H=80-160 GeV);
- limits at high $\tan\beta$ depend significantly on the model parameters;
- limits at low $\tan\beta$ are more robust.



Supersymmetry Searches

Broad spectrum of SUSY models

- constrained and unconstrained MSSM, R-parity violation, GMSB, ...
- CDF http://www-cdf.fnal.gov/physics/exotic/exotic.html
- DØ http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

New results not covered in this talk

- RPV: multilepton (CDF), neutral long lived particles (DØ)

Emphasis on the MSSM model with RP conserved

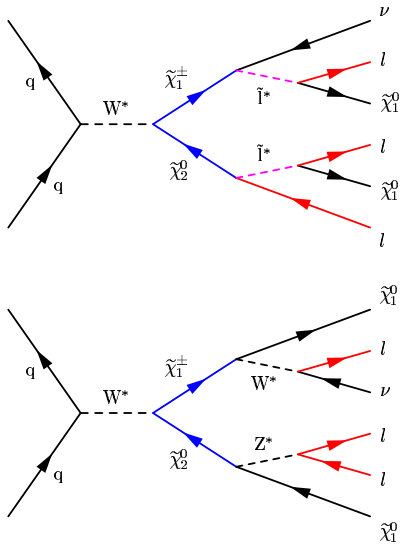
- SUSY particles are pair-produced
- SUSY particles decay to SM particles and the LSP (χ_1^0, undetected)
- SUSY partners of gauge fields: $\chi^{\pm}$, χ^0, $\tilde{g}$
- SUSY partners of matters fields: $\tilde{q}$, $\tilde{l}$

Run II results. All limits are given with 95% C.L.

Charginos and Neutralinos production

Final state:

- consider only decays to leptons and LSP: 3-l + MET
- small $\sigma \times \mathrm{BR}$ but small SM background
- eel, $\mu\mu$l, $\mu^{\pm}\mu^{\pm}$, eμl (l=e/μ/τ) **PRL 95, 151805 (2005)**



Dataset:

- $\mathcal{L}_{int}$ ~320 pb^{-1}
- single and di-lepton triggers

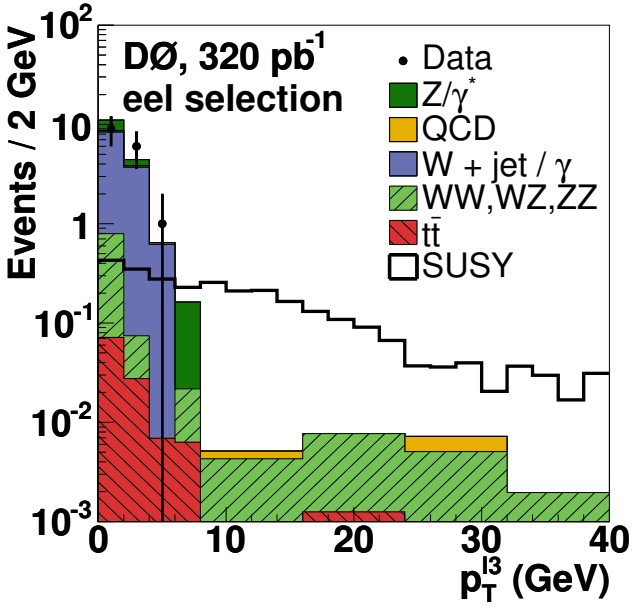
Background: multi-jet, di-boson, $Z \to ll$, $t\bar{t}$

Selection:

- 2 identified leptons (m_{ll}, $\Delta\phi_{ll}$), MET
- hadronic activity (jet veto, total scalar sum)
- additionnal isolated track (e/μ/τ_{had})
- N_{SM}=2.93±0.54(stat)±0.57(syst), N_{obs}=3

Main systematics:

- multi-jet background modelling



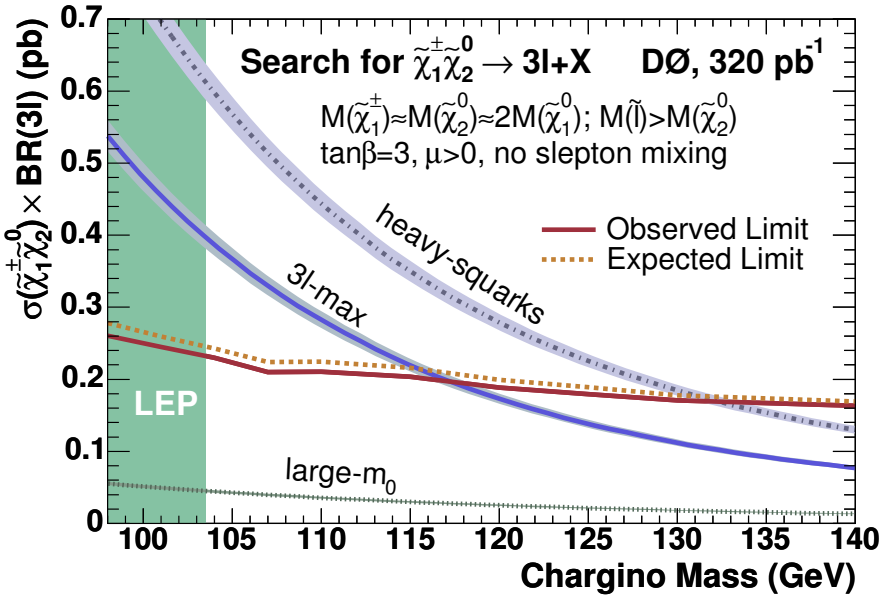
$\chi_1^\pm \chi_2^0$ (cont'd)

Results: no excess found

Assumptions:

- $m_{\chi_1^\pm} \sim m_{\chi_2^0} \sim 2m_{\chi_1^0}$ (mSUGRA)
- degenerate slepton masses

$\Rightarrow$ nearly model independent $\sigma \times \mathrm{BR}(3l)$



Scenarios:

- "large-m0": large sleptons masses, small BR to leptons $\Rightarrow$ no limit
- "3l-max": $m_{\tilde{l}} \gtrsim m_{\chi_2^0}$, leptonic 3-body decay enhanced $\Rightarrow$ 117 GeV
- "heavy-squarks": t-channel squarks exchange reduced, σ maximized $\Rightarrow$ 132 GeV

PRELIMINARY

Additionnal channels:

- high $\tan\beta$: $\tilde{\tau}$ can be light, enhancement of the 3-τ final state
- ≥ 1 tau decaying hadronically (eτ_{had}l, $\mu\tau_{\mathrm{had}}$l)
- combination of the 6 analyses in the works: expected limit increases by ~2 GeV.

$\chi_1^\pm\chi_2^0$ (cont'd)

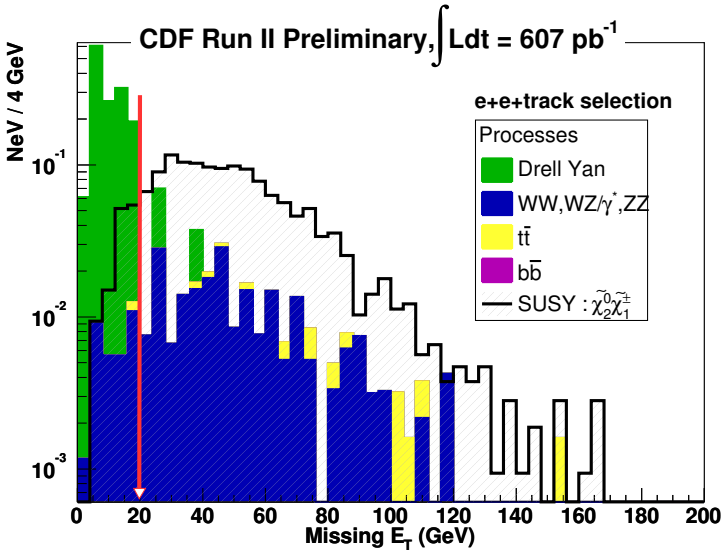
HOT OFF THE PRESS

$\sim$ 600 pb^{-1}

ee+track channel:

- large dataset: $\mathcal{L}_{int}\sim$607 pb^{-1}
- several control regions
- N_{obs}= 1, $N_{exp}(B)$= 0.49$\pm$0.14
- $N_{exp}(S)$= 1.21$\pm$0.09

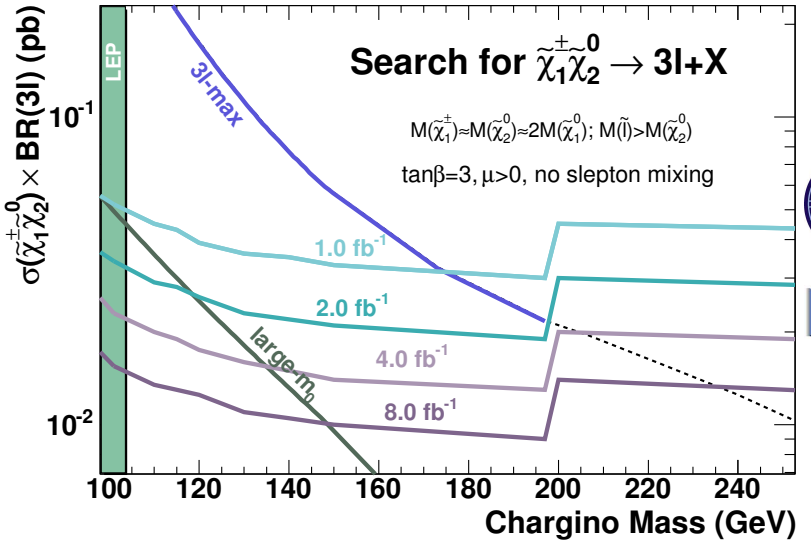
  $m_{\chi_1^\pm}$=119 GeV, $m_{\chi_1^0}$=68 GeV



$\mu\mu$+l (e or μ) channel:

- p_T(l) down to 5 GeV $\Rightarrow$ reach increased
- low p_T dimuon triggers ($\mathcal{L}_{int}\sim$312 pb^{-1})
- several control regions
- N_{obs}= 0, $N_{exp}(B)$= 0.13$\pm$0.03
- $N_{exp}(S)$= 0.52$\pm$0.09

  $m_{\chi_1^\pm}$=103 GeV, $m_{\chi_1^0}$=58 GeV



CDF+DØ $\chi_1^\pm\chi_2^0$ sensitivity projections

Squarks and Gluinos Production

PRELIMINARY

Motivation:

- largest σ (strong interaction)
- large SM background: multi-jet, W+jets, Z+jets

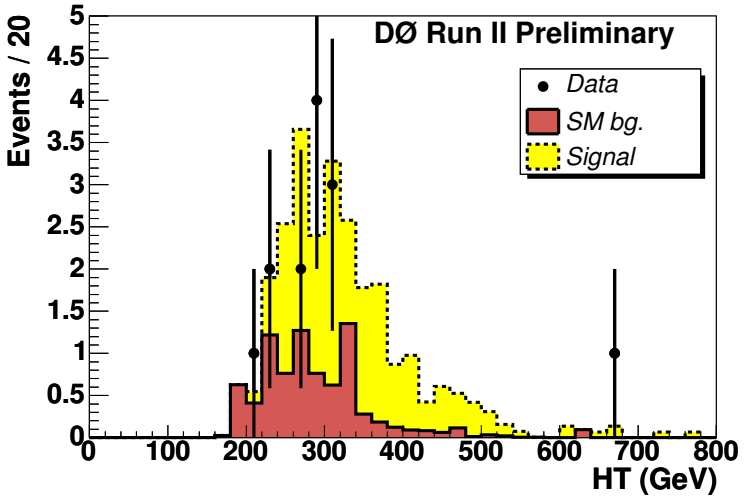
Analysis:

- [2j]: low $\mathrm{m_0}$ ($m_{\tilde{g}} > m_{\tilde{q}}$), $\tilde{\mathrm{q}}\tilde{\mathrm{q}}^\star \to \mathrm{q}\tilde{\chi}_1^0 + \bar{\mathrm{q}}\tilde{\chi}_1^0$ dominates — acoplanar di-jets events
- [4j]: large $\mathrm{m_0}$ ($m_{\tilde{q}} > m_{\tilde{g}}$), $\tilde{\mathrm{g}}\tilde{\mathrm{g}} \to \mathrm{q}\bar{\mathrm{q}}\tilde{\chi}_1^0 + \bar{\mathrm{q}}\mathrm{q}\tilde{\chi}_1^0$ dominates — $\geq$4-jets events
- [3j]: intermediate $\mathrm{m_0}$, all contributions ($\tilde{\mathrm{q}}\tilde{\mathrm{q}}^\star$, $\tilde{\mathrm{g}}\tilde{\mathrm{g}}$, $\tilde{\mathrm{q}}\tilde{\mathrm{q}}$, $\tilde{\mathrm{q}}\tilde{\mathrm{g}}$) — $\geq$3-jets events

Dataset: jets + MET trigger ($\mathcal{L}_{int}$ ~310 pb^{-1})

Selection:

- kinematic and quality cuts ($\mathrm{p_T}$, MET, HT, MET isolation and acoplanarity), lepton veto
- Major backgrounds:
  [2j] $\mathrm{Z} \to \nu\nu + 2\mathrm{j}$
  [4j] $\mathrm{t\bar{t}}$, QCD
  [3j] $\mathrm{W} \to \tau\nu + 2\mathrm{j}$, $\mathrm{t\bar{t}}$



$(\mathrm{m_0}, \mathrm{m_{1/2}})$=(500,80) GeV/C^2 [4j]

(cont'd)

PRELIMINARY

Results:

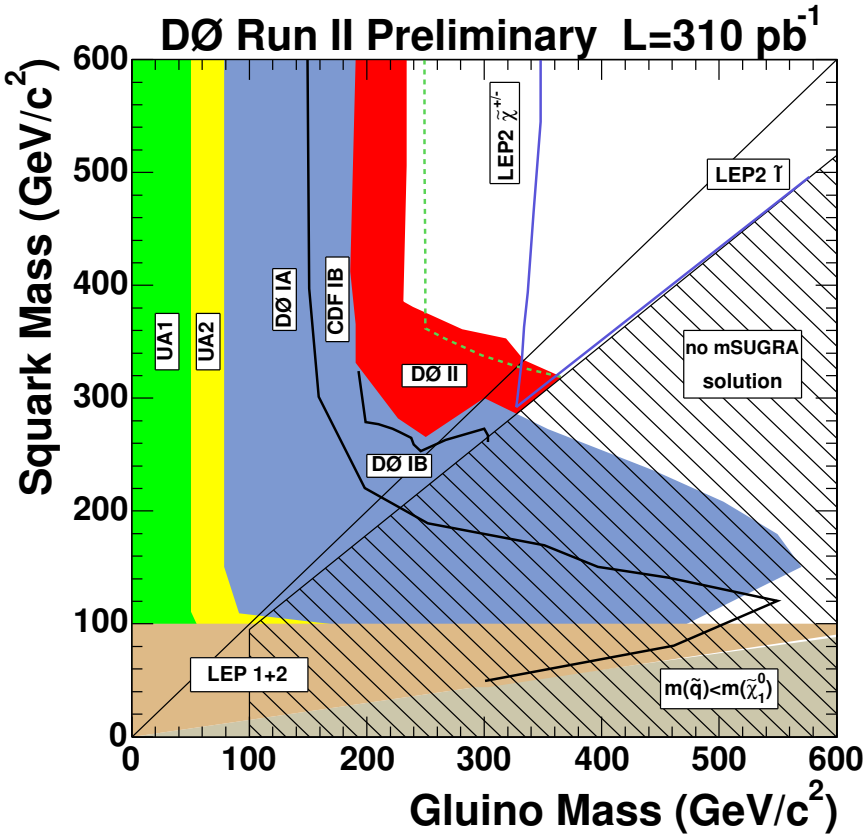
- no evidence for signal
- limits in the mSUGRA model ($\tan\beta$=3, A_0=0, μ <0) for 5 squark flavours

[2j] m_0= 25 GeV/C^2: $m(\tilde{q})$ >318 GeV/C^2

[4j] m_0=500 GeV/C^2: $m(\tilde{g})$ >233 GeV/C^2

[3j] $m(\tilde{q})$=$m(\tilde{g})$: $m(\tilde{q}), m(\tilde{g})$ >333 GeV/C^2

Model already severely constrained by LEP, Tevatron now exploring regions beyond the LEP reach



Stop Production

HOT OFF THE PRESS

Motivation:

- $\tilde{t}$ can be the lightest squark
- hierarchy $m(\chi^+) > m(\tilde{t}) > m(\tilde{\nu})$
- $\tilde{t}\tilde{t}^* \rightarrow (be\nu\chi^0)(b\mu\nu\chi^0)$

Dataset:

- $\mathcal{L}_{int}$= 350 pb^{-1}

Main background:

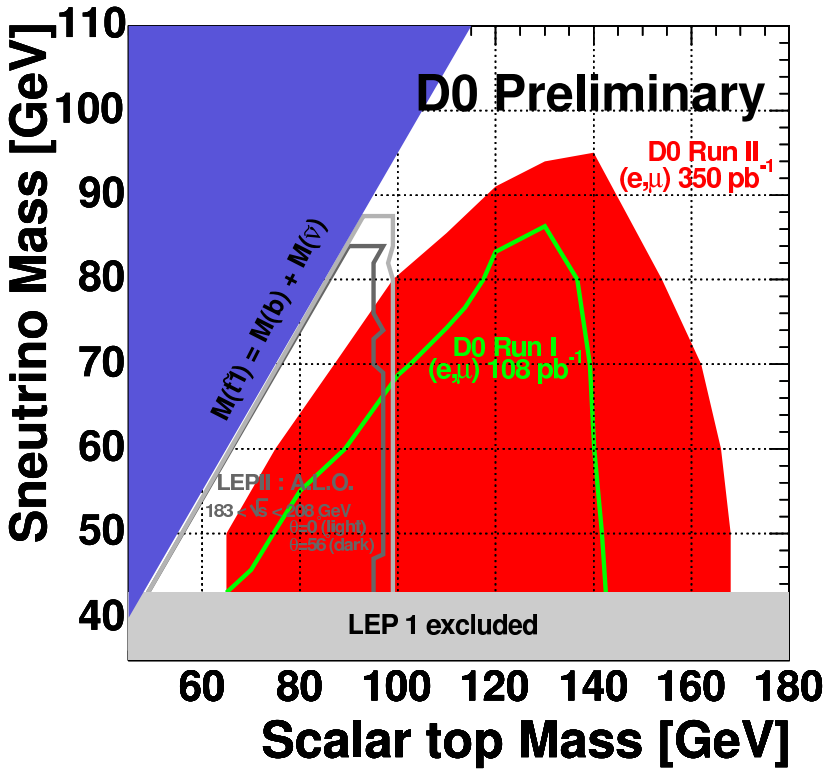
- instrumental, di-bosons, $t\bar{t}$, $Z \rightarrow \tau\tau$

Selection:

- 1 isolated muon, 1 isolated electron, MET, isolation

Results:

- limits optimised (number of non-isolated tracks and scalar p_T sum)



Improvement:

- Combination with the DØ preliminary result in the $\mu\mu$ channel in the works

Sbottom Production

PRELIMINARY

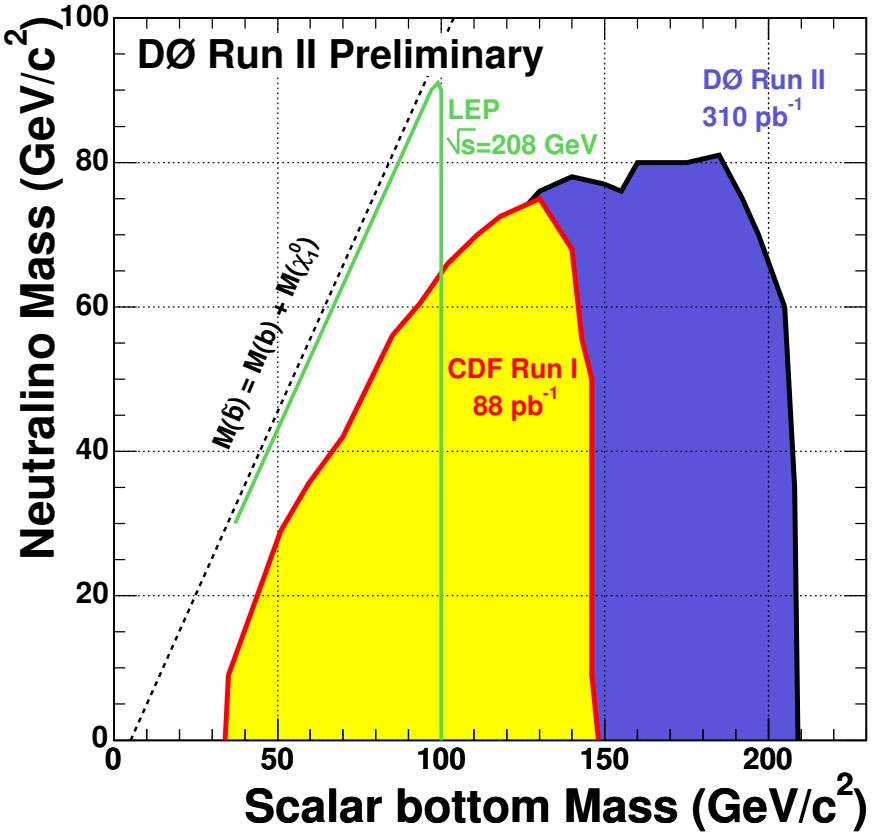
Motivation:
- $\tilde{b}$ is the NLSP: $\tilde{b} \rightarrow b\chi_1^0$
- signature: b-jets and MET

Dataset:
- jets+MET triggers, $\mathcal{L}_{int}$= 310 pb^{-1}

Background:
- $\mathrm{Z}(\nu\nu) + \mathrm{jj}$, $\mathrm{W}(\tau\nu) + \mathrm{jets}$, $\mathrm{Z}(\nu\nu) + \mathrm{b\bar{b}}$

Selection:
- kinematical and quality cuts (p_T, MET, isolation and acoplanarity), lepton veto
- $\geq$1 b-tagged jet required

Main systematics:
- jet energy scale ($\sim$15%), σ (15%)



Results: optimisation according to MET and $\mathrm{p_T(jet)}$

RPC GMSB $\gamma\gamma$+MET

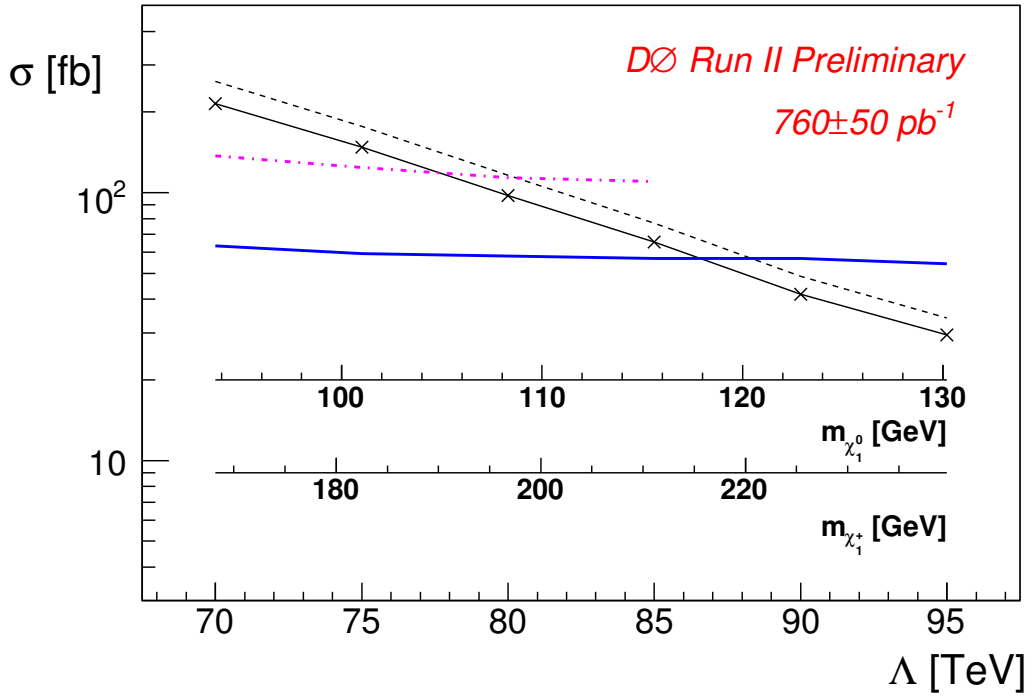
HOT OFF THE PRESS
$\sim$ 760 pb^{-1}

Motivation:
- gravitino LSP ($\sim$ massless), χ_2^0 NLSP
- $\chi_2^0 \rightarrow \tilde{G} + \gamma$ (prompt decay assumed)

Dataset:
- single EM triggers, $\mathcal{L}_{int}$=760 pb^{-1}

Selection:
- 2 central photons (p_T >25 GeV)
- confirm primary vertex with photon pointing
- MET (>45 GeV), MET isolation

Results:
- no excess observed
- interpretation within one Snowmass Slope benchmark: one parameter Λ (SUSY breaking scale)



$m(\chi_1^{\pm})$>220 GeV/c^2, $m(\chi_1^0)$>120 GeV/c^2

Summary and Perspectives

Run IIa

CDF and DØ investigate several models beyond the SM.
Most of the current results are based on a fraction
of the 1.2 fb^{-1} recorded dataset.
No discoveries yet.

Run IIb

The Tevatron entered a shutdown period 2 weeks ago.
Detector upgrades are ongoing.
The coming dataset will increase the luminosity by a factor of 3-6.

A bump may be around the corner...