Search for SUSY Trileptons at D0

Maxim Titov
CEA SACLAY, DAPNIA, France
(ON BEHALF OF THE DØ COLLABORATION)

- Introduction: MSSM and mSUGRA
- Tevatron Collider and D0 Experiment
- Signal Selection / Background Composition / Limits
- Experimental / WMAP Cosmological Constraints
- Summary and Outlook

A Symposium on Collider, Direct and Indirect Searches
"The Hunt for Dark Matter", Fermilab, May 10-12, 2007

SUperSYmmetry (SUSY)

- **Supersymmetric extensions of the SM provide a consistent framework for gauge unification and stabilization of EWK scale**
- **Each SM particle gets a SUSY partner (spin differ by ΔS = ½)**
- **Superpartners are heavy → SUSY must be broken**

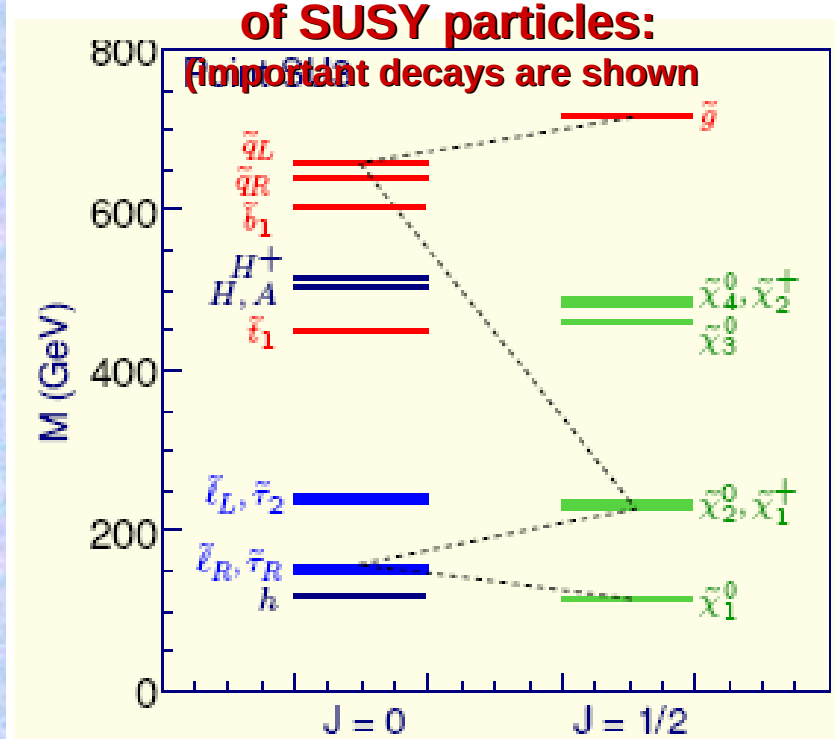
- **Several SUSY breaking scenario under consideration:**

mSUGRA, Gauge-Mediated SB, Anomaly-Mediated SB → determines SUSY structure

SM Particles	SUSY Particles			
quarks: q	q	squarks: $\tilde{q}$		
leptons: l	l	sleptons: $\tilde{l}$		
gluons: g	g	gluino: $\tilde{g}$		
charged weak boson: $W^{\pm}$	$W^{\pm}$	Wino: $\tilde{W}^{\pm}$	$\tilde{\chi}^{\pm}_{1,2}$	chargino
Higgs: H^0	$H^{\pm}$	charged higgsino: $\tilde{H}^{\pm}$		
	h^0, A^0, H^0	neutral higgsino: $\tilde{h}^0, \tilde{A}^0, \tilde{H}^0$		higgsino
neutral weak boson: Z^0	Z^0	Zino: $\tilde{Z}^0$	$\tilde{\chi}^0_{1,2,3,4}$	neutralino
photon: γ	γ	photino: $\tilde{\gamma}$		

Typical mass spectrum of SUSY particles:

(Important decays are shown



Strong limits on SUSY searches from LEP:

$M(\chi^{\pm}) > 103.5$ GeV; $M_{slepton} > 95$ GeV

Minimal SuperGravity (mSUGRA)

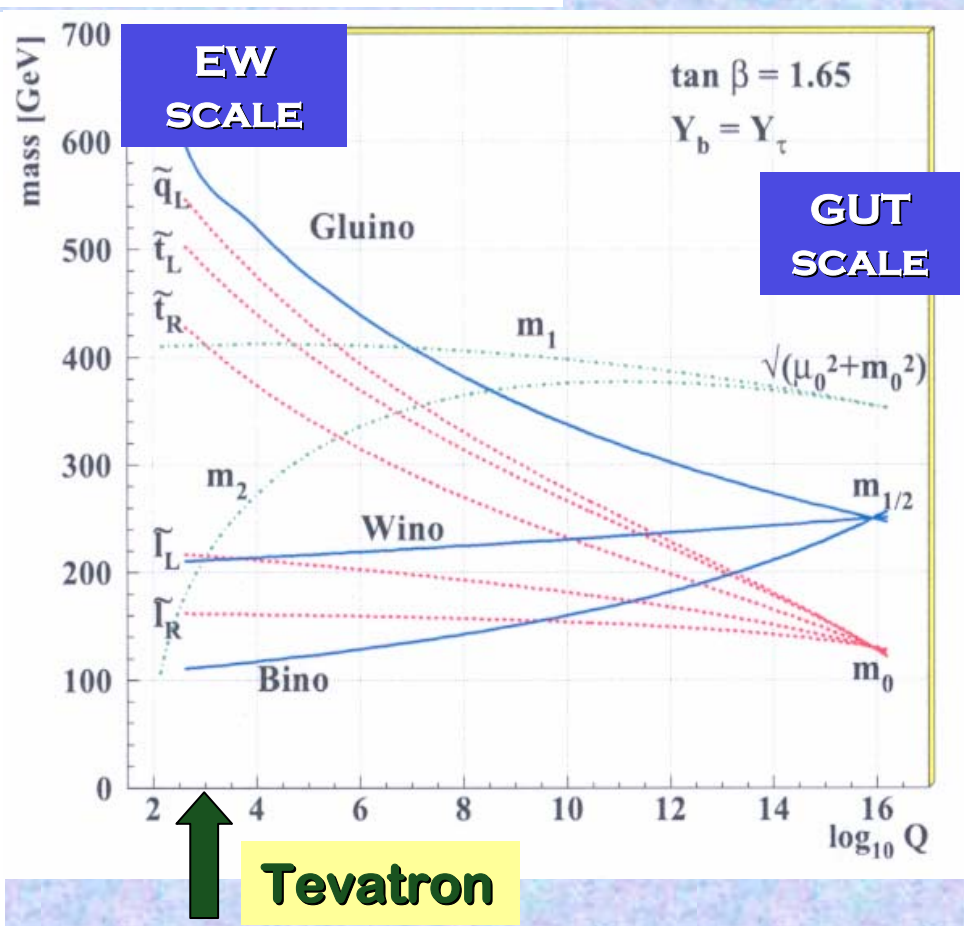
THE SYMMETRY BREAKING TAKES PLACE IN A "HIDDEN SECTOR" AND IS TRANSMITTED TO THE "VISIBLE SECTOR" BY GRAVITATION

Only FIVE parameters:

- **m_0: common scalar (Higgs, sleptons, squarks) mass at the GUT scale**
- **$m_{1/2}$: common gaugino (bino, wino, gluino) mass at the GUT scale**
- **A_0: common trilinear scalar couplings at the GUT scale (sfermion mixing)**
- **tan β: ratio of Higgs vacuum expectation values**

Sign(μ): higgsino mass parameter

LIGHTEST SUPERSYMMETRIC PARTICLE ($\tilde{\chi}_0$) → STABLE, if R_P IS CONSERVED



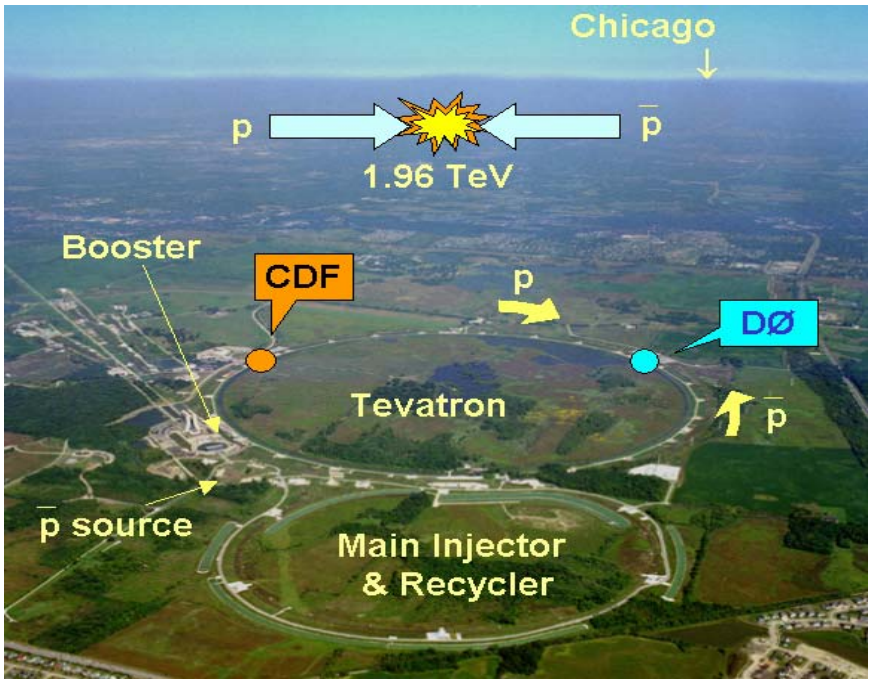
Assume mSUGRA mass relation:

$$m(\chi_1^{\pm}) \sim m(\chi_2^0) \sim 0.8\, m_{1/2}$$
$$m(\chi_1^0) \sim 0.4\, m_{1/2}$$

Tevatron & D0 Experiment

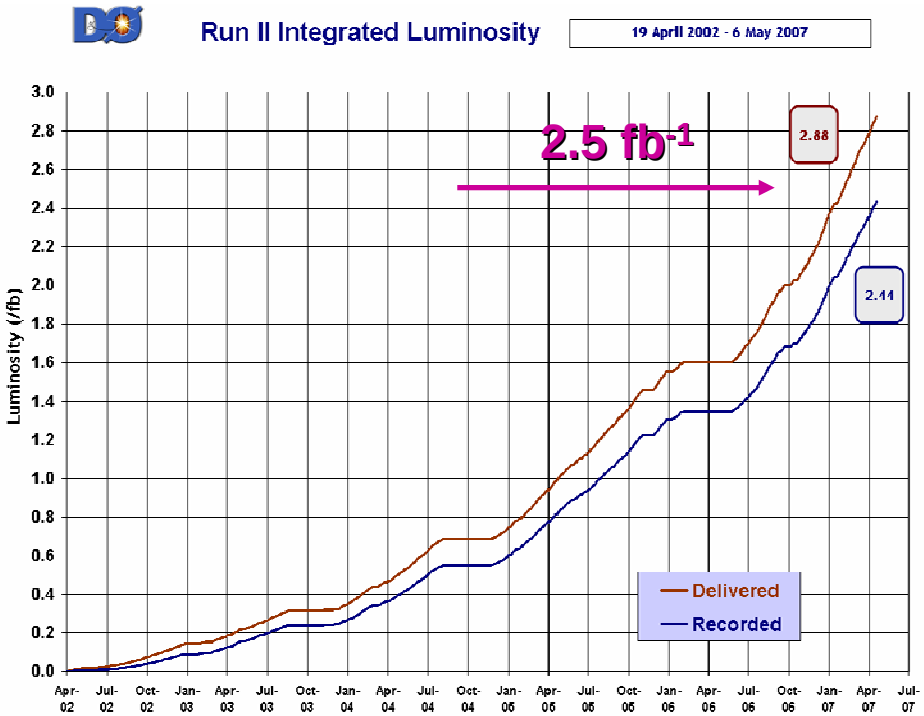
Run II started March 2001:

- **Higher energy (1.8 TeV -> 1.96 TeV)**
- **Higher antiproton intensity (6*6 bunches -> 36*36 bunches)**



Results presented in this talk are based on integrated luminosity of 1 fb^{-1}

More than double of this dataset is already on the tape



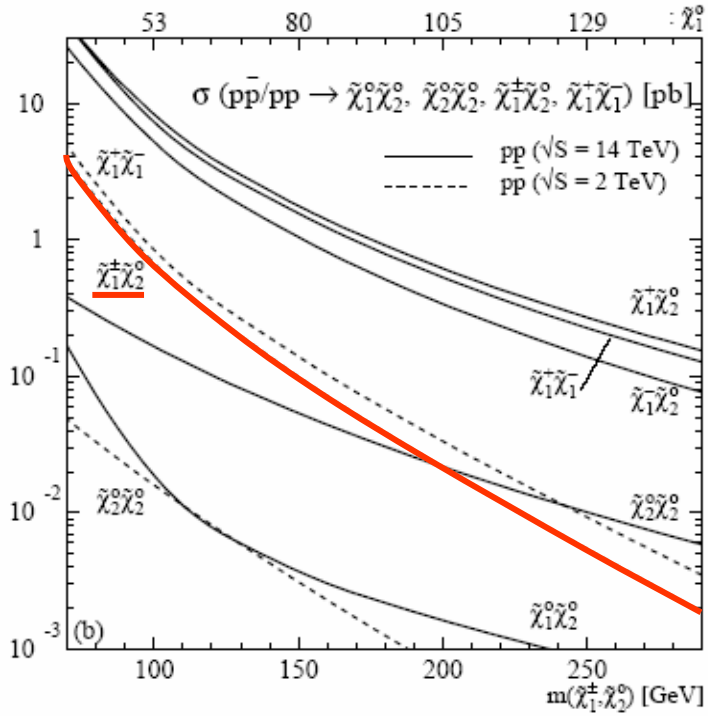
DØ General Purpose Detector:

- **Excellent particle ID, coverage, tracking, powerful trigger system**
- **Data taking efficiency ~ 85-90 %**

Electron ID acceptance	$\|\eta\|<3.0$
Muon ID acceptance & trigger	$\|\eta\|<2.0$
Precision tracking (Si)	$\|\eta\|<3.0$
Jet ID	$\|\eta\|<4.2$

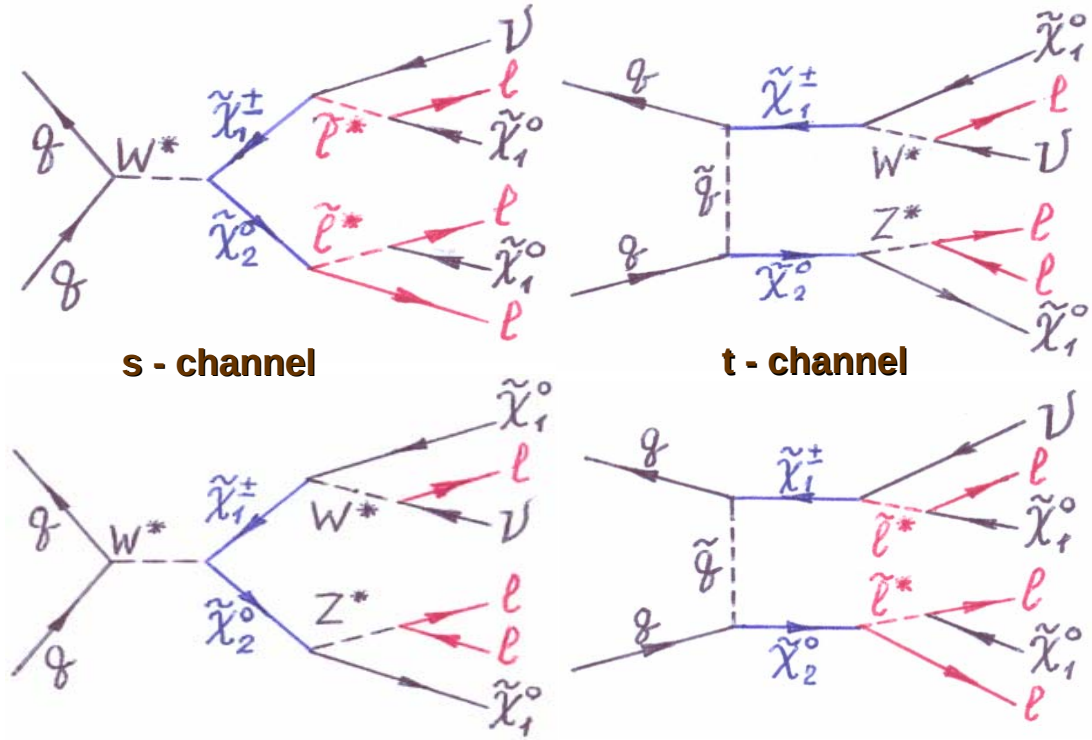
Chargino / Neutralino Production and Decays

$\sigma(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0})$ DEPEND ON GAUGINO-HIGGSINO MIXING, SQUARK MASSES



SUSY GOLDEN MODE: $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0} \rightarrow 3\,l + 2\tilde{\chi}_0 + X$

Destructive interference between s- and t-channels:



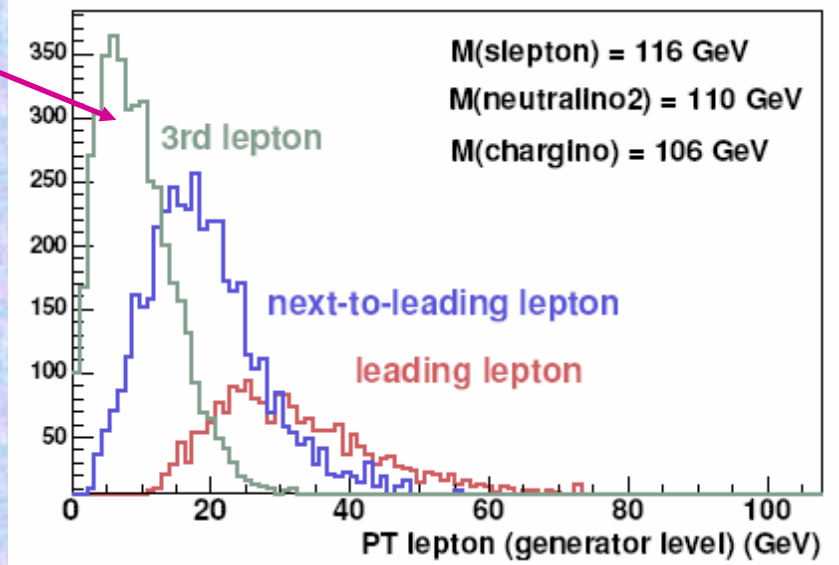
Clean signature: 3 charged leptons + E_T^{miss} (low SM bkg)

- Electroweak production → small event rates (σ x Br ($3l$) ~ 0.1- 0.5 pb)
- Large cross section → low gaugino masses ($m_{1/2}$), large squark masses
- Large leptonic branching fraction → low slepton masses → low m_0
- Large e(μ) branching fraction → low degree of stau mixing → low tan β

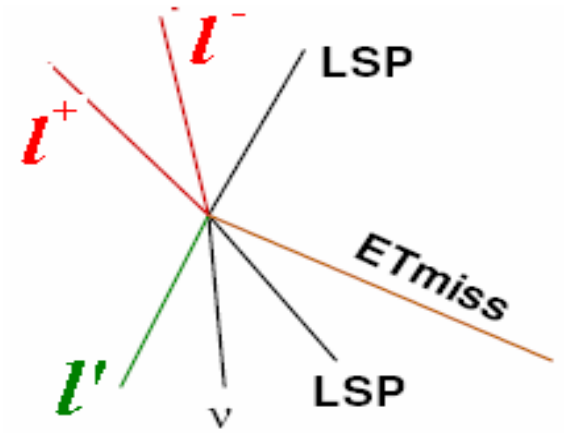
Search for Charginos and Neutralinos --> 3 l + E_T^{miss}

Experimental challenge: low-p_T leptons

- Need multilepton triggers w/ low p_T-thresholds
- Need efficient lepton ID @ low p_T



ANALYSIS STRATEGY / SIGNATURE:



- **3 leptons + E_T^{miss}**

-- 2 leading P_T leptons (tight ID)

-- Isolated low p_T 3rd track (no lepton ID)

(3rd track = e, μ, τ, including hadronic τ_{had})

- **2 Like–sign leptons + E_T^{miss}**

-- No 3rd track requirement

(important when 3rd lepton P_T is very soft)

Major SM Backgrounds:

- WZ/ZZ → 3 *l* (irreducible)

Fake Leptons:

(γ-conversion or fake leptons: π^0)

- W + γ/jet → 1 *l* + 2 fakes
- Z/γ* + γ/jet → 2 *l* + fake
- WW + γ/jet → 2 *l* + fake
- ttbar → 2 *l* + fake
- QCD multijet → no isolated leptons (determined from data)

Search for Charginos and Neutralinos --> 3 l + E_T^{miss}

6 D0 ANALYSIS: 1 → LS ($\mu^\pm\mu^\pm$), 3→ *ll* (e,μ) + track; 2 →(e/μ + τ_{had}+ track)

2 leading leptons:

$P_T^{l1} > 12$ GeV; $P_T^{l2} > 8$ GeV

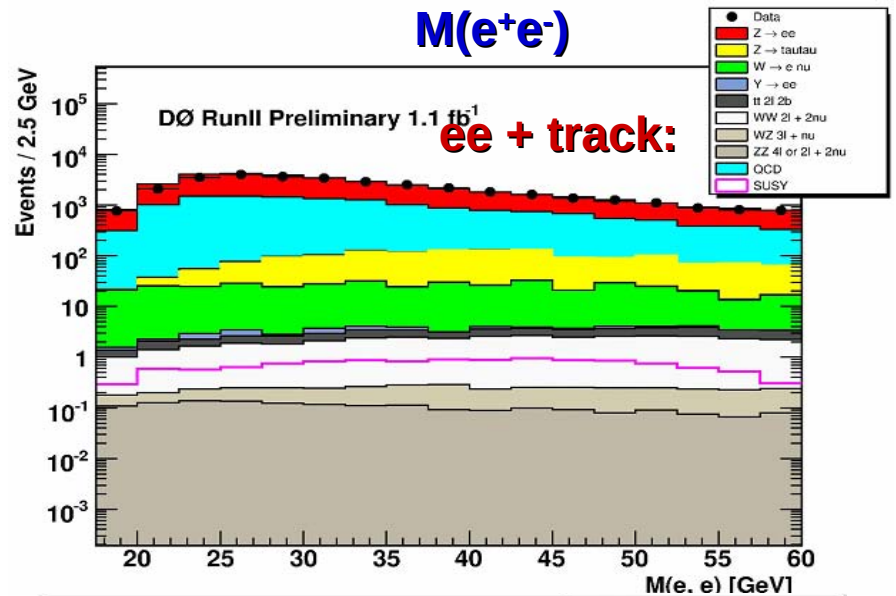
Anti Z/γ*, Y, W/γ* invariant mass cuts:

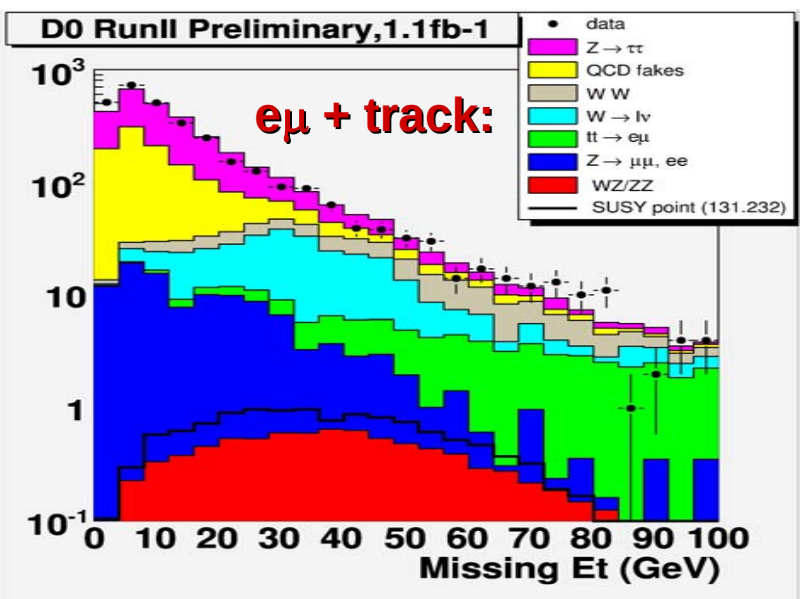
Anti - ttbar Cut: $H_T = \Sigma P_T^{jet} < 50$ GeV

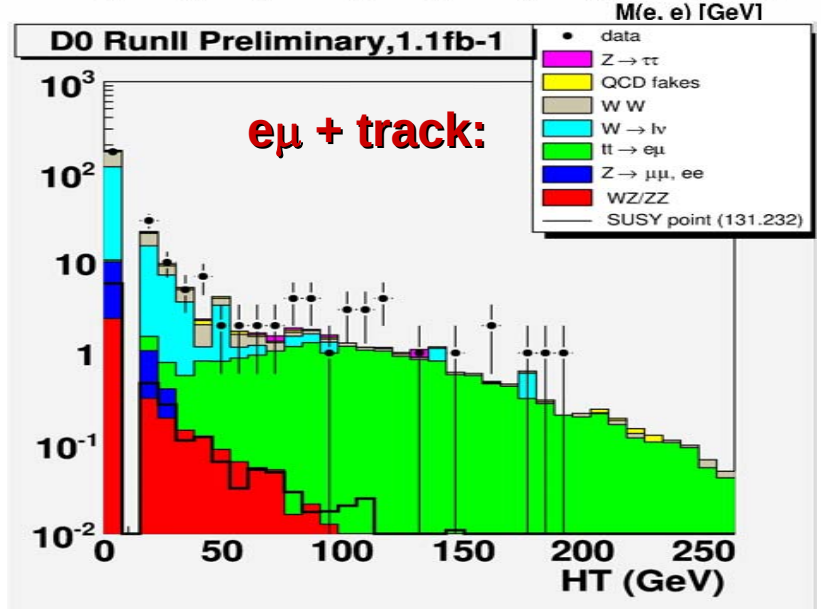
E_T^{miss}-based Cuts:

$E_T^{miss} > 22$ GeV; $E_T^{\ significance} > 8$

M_T (e, E_T^{miss}) > 20 GeV

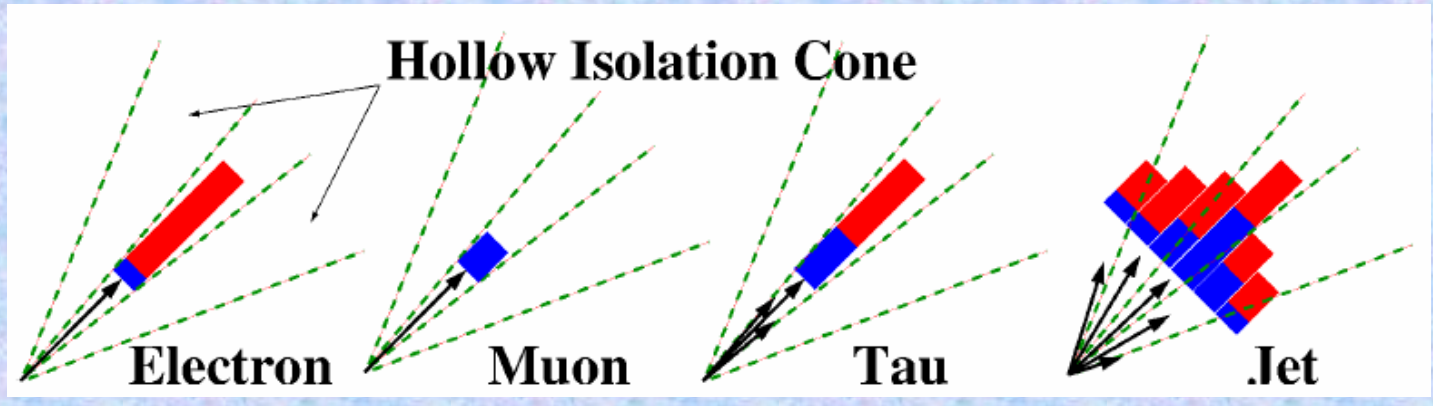


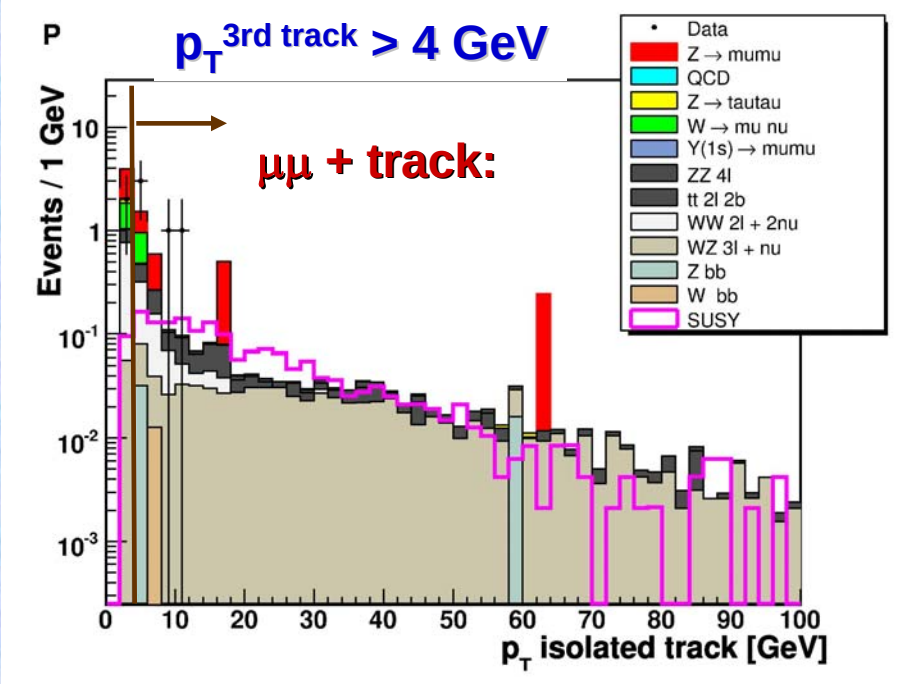


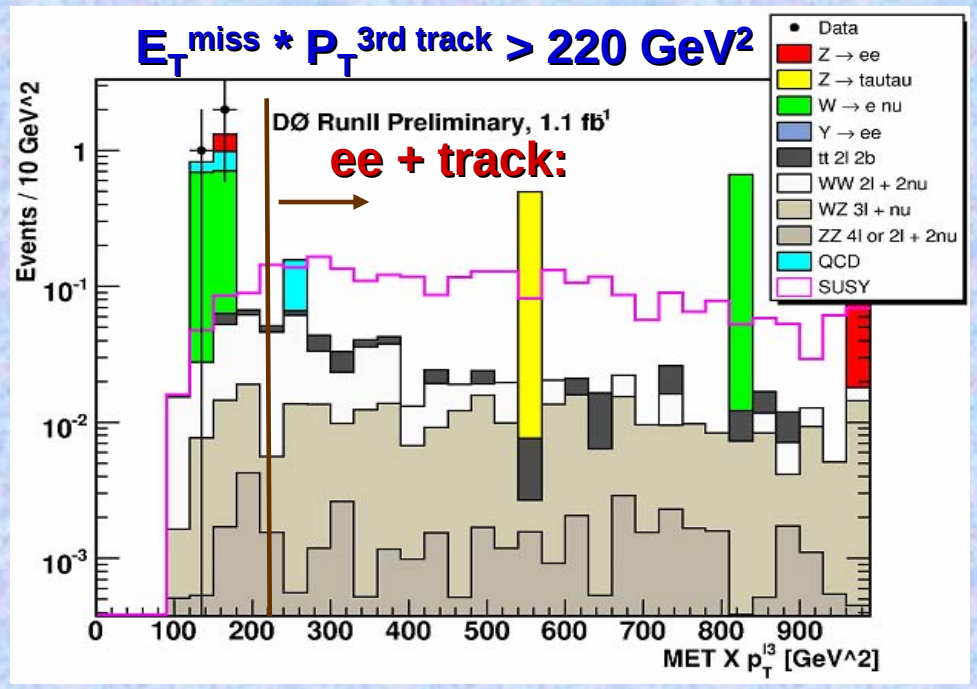


Search for Charginos and Neutralinos: 3rd lepton

- Increase sensitivity by requiring 3rd isolated track instead of lepton ID
- Isolation in tracker and calorimeter are required to reject background from jets
- Isolation criteria are designed to be efficient for e, μ and hadronic τ_{had} decays







Search for Charginos and Neutralinos: $\mu^{\pm}\mu^{\pm}$

Increase acceptance by requiring 2 out of 3 leptons, while reducing SM bkg

Preselection (2 isolated LS-muons):

$P_T^{\mu 1} > 13$ GeV; $P_T^{\mu 2} > 8$ GeV

Anti $Z/\gamma^* \rightarrow \mu\mu$ & Anti-QCD Cuts:

25 GeV < $M_{\mu^+\mu^-}$ < 65 GeV; $\Delta\varphi(\mu,\mu) < 2.9$

E_T^{miss}-based Cuts:

$E_T^{miss} > 10$ GeV; $E_T^{\ significance} > 12$

15 GeV < $M_T(E_T^{miss}, p_T^{\mu 2})$ < 65 GeV

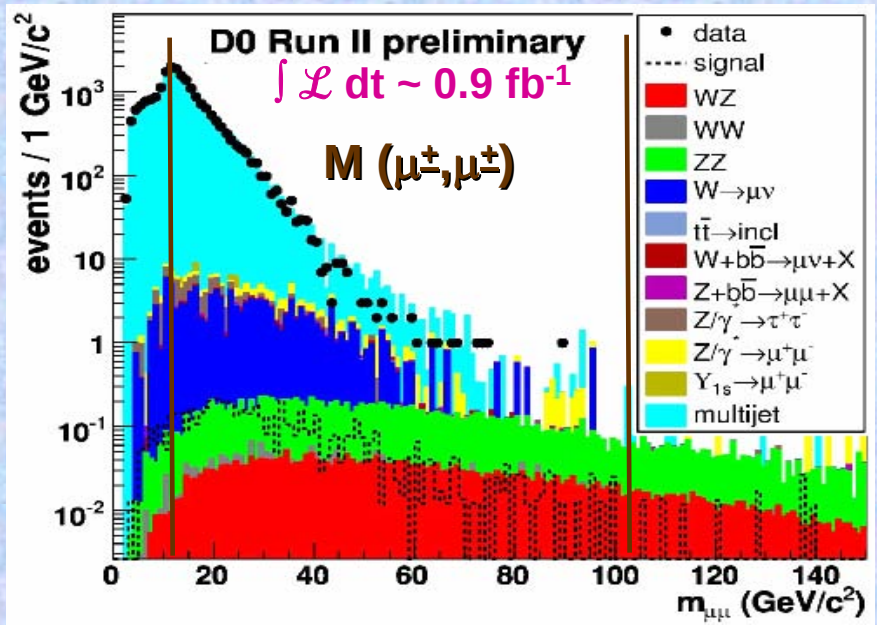
LS Invariant Mass Cut:

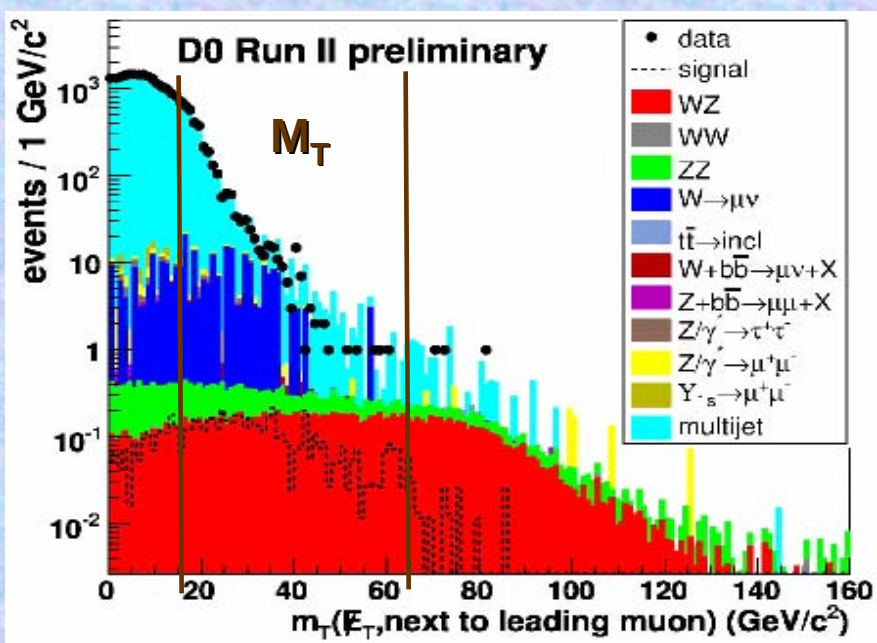
12 GeV < $M(\mu^{\pm},\mu^{\pm})$ < 110 GeV

Product of E_T^{miss} and 2nd muon P_T:

$E_T^{miss} * P_T^{2nd\ muon} > 160\ GeV^2$

LS dilepton channel is also sensitive to squark / gluino production





SUSY Interpretation: Trilepton Analysis

- mSUGRA inspired model:
  $m(\chi_1^{\pm}) \sim m(\chi_2^0) \sim 2\, m(\chi_1^0)$
- R-parity is conserved
- Degenerate slepton masses
- No slepton mixing
- Low $\tan\beta = 3$

$\sigma \times Br(3l)$ is mainly a function of $m(\tilde{l})$ and $m(\tilde{\chi}_2^0)$ → with small dependence on other SUSY parameters

D0 ANALYSIS	LUMI (PB^{-1})	BACKGROUND EXPECTED	DATA
e e + track	1100	0.76 ± 0.67	0
LS $\mu^{\pm}\ \mu^{\pm}$	900	1.1 ± 0.4	1
e μ + track	1100	0.94 ± 0.4	0
$\mu\ \mu$ + track	1100	0.32 ± 1.34	2
e τ_{had} + track	300	0.58 ± 0.14	0
$\mu\ \tau_{had}$ + track	300	0.36 ± 0.13	1

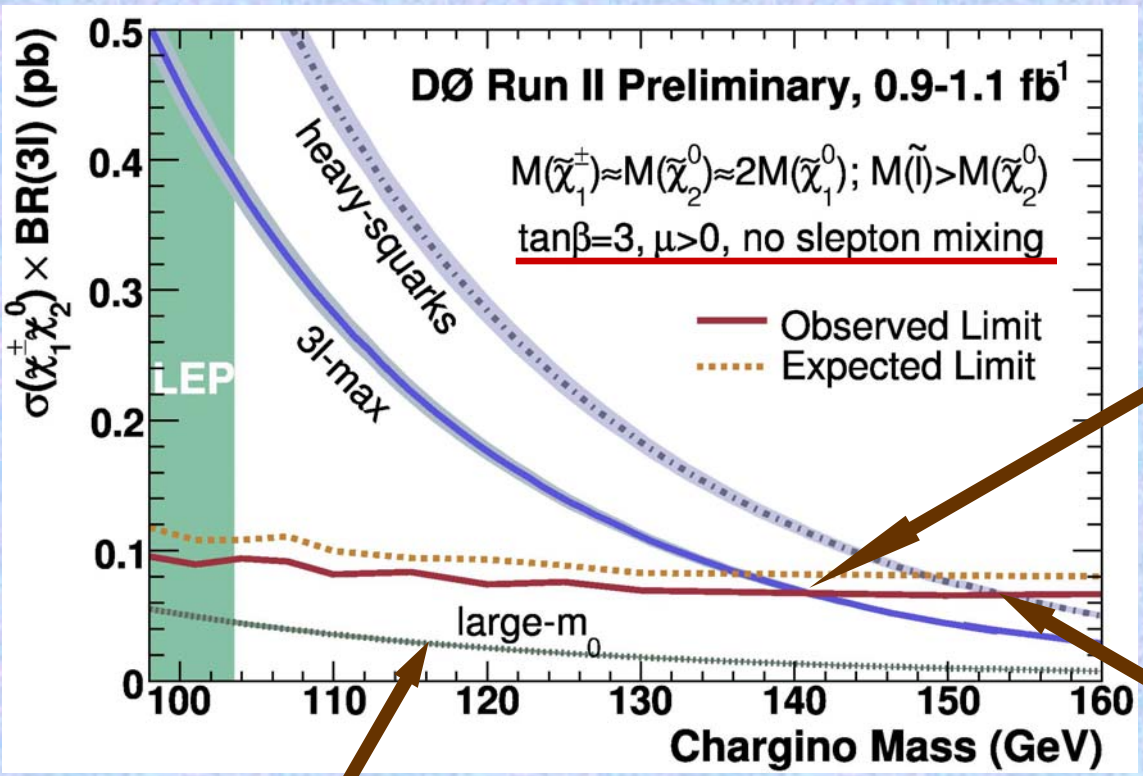
Large $\tan\beta$ scenarios are challenging:

$\tilde{\tau}$ becomes the lightest $\tilde{l}$ → dominant BR → 3τ
Lighter $\tilde{\tau}$ mass → lower $p_T(\tau_{had})$

Need efficient τ_{had} reconstruction @low pT
Need efficient trigger for $e/\mu + \tau_{had}$ final states

SUSY Limits for Charginos and Neutralinos (I)

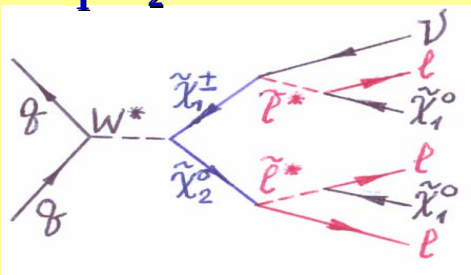
Combination: ee+track, eμ+track, μμ+track (1.1 fb^{-1}), $\mu^{\pm}\mu^{+}$ (0.9 fb^{-1})



"3l – MAX" (m_0 ~ 80 - 120 GeV):

$M(\tilde{l}) = M(\tilde{\chi}_2^0) + \varepsilon\ (>0)$

Br $(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \rightarrow 3\,l$ ~ 20 - 30 %



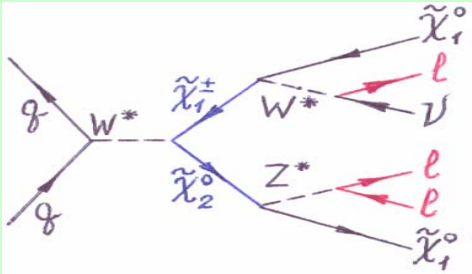
$M(\tilde{\chi}_1^{\pm}) > 141$ GeV;

$\sigma * Br < 0.07$ pb

"LARGE - m_0" SCENARIO (m_0 ~ TeV):

$M(\tilde{l},\tilde{q}) >> M(\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0)$

(small Br $(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \rightarrow 3\,l$, W*, Z* decays dominate)



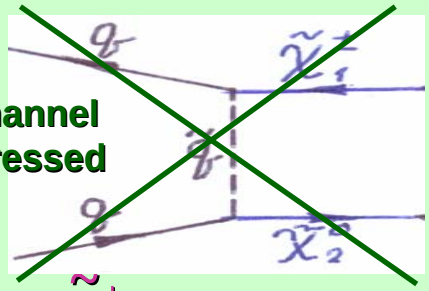
No Sensitivity

"HEAVY SQUARKS":

$M(\tilde{q}) >> M(\tilde{l})$

(no scalar mass unification)

t – channel suppressed



$M(\tilde{\chi}_1^{\pm}) > 155$ GeV

$\sigma * Br < 0.06$ pb

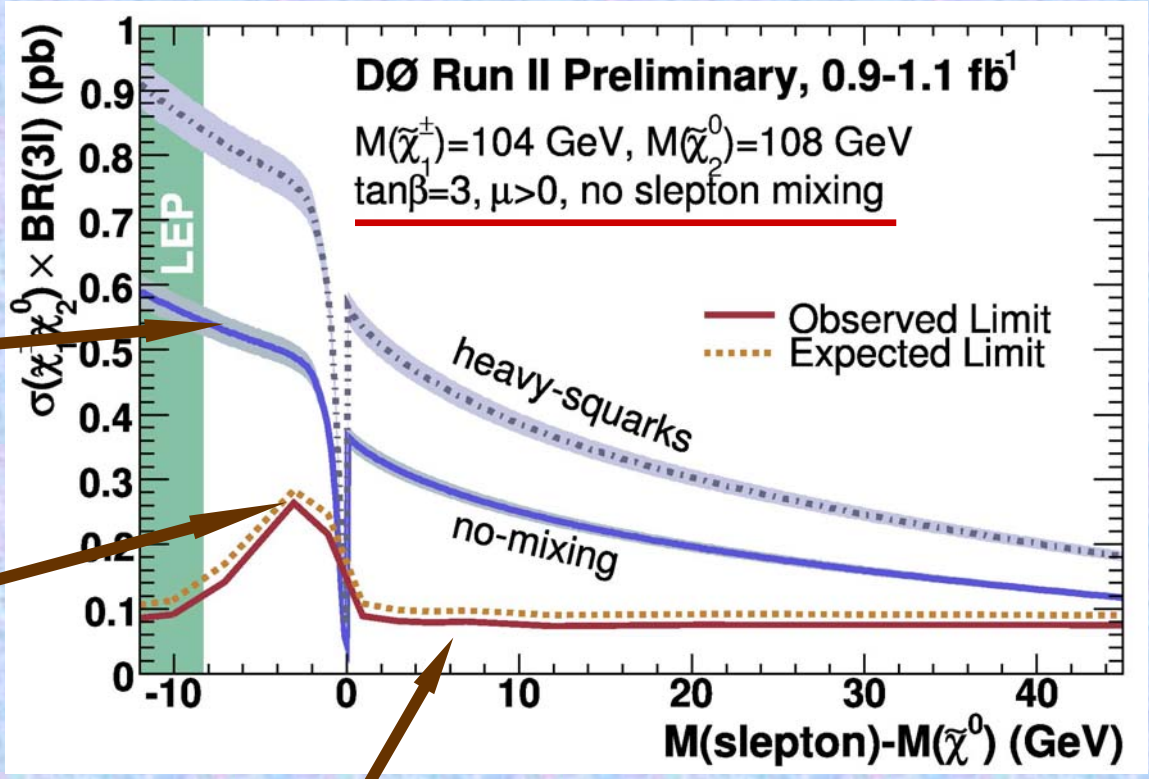
SUSY Limits for Charginos and Neutralinos (II)

Combination: ee+track, eμ+track, μμ+track (1.1 fb^{-1}), $\mu^{\pm}\mu^{+}$ (0.9 fb^{-1})

$\Delta M = M(\tilde{l} - \tilde{\chi}_2^0) < 0$: 2-body decay into real $\tilde{l}$

$\Delta M < -6$ GeV: $Br(\chi_2^0\chi_1^{\pm} \rightarrow e,\mu)$ dominant

-6 GeV $< \Delta M < 0$ GeV: Soft 3rd lepton P_T → limit set by LS $\mu^{\pm}\mu^{\pm}$



$\Delta M = M(\tilde{l} - \tilde{\chi}_2^0) > 0$: 3-body decay via virtual $\tilde{l}$ or W/Z

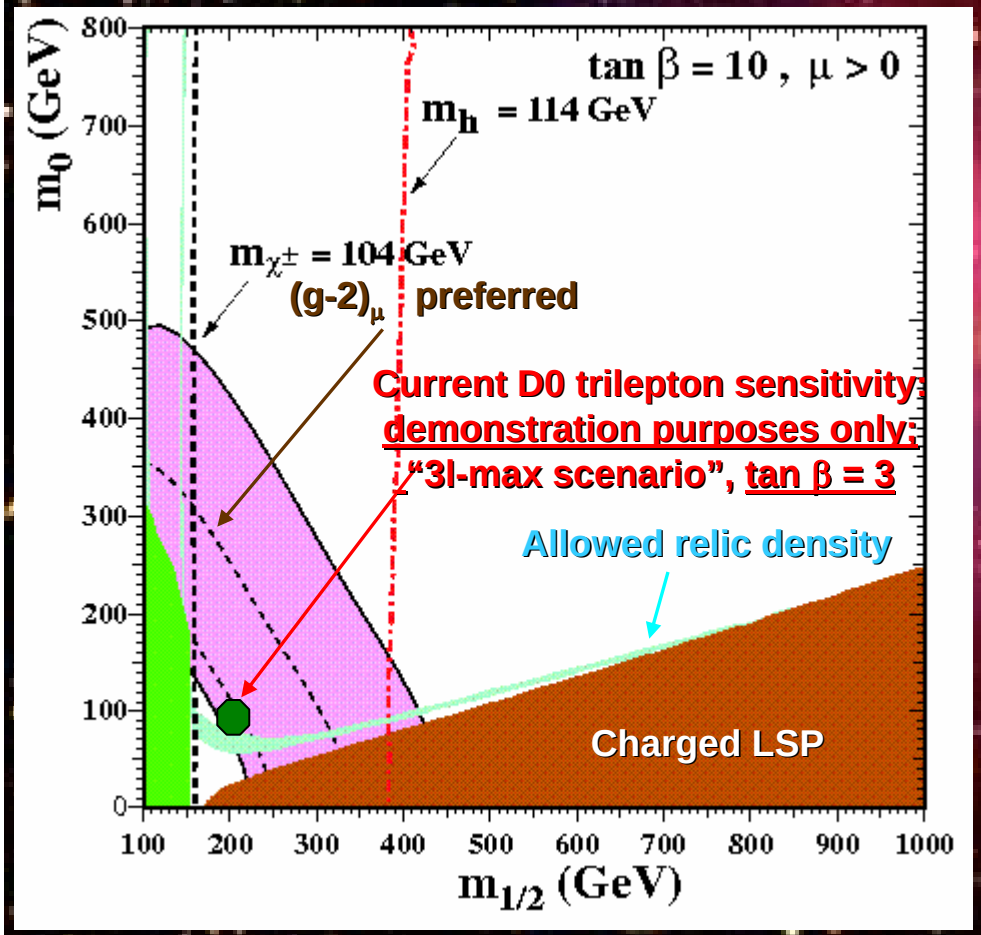
$\Delta M \geq 0$: $\tilde{l}$ - exchange dominates: Large $Br(\chi_2^0\chi_1^{\pm} \rightarrow e,\mu,\tau)$ → "3*l*-max" scenario

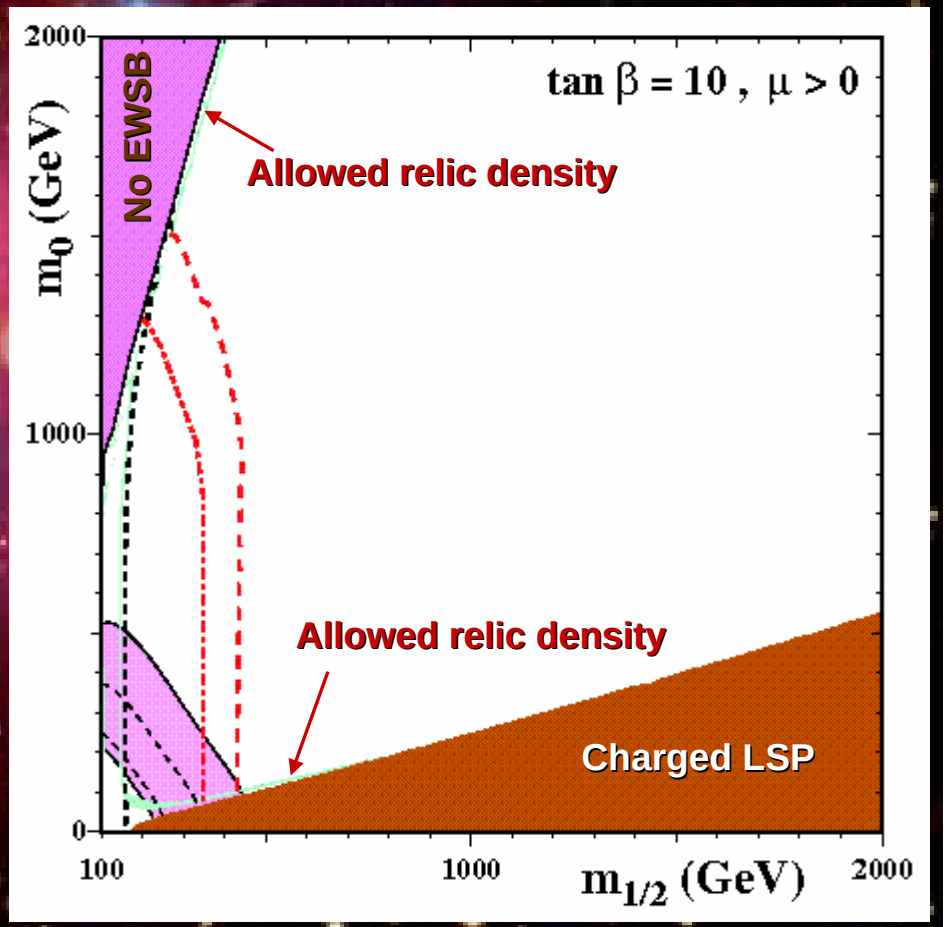
$\Delta M >> 0$: W/Z*- exchange dominates: Small $Br(\chi_2^0\chi_1^{\pm} \rightarrow e,\mu,\tau)$: "large-m_0" scenario

Experimental/Cosmological Constraints (low tan β)

Cosmological constraints: Neutralino LSP constitutes the whole dark matter
WMAP allowed range: $0.0855 < \Omega h^2 < 0.1189$

Experimental observations: $m_t = 171.4$ GeV; $m_h > 114.4$ GeV
$10.7 * 10^{-10} < \Delta a_\mu < 44.3 * 10^{-10}$; Br ($b \rightarrow s\gamma$) = $3.55 * 10^{-4}$





J. Ellis, K. Olive, P. Sandick, arXiv:0704.3446 (2007); K. Olive, private communications

Summary and Outlook

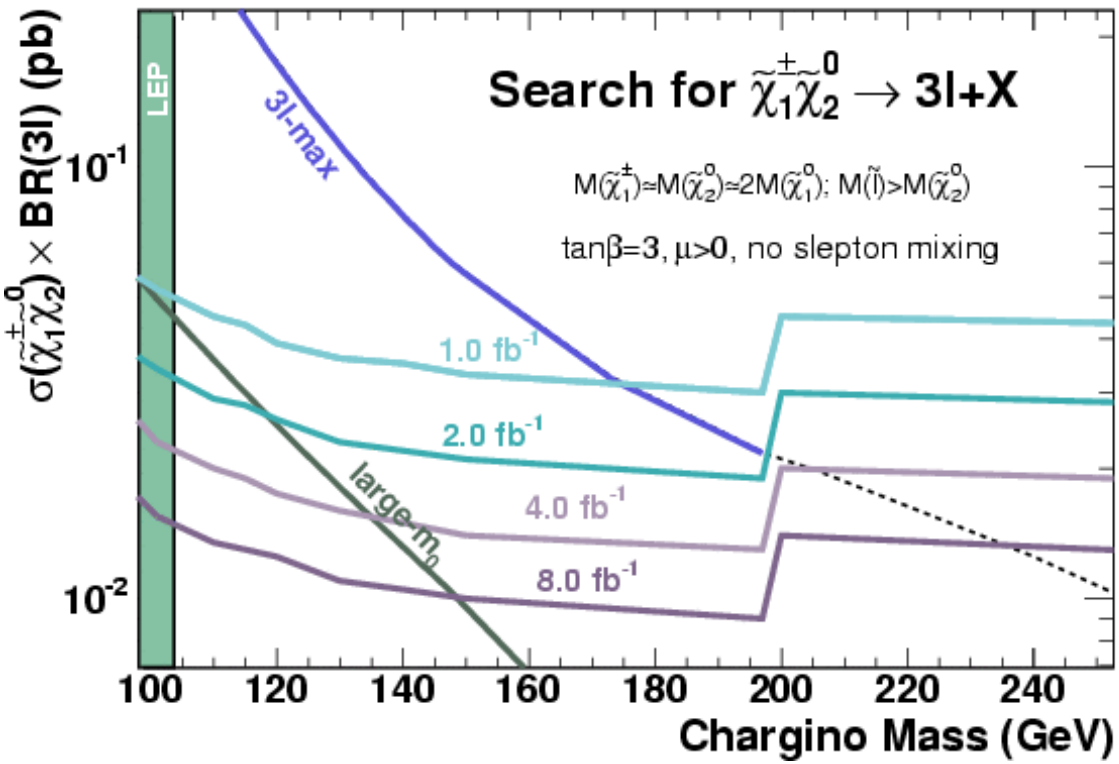
- **DØ SUSY searches are exploring new territory beyond LEP limits (most significant impacts at <u>low tan β</u> & <u>low $m_{1/2}$ and m_0</u> values)**

- **Chargino mass limit ~ 140 GeV & σ * Br < 0.07 pb for "3l-max" scenario**

- **Start counting on > 2 fb^{-1} data sample**

→ We hope that chargino and neutralino are light enough to find them at Tevatron

Expected sensitivity for SUSY chargino / neutralino searches (95 % C. L.) in final state with 3 leptons (D0 + CDF combined):



Backup Slides

SUSY Dark Matter

The LSP (neutral, colourless) interacts only weakly with matter
R-parity conservation requires a relic density → ideal dark matter candidate?

Neutralinos (χ^i_1) are mixture of Wino (W), Bino (B), and 2 neutral higgsinos (h)

<u>SUSY naturally gives the wrong dark matter density</u>

- Bino (B) Dark Matter: $\Omega_{CDM} h^2 >> \Omega_{CDM}^{WMAP} h^2$
- Wino, Higgsino (W,h) Dark Matter: $\Omega_{CDM} h^2 << \Omega_{CDM}^{WMAP} h^2$

<u>Allowed SUSY parameter space is pretty much constrained:</u>

- LSP has "correct" proportions of Wino/Higgsino in Bino dark matter
- There exists exhanced annihillation channels of Bino dark matter (e.g. LSP and NSLP are hearly degenerate in mass, …)

Experimental/Cosmological Constraints (large tan β)

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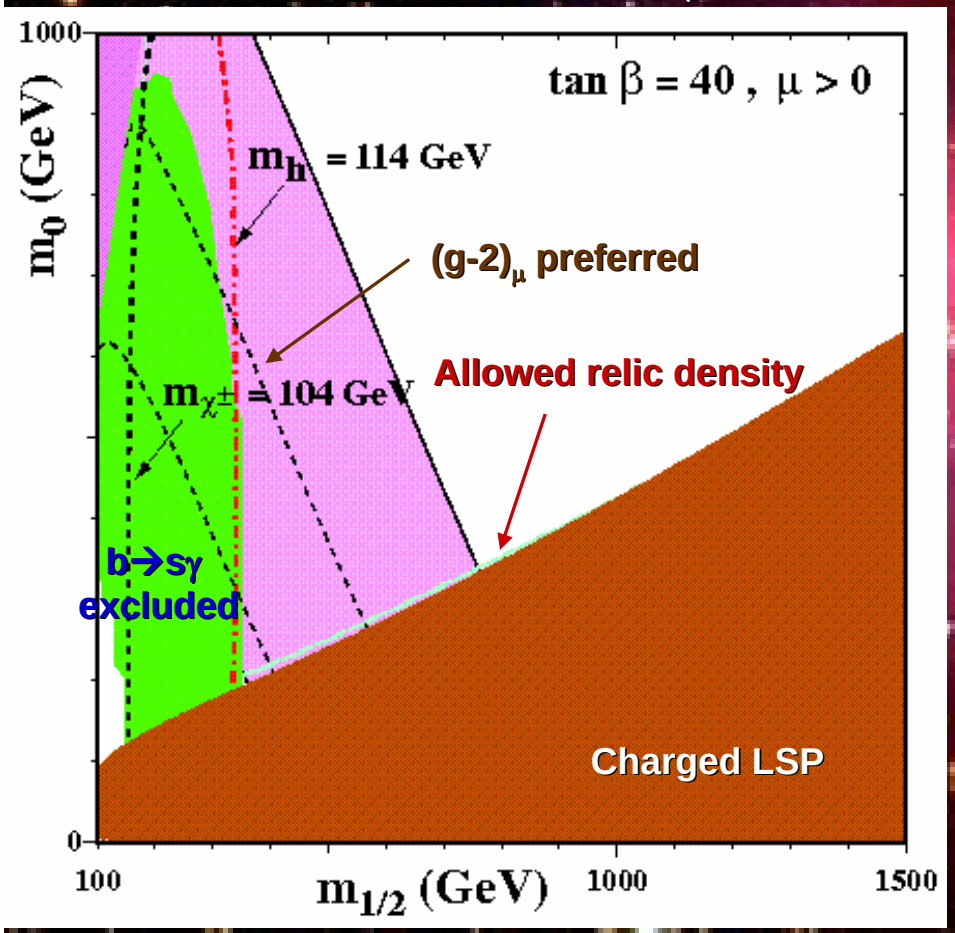

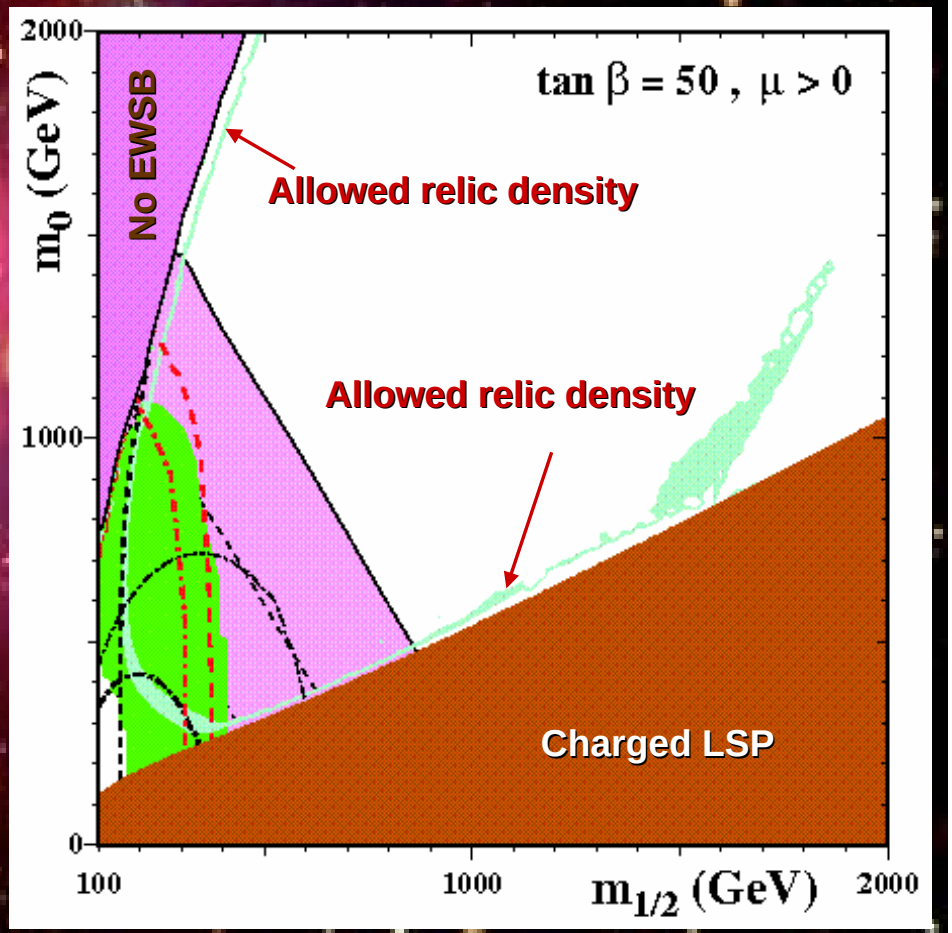

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