Searches for New Physics in Lepton Final States

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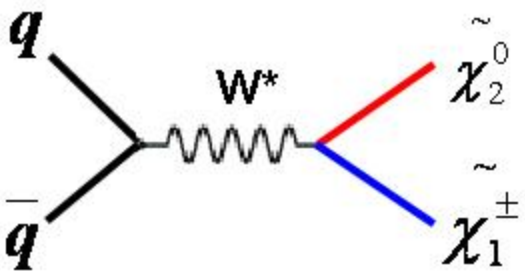
Moriond Electroweak Interactions and Unified Theories
March 14, 2006

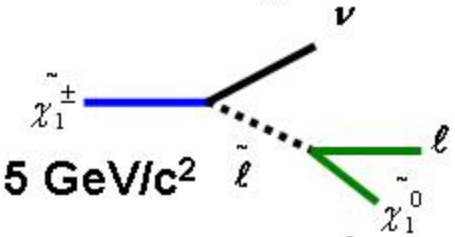
Lepton Final States

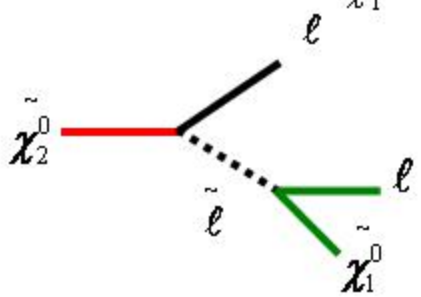
- Experimenter's choice: charged lepton, photon, jet (and missing energy from ν's), or combinations of these
- Why look for new physics in leptonic final state events?
- Both CDF and DØ have very good *e* and μ identification capabilities:
  - ↗ low backgrounds
- Jets are less-well measured than leptons. Jet events typically have:
  - ↗ larger rate, but larger backgrounds
- Photons are neutral – no tracking!
- Jet and photon (and τ's) final state searches will be shown in the next talk.

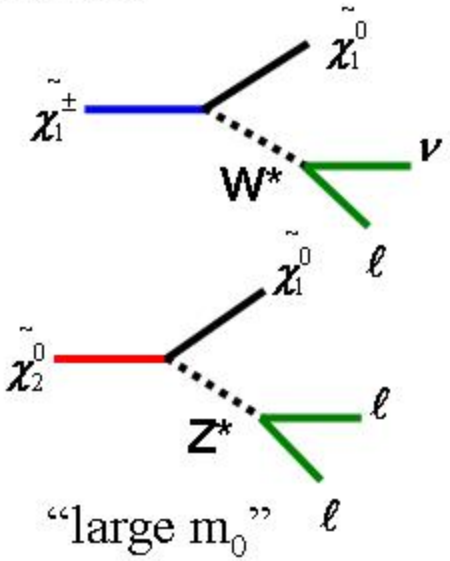
Chargino/Neutralino

- Supersymmetry? SM fermion ⇔ SUSY boson; SM boson ⇔ SUSY fermion
- SUSY fermions $\tilde{W}$, $\tilde{Z}$, $\tilde{\gamma}$, $\tilde{H}$ mix to form charginos and neutralinos:
  - **Chargino:** $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^{\pm}$
  - **Neutralino:** $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$
  - **LEP constraints: m($\tilde{\chi}$+) > 103.5 GeV/c²**

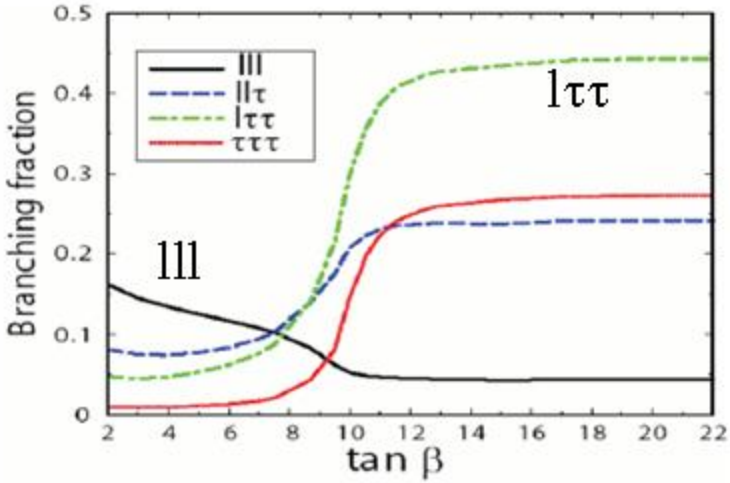








- Striking signature at the Tevatron: 3 leptons + large $\not{E}_T$
- Experimentally: low background + easy to trigger
- Small cross-section and acceptance

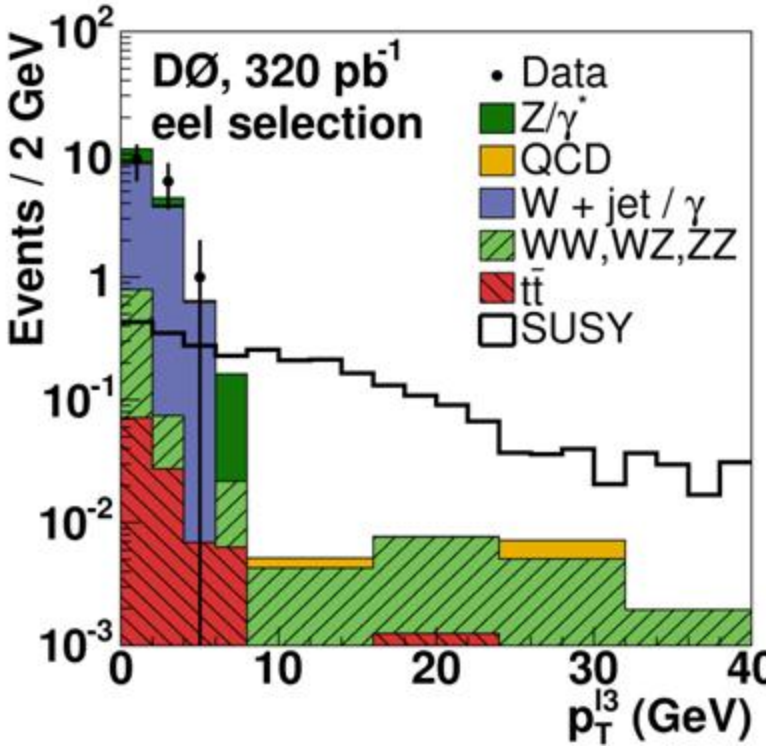


Chargino/Neutralino

- Electrons and muons combined in *Phys. Rev. Lett.* **95** *151805 (2005).*
- Added τ channels: six analyses: 2l(e, μ, τ) + track, $\mu^{\pm}\mu^{\pm}$ (like sign)
  - Impose $\not\!\!E_T$ and topological cuts (M_{ll}, $\Delta\Phi$, M_T)
- Backgrounds:
  - Drell-Yan dilepton production
  - Jets faking leptons
  - W, Dibosons, $t\bar{t}$

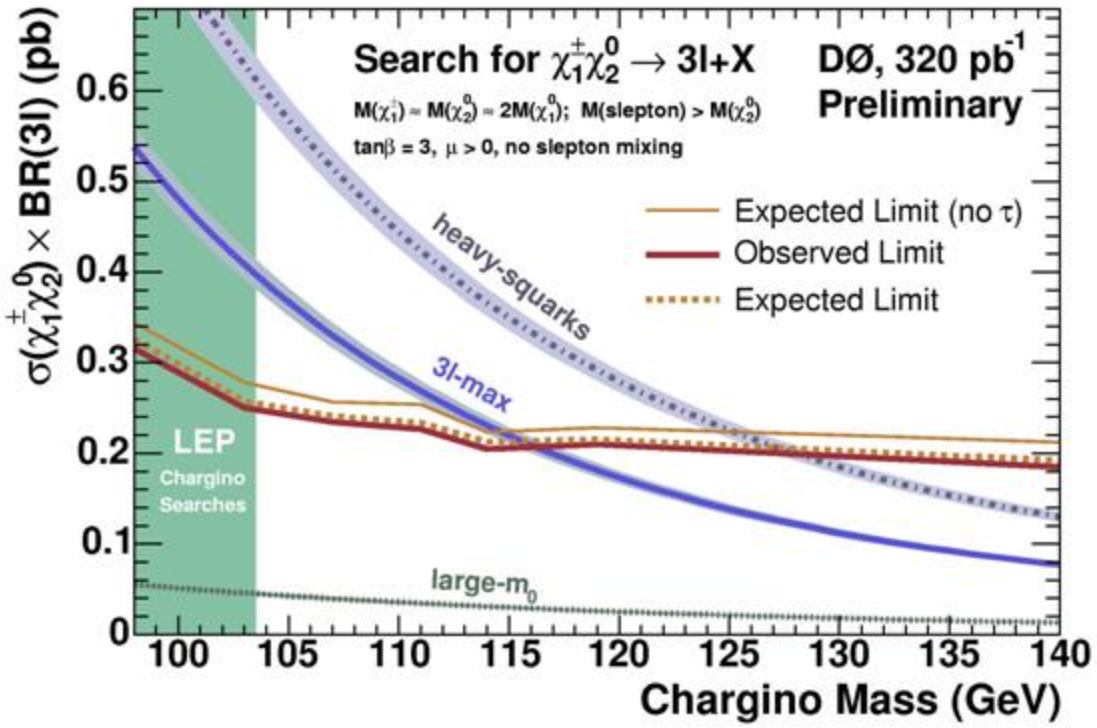
320 pb^{-1}

Selection	SM expected	OBSERVED
ee+l	0.21±0.12	0
eμ+l	0.31±0.13	0
μμ+l	1.75±0.57	2
$\mu^{\pm}\mu^{\pm}$	0.64±0.38	1
eτ+l	0.58±0.14	0
μτ+l	0.36±0.13	1
SUM	3.85±0.75	4

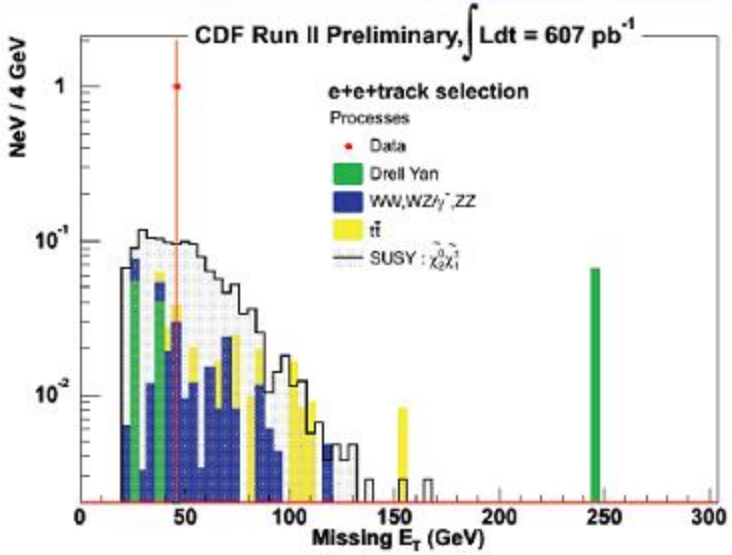


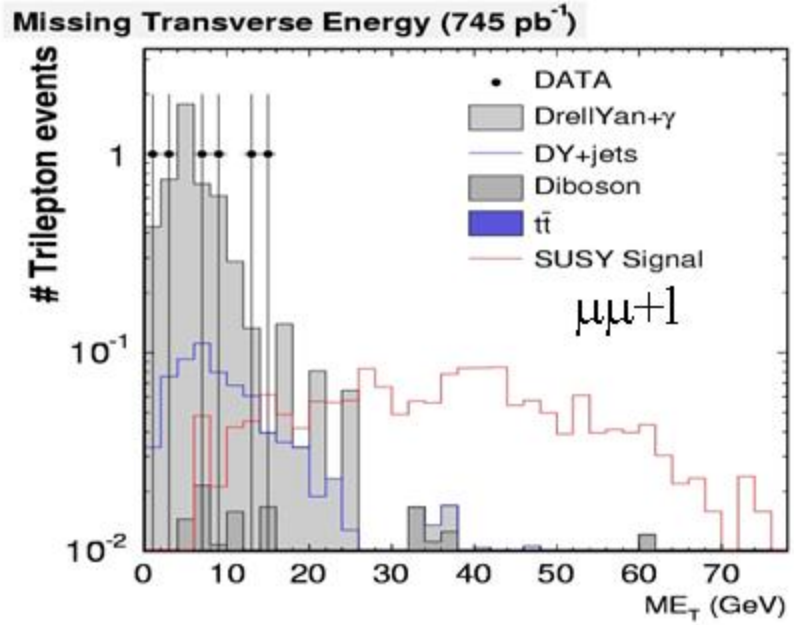
Chargino/Neutralino - Results

- mSUGRA: $m(\tilde{\chi}^{\pm}) \approx m(\tilde{\chi}^0_2) \approx 2\, m(\tilde{\chi}^0_1)$
  - **3l-max: $m(\tau) \geq m(\tilde{\chi}^0_2)$**
  - **No slepton mixing**
- $\sigma \cdot BR < 0.2$pb (95%CL)
  - $m(\tilde{\chi}^{\pm})$ **>116 GeV/c²**
- Heavy squarks:
  - $m(\tilde{\chi}^{\pm})$ **>128 GeV/c²**
- Large m_0: no sensitivity
- Adding τ's - improvement of 2-3 GeV



Chargino/Neutralino





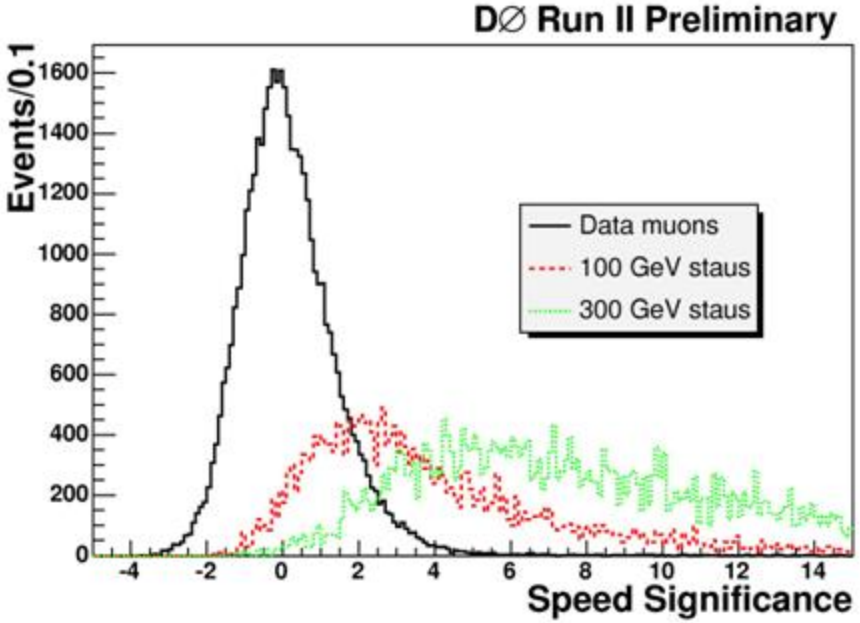
Channel	L (pb^{-1})	Exp (S+B)/B	Observe
ee+track	607	1.2 / 0.5	1
μμ+l	745	1.6 / 0.6	1
μe+l	680	1.0 / 0.8	0
ee+l	346	0.5 / 0.16	0
μμ+l (low P_T)	312	0.5 / 0	0

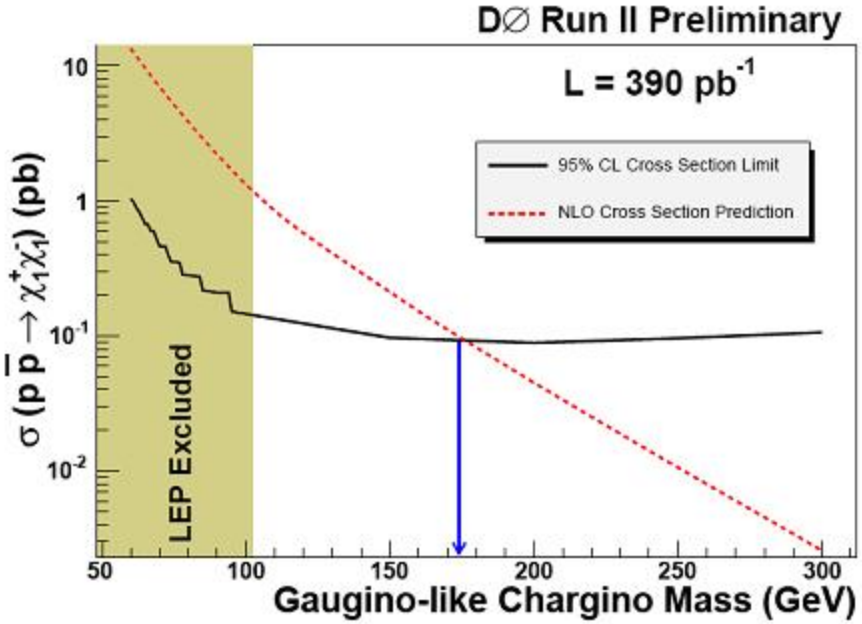
No excess seen.

Combination of all channels available soon!

Charged Massive Particles

- Charged Massive Stable Particles
  - **Anomaly Mediated Susy Breaking models**
  - **Stable = long enough to escape the detector**
    - **Traverse the detector, registering (late) in the muon detectors**
  - **Invariant mass and speed inconsistent with dimuon production**
  - **Significance = (1-speed)/σ(speed).**





Gaugino(Higgsino)-like chargino: m($\chi^{\pm}$) > 174 (140) GeV/c^2 (95%C.L.)

Lightest Scalar Top Search

- Pair production, decay $\tilde{t}_1\bar{\tilde{t}}_1 \longrightarrow b\bar{b}\ \ l^+ l^-\ \ \tilde{\nu}\bar{\tilde{\nu}}$ (eμ, μμ)
- Other decay channels severely constrained. Need m($\tilde{\nu}$) ≈ m(W)
- Backgrounds (μμ): Drell Yan dimuon, QCD multijet, Υ(1S), WW, $t\bar{t}$
- Require $N_{jets} \geq 1$, large $\not\!\!E_T$, b-jet, $M_{\mu\mu}$ (away from Z-peak)

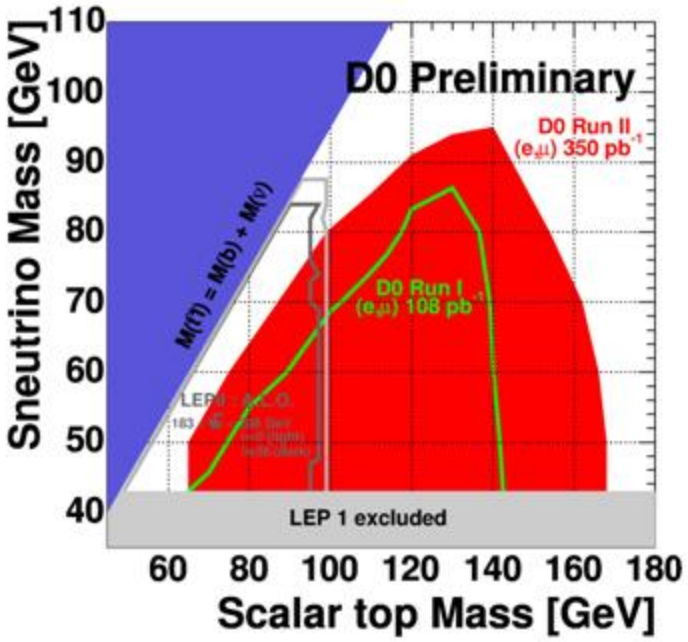
assume:

$BR(\tilde{t}_1 \to b l \tilde{\nu}) = 100\%$

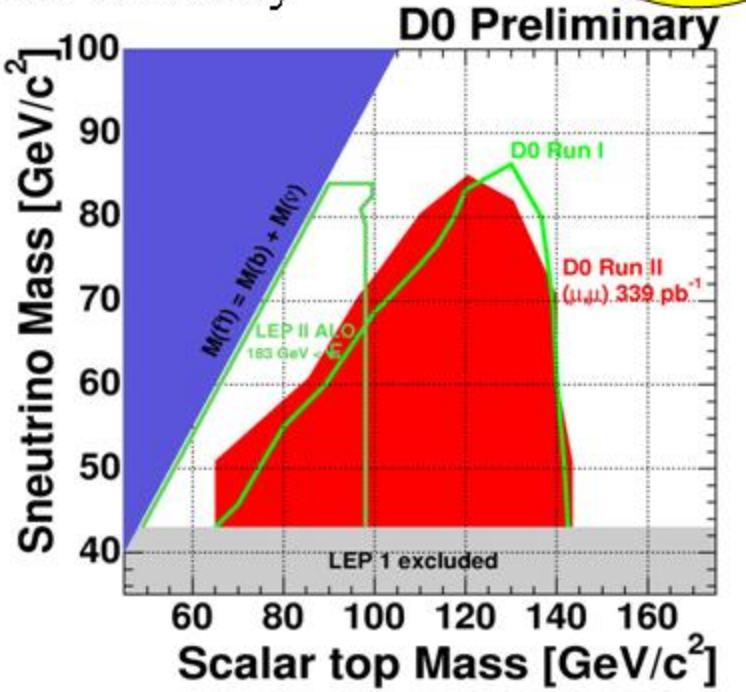
Dominant if kinematically allowed

Combination underway

350 pb^{-1}

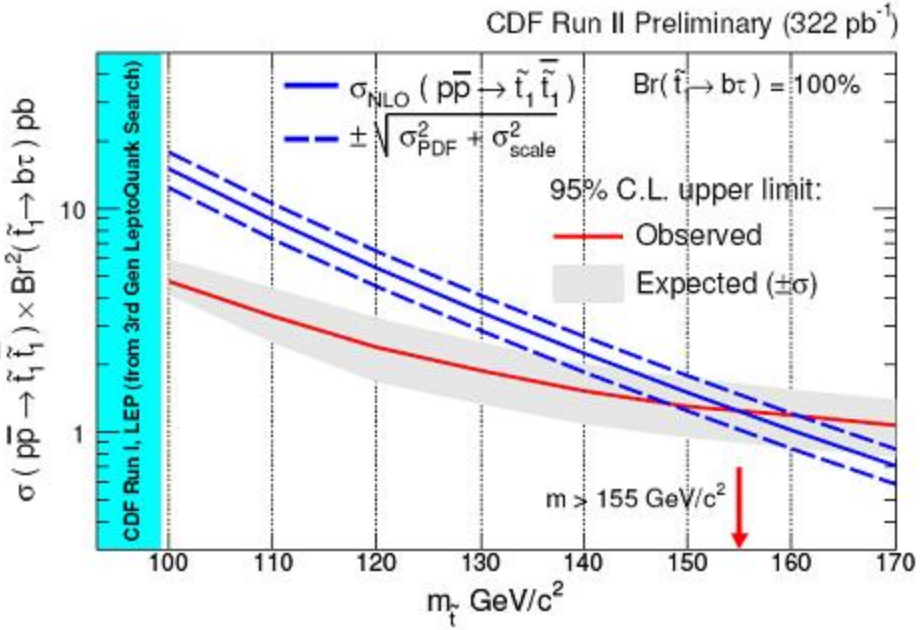


340 pb^{-1}



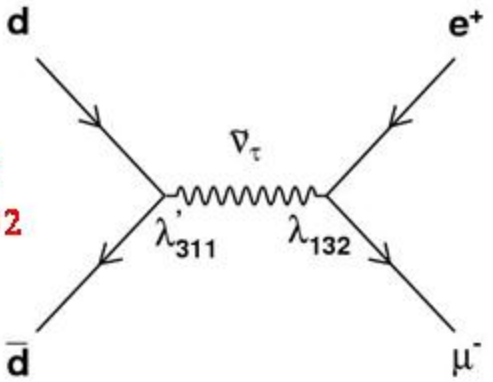
RPV SUSY decays

- Models with R_p not conserved, look for $\tilde{t} \to \tau b$ decays
- Selection: τ (had) + τ(lep=e,μ) + $\geq$2jets
- Backgrounds: $Z \to \tau\bar{\tau}$, $t\bar{t}$, W+jets, QCD fakes, diboson
- Expect $2.26\ ^{+0.46}_{-0.22}$ events, observe 2 events
- Also applies to 3rd gen. LQ

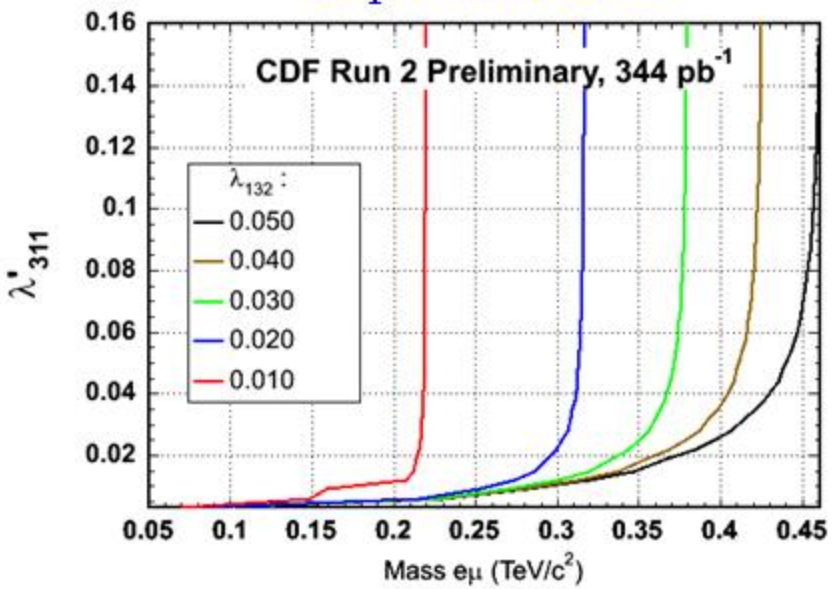


- Look for $\tilde{\nu} \to e\mu$

$\sigma \propto \lambda'^2_{311}\ \lambda^2_{132}$



hep-ex/0603006



More RPV SUSY decays

R-parity Violation ⇨ LSP can decay!

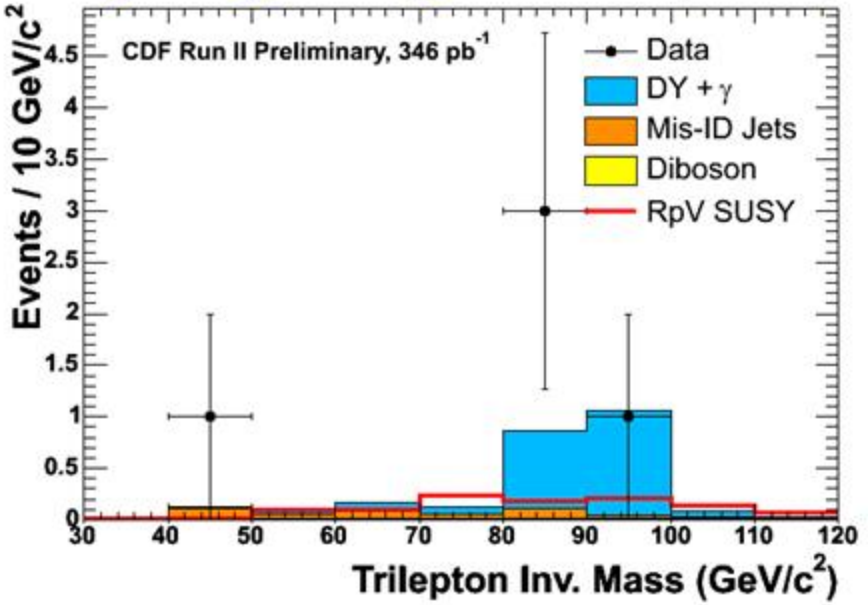
- **Sparticle pair production:**
  - **Decay into LSP via R-parity conservation.**
- **LSP decays through LLE coupling (λ' and λ" = 0).**
  - **2 leptons per LSP: final state 4 leptons! No $\not\!\!E_T$ or jet selection.**
  - **Assume only one $\lambda_{ijk} \neq 0$.**
- 3-lepton and 4-lepton contributions in agreement with the SM prediction

Observed Limits (95% C.L.)	
λ_{121}	λ_{122}
$\sigma \leq 0.21$ pb	$\sigma \leq 0.11$ pb

4-lepton signal region

Dataset	Signal
Total Background	0.008 ± 0.004
RpV SUSY (λ_{121})	1.5 ± 0.2
RpV SUSY (λ_{122})	1.5 ± 0.3
Data	**0**

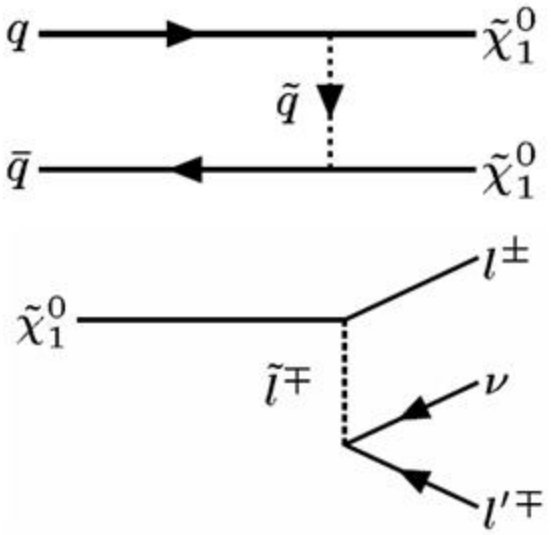
3-lepton signal: exp. 3.7±1 ev. (obs. 6)



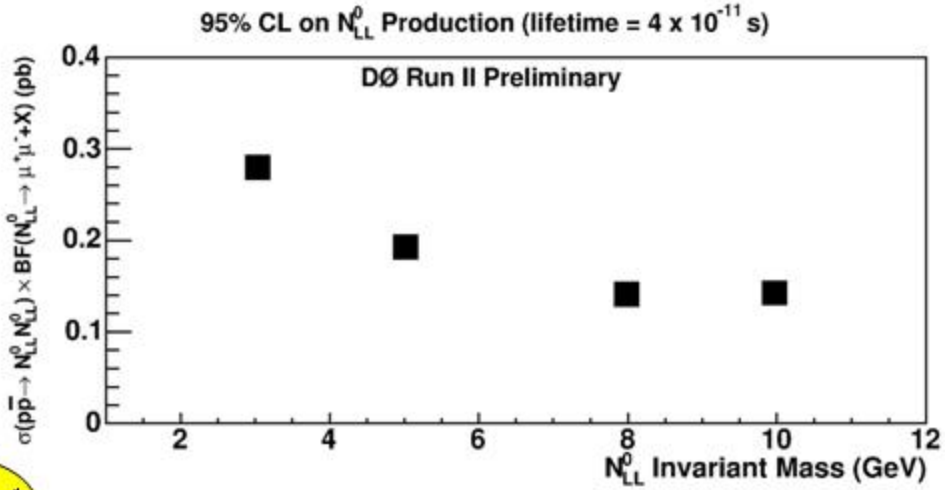
Signal Point: M_0 = 250 GeV/c^2, $M_{1/2}$ = 260 GeV/c^2, tanβ = 5, m > 0, σ = 0.143 pb

Neutral Long Lived Particles

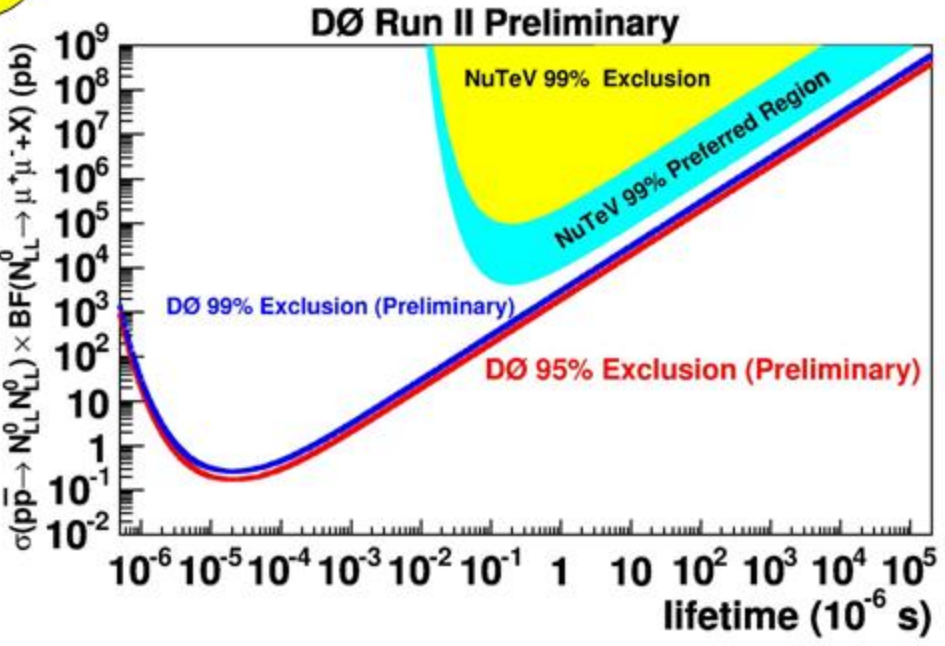
- *3 intriguing events seen at NuTeV*
  - *hep-ex/0009007*
- Looking for N_{LL}^0 decays to dimuons
- Decays at least 5cm from primary interaction



- λ_{122} determines the lifetime
- Excludes this SUSY interpretation of the NuTeV events



380 pb^{-1}

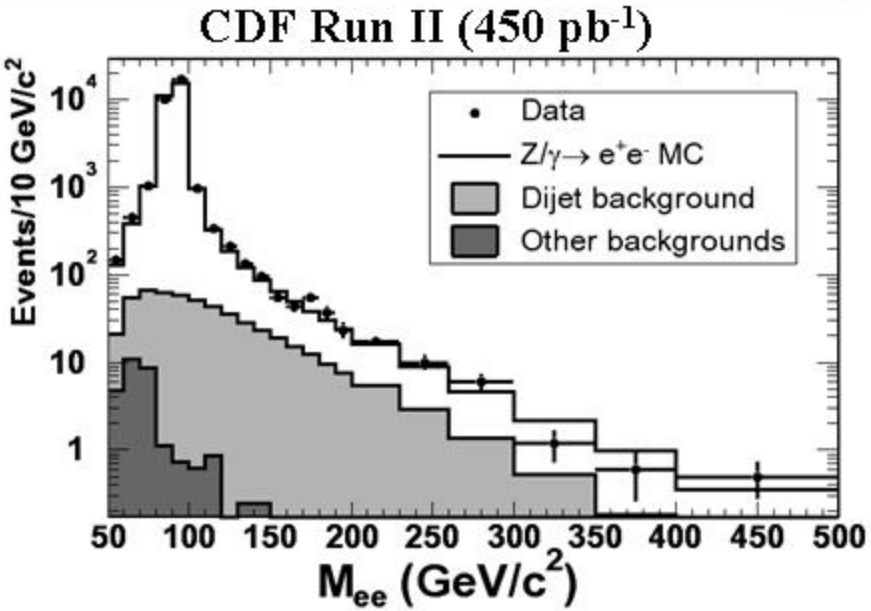


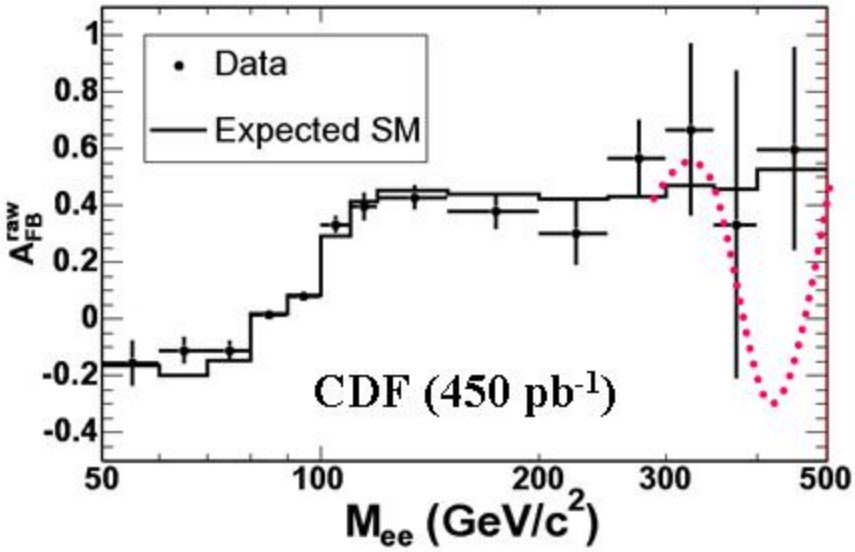
Z′ Search

- Most extensions to SM predict new gauge interactions
  - **Neutral or singly charged bosons**
  - **Constraints on Z^0-Z' mixing from LEP**
- Search for decays: $Z' \rightarrow e^+e^-$
  - **Use dielectron mass M_{ee} and $\cos\theta^*$**

hep-ex/0602045

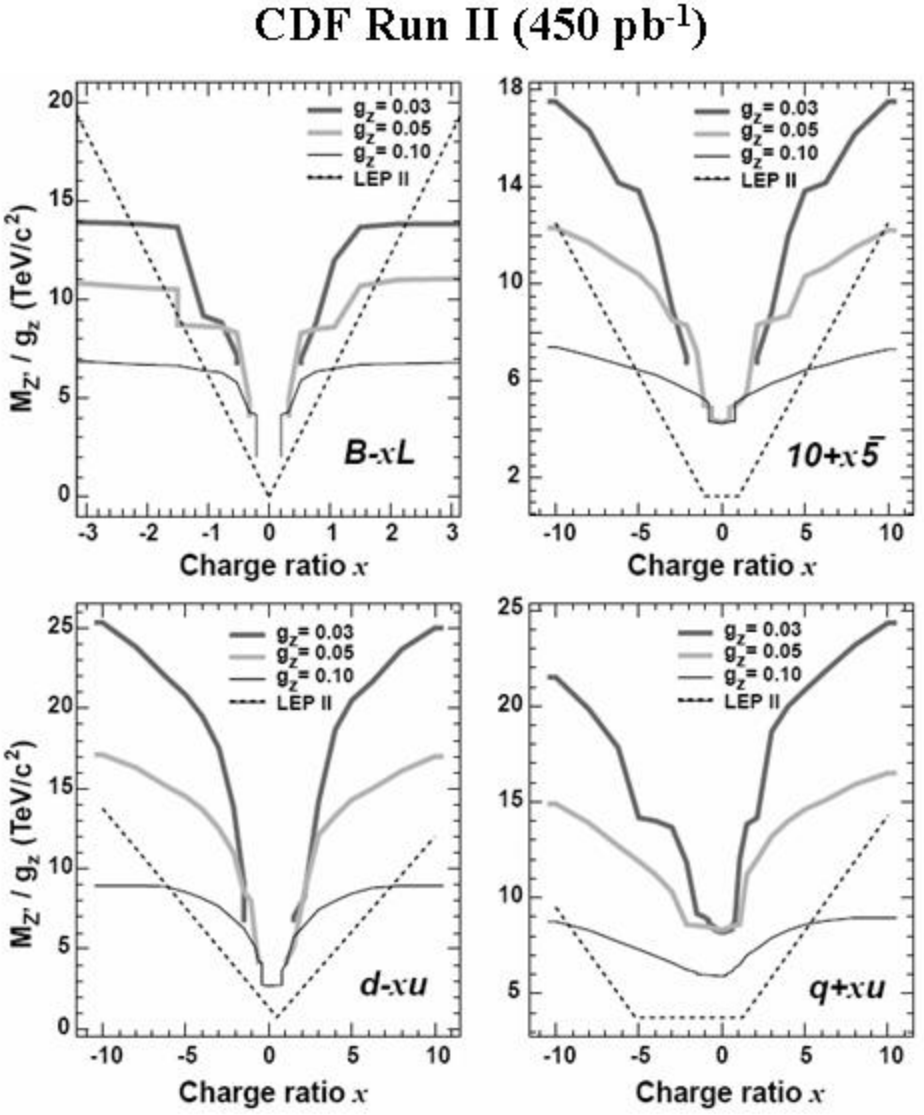
Z' Model	M_Z Limit (GeV)
Seq. Z'	850
E_6 Z_χ	740
E_6 Z_ψ	725
E_6 Z_η	745
E_6 Z_I	650



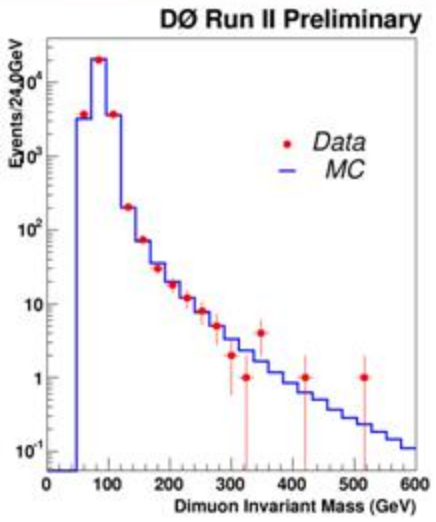


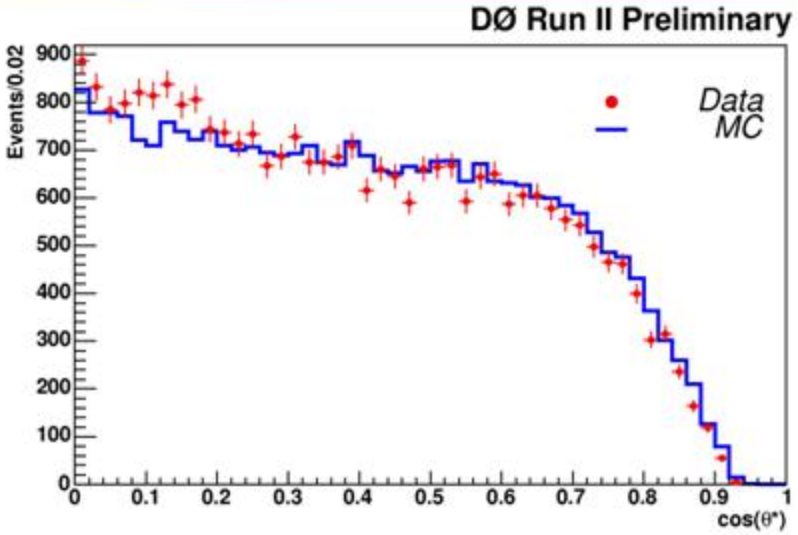
Generic Z′ exclusion

- Adding angular information helps:
  - **More important as luminosity increases**
  - **At 450 pb^{-1}: use cosθ* ≡ +25% data (seq. Z')**
- 2004 paper by *Carena et al* defines 4 model classes (***Phys.Rev.D70:093009,2004***):
  - **B-xL, q+xu, 10+x$\bar{5}$, d-xu**
  - **Within each class, Z' defined by: mass $M_{Z'}$, strength g_z, parameter x**
- Bonus:
  - **Comparisons to LEP II possible.**



qqll Contact Interactions





Model	Λ^+(TeV)	Λ^-(TeV)
LL	4.19	6.98
RR	4.15	6.74
LR	5.32	5.10
RL	5.31	5.17
LL+RR	5.05	9.05
LR+RL	6.45	6.12
LL-LR	4.87	7.74
RL-RR	5.07	7.41
VV	6.88	9.81
AA	5.48	9.76

- Contact Interactions qqμμ:
  - Using both mass $M_{\mu\mu}$ and angular information cosθ*
- Tightest constraints on Λ_{CI}

400 pb^{-1}

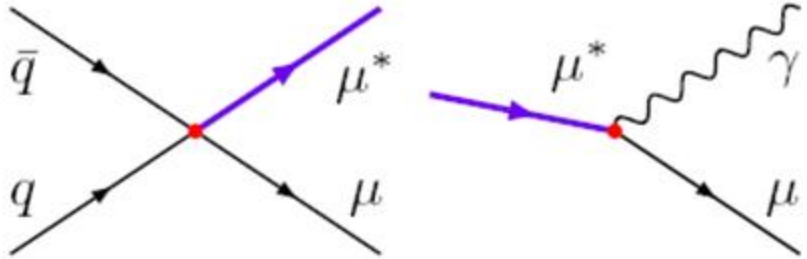
Interaction	LL	LR	RL	RR	VV	AA
Λ^+_{qe} limit (TeV/c^2)	3.7	4.7	4.5	3.9	5.6	7.8
Λ^-_{qe} limit (TeV/c^2)	5.9	5.5	5.8	5.6	8.7	7.8

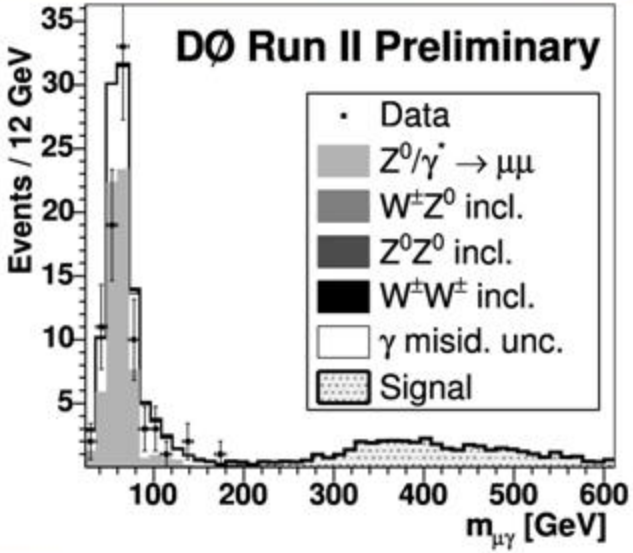
CDF limits for qqee CI scales

450 pb^{-1}

Excited Muons

- *Do leptons have structure?*
- μ* produced in qqμμ contact interactions (CI)

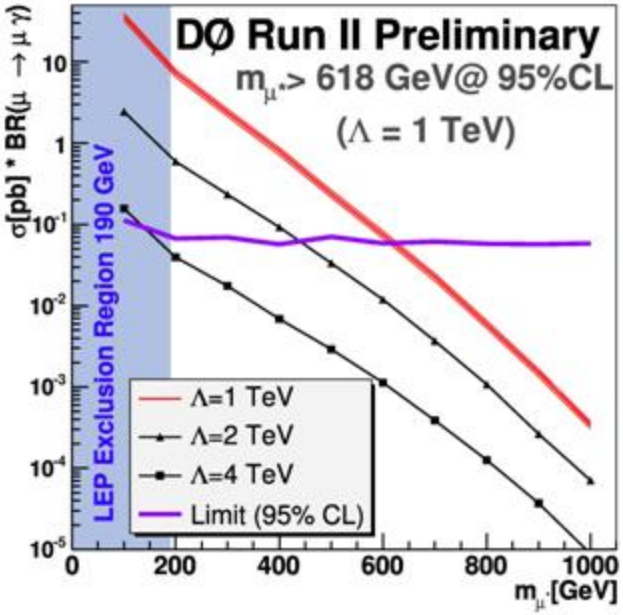




- μ* decay via CI or EWK:
  - **Look for μμγ**

380 pb^{-1}

- Backgrounds:
  - **Drell-Yan: 65±8 events,**
  - **Diboson: ~ 1 event**
  - **Fakes (jet misID as γ) ~ 39 ±5 events**
- Observed 90 events
- CDF, *no CI decays*: M_{μ^*} <850 GeV (95%C.L.)

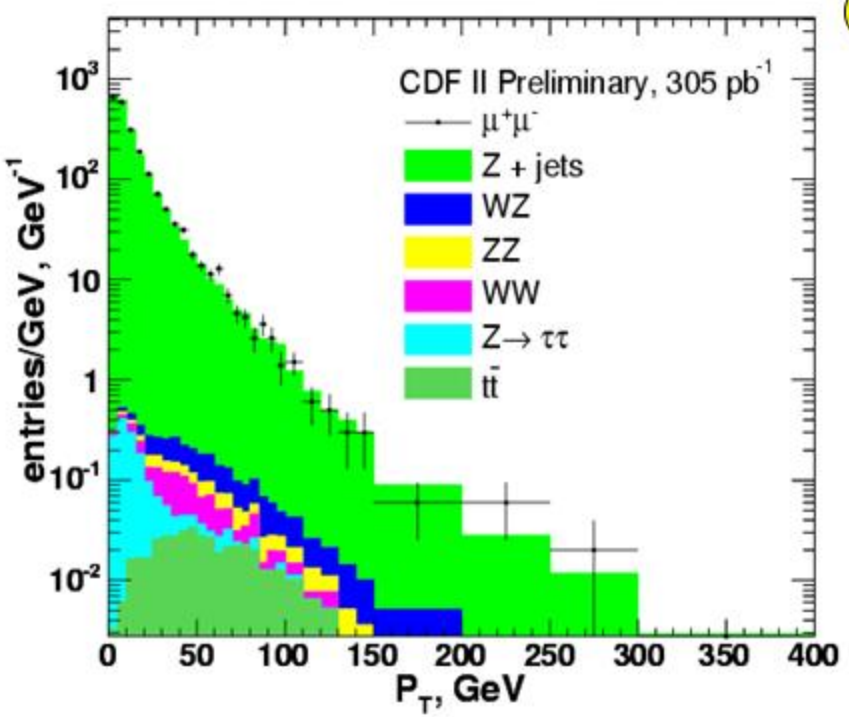


Signature-based searches for dileptons + X

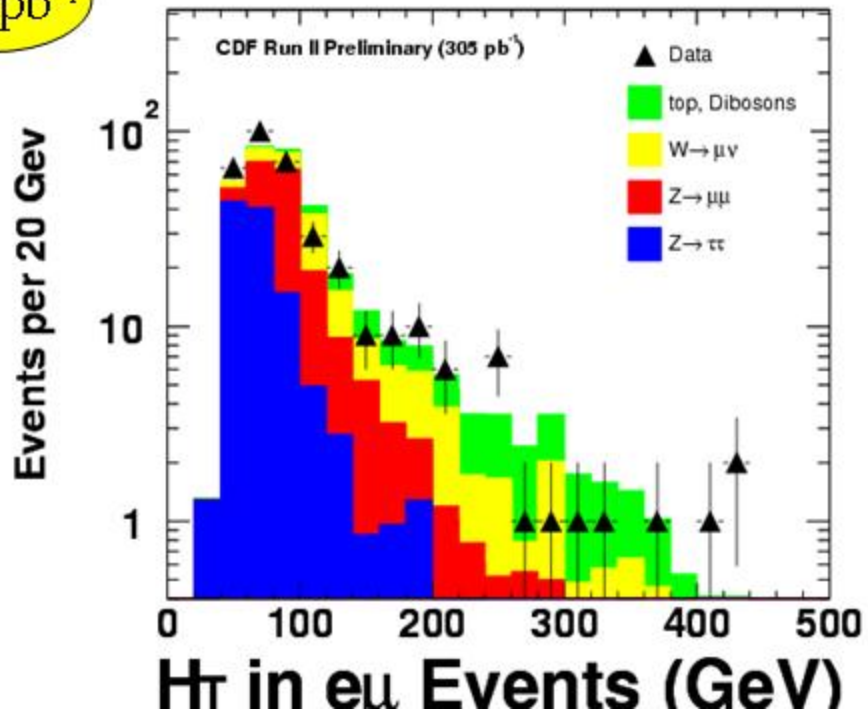
- Look for excess above SM prediction in dilepton +X (X = photon, lepton, b-jet, HT, $\not\!\!E_T$
  - Z+X and dilepton+X
- **Set cuts on first 1/3rd of dataset(now),apply to next part of data (coming soon)**
  - **can be further applied to many models; e.g. heavy quarks (BPT) as first example**
- Dilepton (ee, μμ , eμ) + high HT

High p_T Z's (inclusive) in dimuons

305 pb^{-1}



Search region: H_T>400 GeV

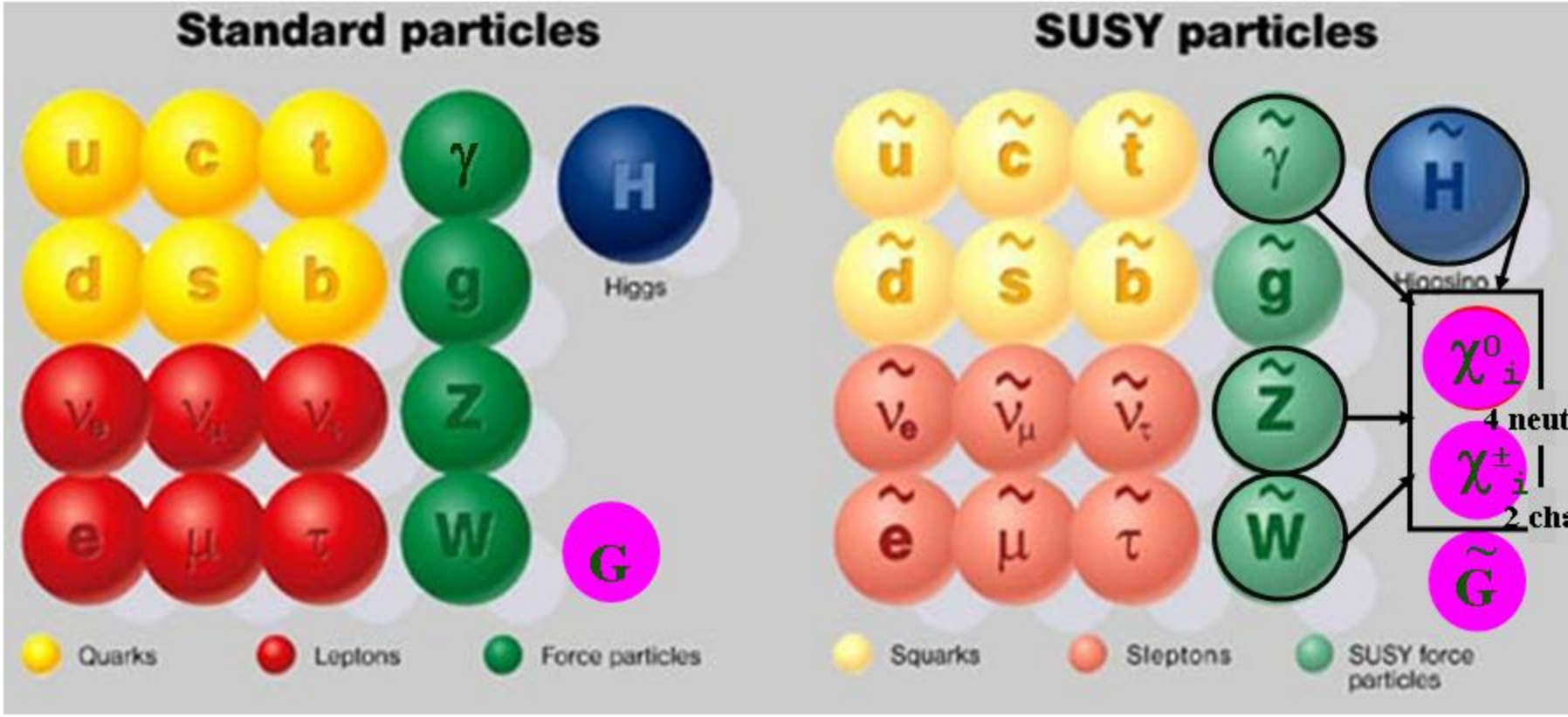


Conclusions

- Lepton final state searches at DØ and CDF
  - Very diverse and mature sector of the exotic physics program
  - No signal found, set tightest constraints in most cases
  - Searches shown: 0.3-0.7 fb^{-1}
  - Collected to tape ~ 1 fb^{-1} for each experiment
  - Searches with 1 fb^{-1} dataset ready in the summer

- Both experiments are in position to find non-SM physics, if it is within the Tevatron's energy and luminosity reach!

Supersymmetry



- Supersymmetry: SM fermion ⇔ SUSY boson; SM boson ⇔ SUSY fermion
- Needed to cancel divergences in Higgs mass Δm_H^2.

R-Parity Quantum Number -> $R_p = (-1)^{B+L+2s}$ **+1 (SM particles)**

-1 (Susy particles)

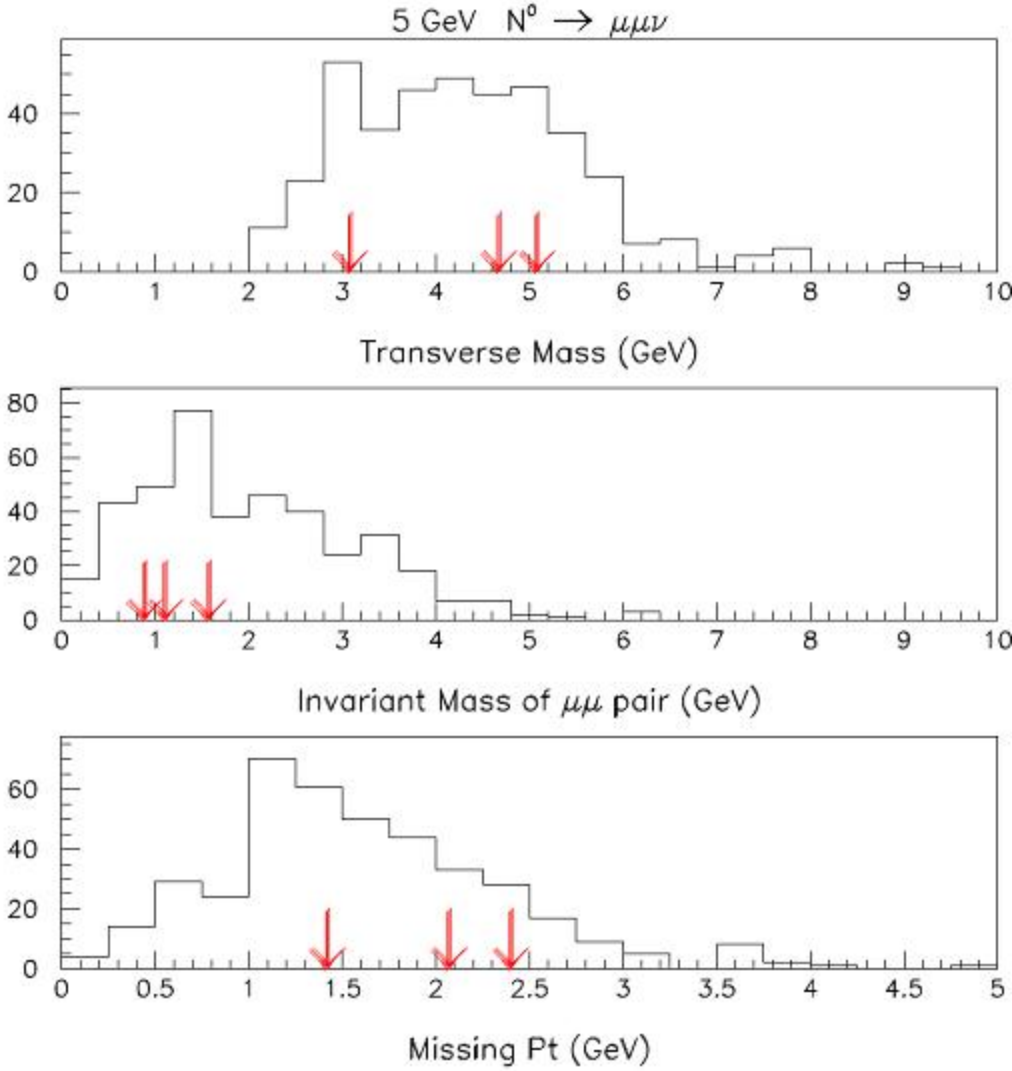
NuTeV's 3 dimuon events

See for example hep-ex/0009007

Int.J.Mod.Phys. A16S1B (2001) 761-763

Phys.Rev. D 65 (2002) 015001

In conclusion, the rate corresponding to the observed three events is not consistent with Standard Model processes we have identified and the source of the events is not clear.

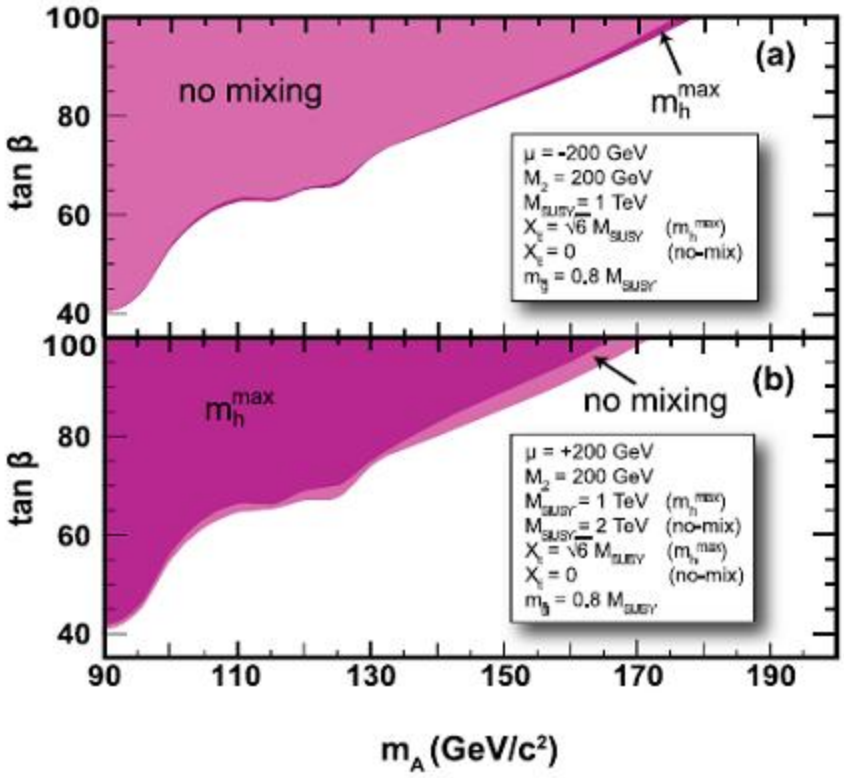


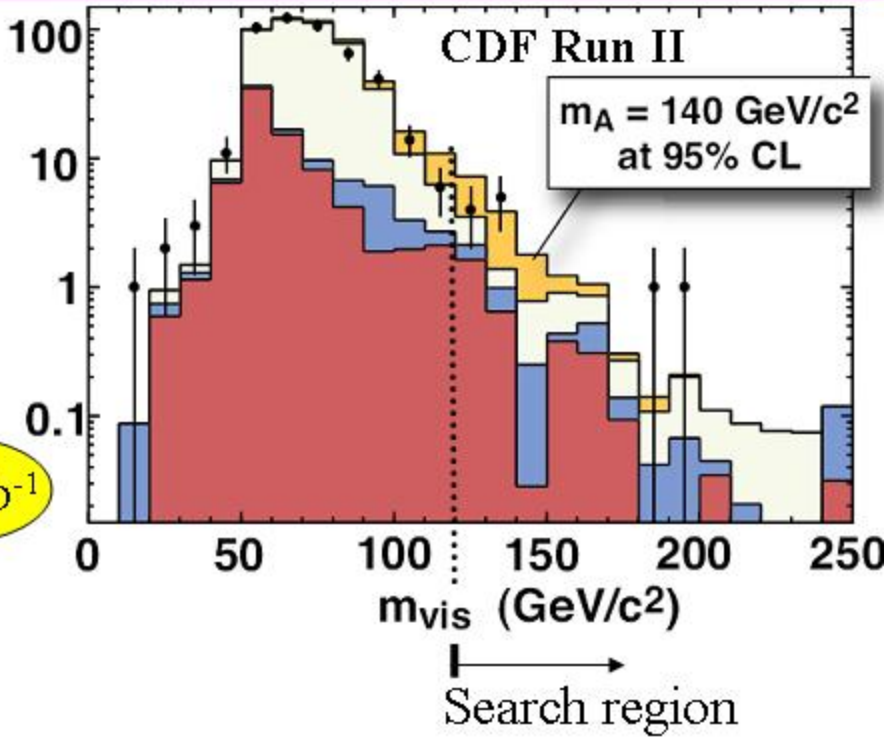
MSSM Higgs: $A \to \tau\bar{\tau}$

- Enhanced production of A at hadron colliders

  $\sigma(pp \to H/A/h) \propto \tan^2\beta$

- A decays: $b\bar{b}$ (~90%), $\tau\bar{\tau}$ (~8-9%)
  - **Huge backgrounds associated with $b\bar{b}$ make limits comparable**





- One tau decays leptonically, the other one hadronically
- Backgrounds: $Z \to \tau\bar{\tau}$, jet $\tau \to$ fakes
- Observe 11 events (expect 8.4)

PRL 96 (2006) 011802

Bjorken, Pakvasa, Tuan: Yet Another Extension of the Standard Model: Oases in the Desert?, hep-ph/0206116

Expected Events from BPT Signal and total SM background for Ht > 400 GeV and two jets with Et > 50 GeV.

Channel	Expected Events
QQ -> ddHH	0.0246 +/- 0.0017
QQ -> ddHZ	0.0535 +/- 0.0053
QQ -> ddZZ	0.0107 +/- 0.0024
QQ -> udWH	0.157 +/- 0.009
QQ -> udWZ	0.0834 +/- 0.009
QQ -> uuWW	0.197 +/- 0.020
Total (with Systematics)	0.536 +/- 0.058
SM (with Systematics)	0.802 +/- 0.440

We see no events and set a Bayesian limit at 90% CL of 4.49* $\sigma(Q)$ where $\sigma(Q)$ =0.289 pb is the expected cross section