Search for the Associated Production of Charginos and Neutralinos at the TeVatron

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for the
CDF and DØ Collaborations

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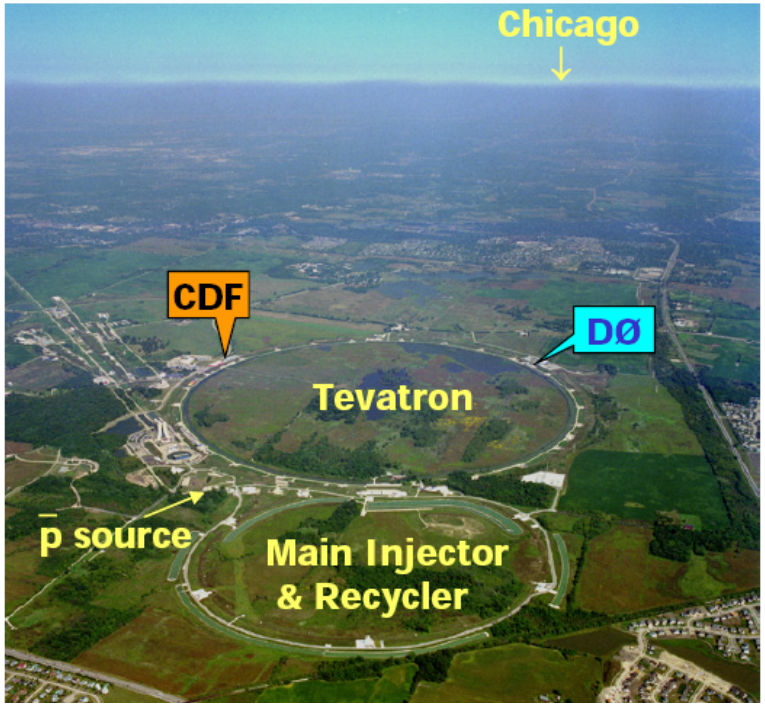
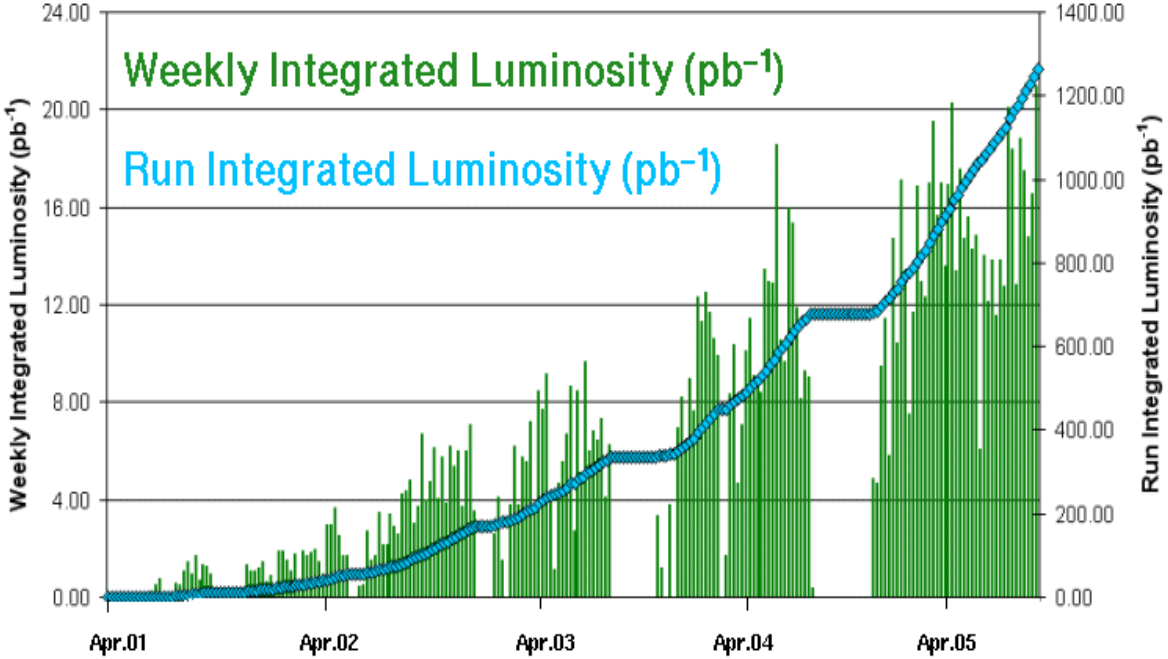
1. TeVatron and Detectors
2. Phenomenology / Motivation
   - Associated $\tilde{\chi}^{\pm}\tilde{\chi}^{0}$ Production and Decay
   - Multilepton Final States
3. Analysis Strategies
   - SM-Background / Data Understanding
   - Special τ_{had}-analyses
4. Interpretation
   - Results from CDF and DØ
   - Interpretation in Different Scenarios
5. Conclusion

TeVatron and Its Performance

The CDF and DØ detectors at the TeVatron with:

E_{CM}: $\sqrt{s} = 1.96$ TeV





peak luminosity: $\mathcal{L} \approx 1.2 \cdot 10^{32} \frac{1}{\mathrm{cm}^2\mathrm{s}}$

Both experiments running stable with a data-taking efficiency of 85% - 90%.

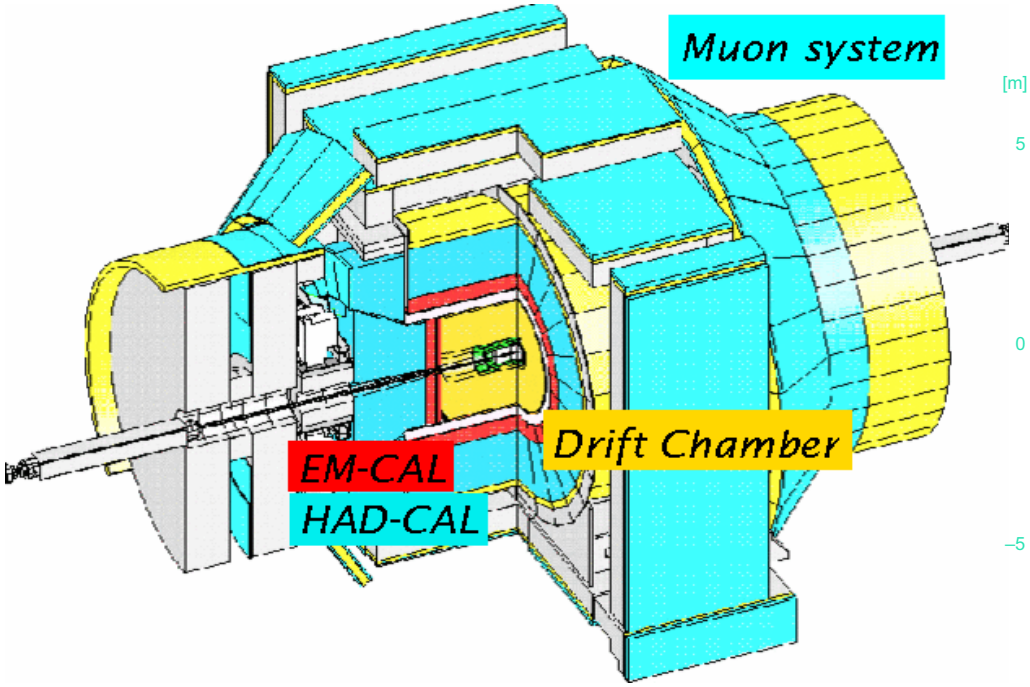
The CDF and DØ Detectors

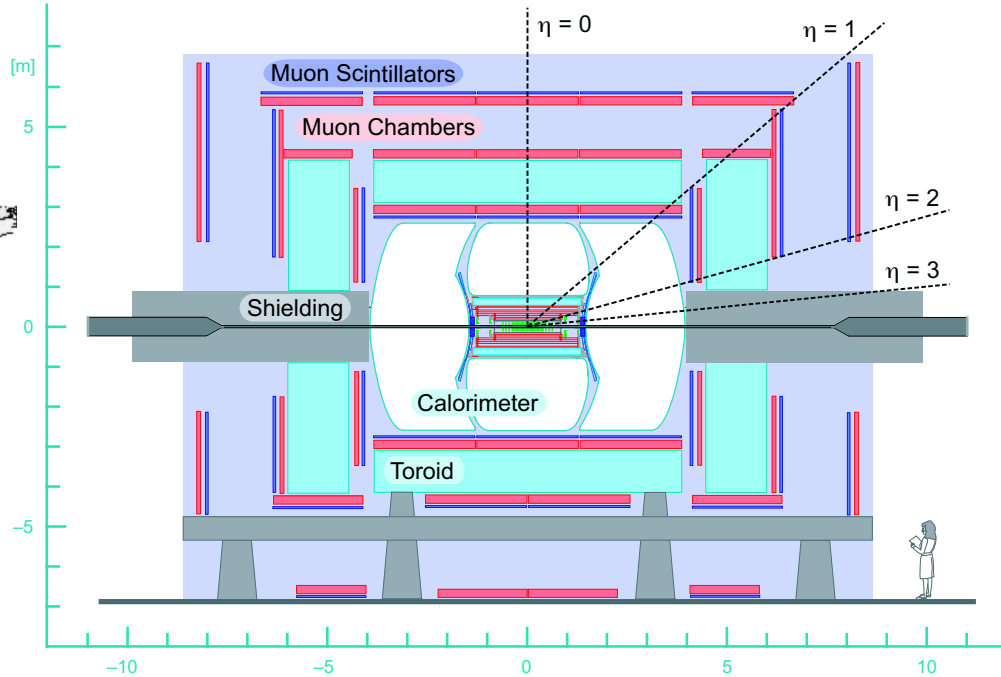
CDF acceptances (used)

tracking (Si-Vtx.)	$\lvert\eta\rvert \leq 2.0$
Drift Chamber: high precision tracking	$\lvert\eta\rvert \leq 1.0$
Em-Cal: e/γ	$\lvert\eta\rvert \leq 1.1$
Had-Cal: jets/$\not\!\!E_T$	$\lvert\eta\rvert \leq 3.0$
Em: scintillator/lead, Had: scintillator/steel ($e/\pi \approx 1.3$)	
μ-acceptance	$\lvert\eta\rvert \leq 1.0$

DØ acceptances (used)

tracking (Silicon)	$\lvert\eta\rvert \leq 3.0$
Scintillating Fibers: tracking/triggering	$\lvert\eta\rvert \leq 1.6$
Em-Cal: e/γ	$\lvert\eta\rvert \leq 3.0$
Had-Cal: jets/$\not\!\!E_T$	$\lvert\eta\rvert \leq 4.0$
Compensating liquid Ar with Ur/Cu ($e/\pi \approx 1.06$)	
wide muon coverage	$\lvert\eta\rvert \leq 2.0$





R_pC-SUSY: $\tilde{\chi}^{\pm}\tilde{\chi}^{0}$ Production and Decay

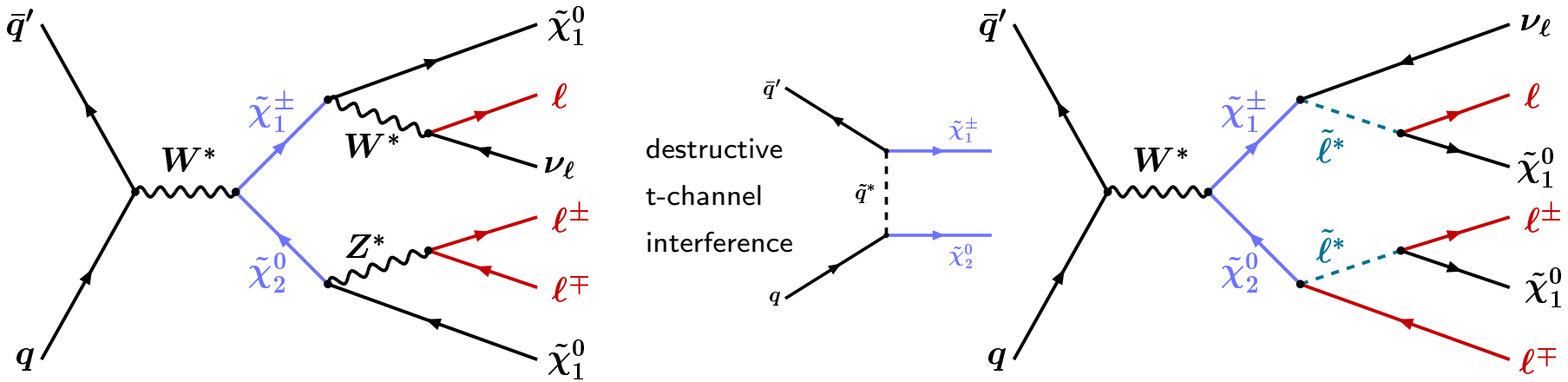
Definition of R-parity:

$$R_P = (-1)^{3B+L+2S}$$

B: baryon / L: lepton number / S: spin

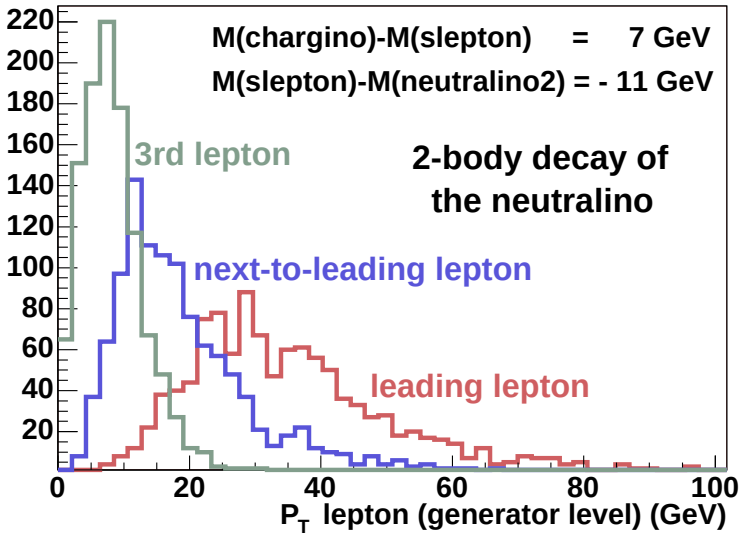
SUSY: $R_p = -1$, SM: $R_p = +1$

- LSP (usually $\tilde{\chi}_1^0$) is stable $\longrightarrow$ "good" dark matter candidate
- LSP escapes detection $\longrightarrow$ much missing energy ($\not{E}_T$)



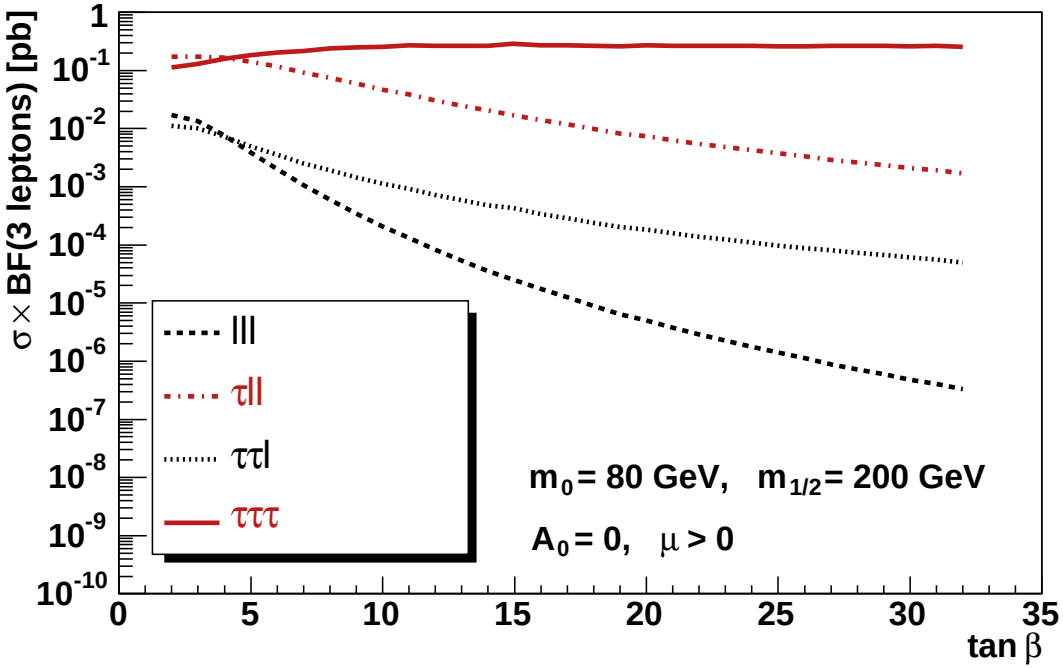
- EW production $\rightarrow$ small cross section: $\sigma_{SUSY} \approx 0.1 - 0.5\ pb$
- choose "golden" channel: $\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^0 \rightarrow 3\ell + \not{E}_T$
- provides a clean leptonic signature with low SM-background

Multilepton Final States Including τ's



- SUSY leptons $\rightarrow$ very low $p_\perp$
- triggering/identifying not as easy
- many different final states $\rightarrow$ need several dedicated analyses

U. Blumenschein, Ph.D. thesis:
http://www-d0.fnal.gov/results/publications_talks/thesis/

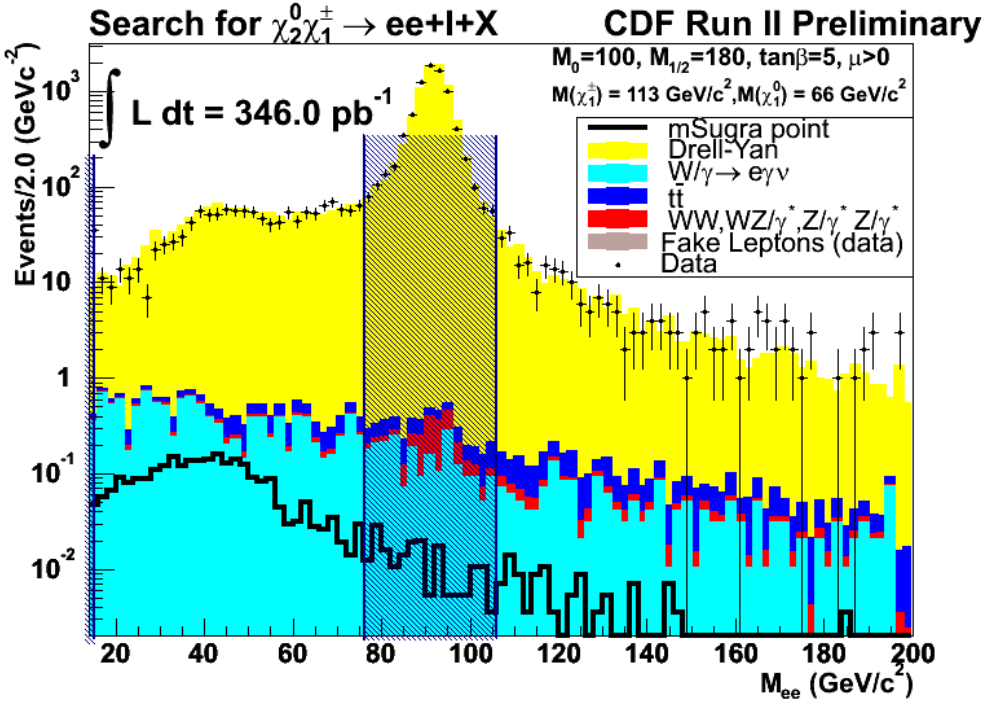


Due to mixing in the 3rd gen. $\tilde{\tau}$ becomes lightest $\tilde{\ell}$ and $\tilde{\chi}_1^\pm\,\tilde{\chi}_2^0$ mainly decay via $\tilde{\tau}$

$$\boxed{\tilde{\chi}_1^\pm\,\tilde{\chi}_2^0 \rightarrow \tau\tau\tau \text{ or } \tau\ell\ell}$$

SM-Backgrounds and Selection Cuts

- $Z/\gamma^* \rightarrow \ell\ell +$ add. lepton
  (γ-conversion or fake leptons: π^0)
- QCD multijet & heavy flavour production ($b\bar{b}$ and $t\bar{t}$)
- Di-boson: WW/WZ/ZZ
  W+γ/jet $\rightarrow \ell\nu$+γ/jet



Common strategy

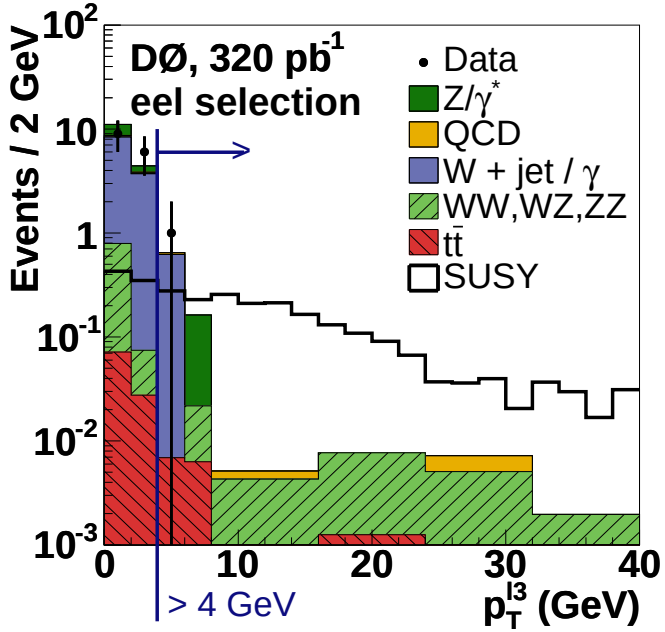
- identify 2 leading leptons
- require large $\not{E}_T >$ 15-25 GeV
  ensure that $\not{E}_T$ is not parallel to ℓ/jet since mismeasured ℓ/jets may produce fake $\not{E}_T$
- mass selection: J/Ψ, Υ, Z-veto
- add 3rd isolated track
  $\rightarrow$ covers e, μ and partially $\tau_{\rm had}$

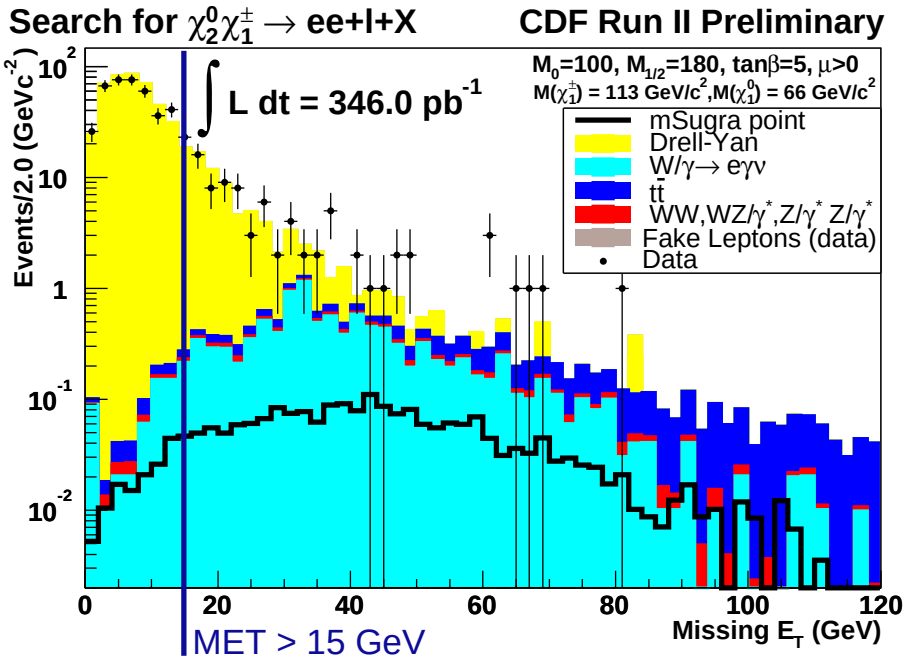
CDF: ee+e/μ, $\mu\mu$+e/μ, $ee\ell$
DØ: $ee\ell$, $\mu\mu\ell$, $e\mu\ell$, like-sign $\mu\mu$
additionally: $e\tau\ell$, $\mu\tau\ell$

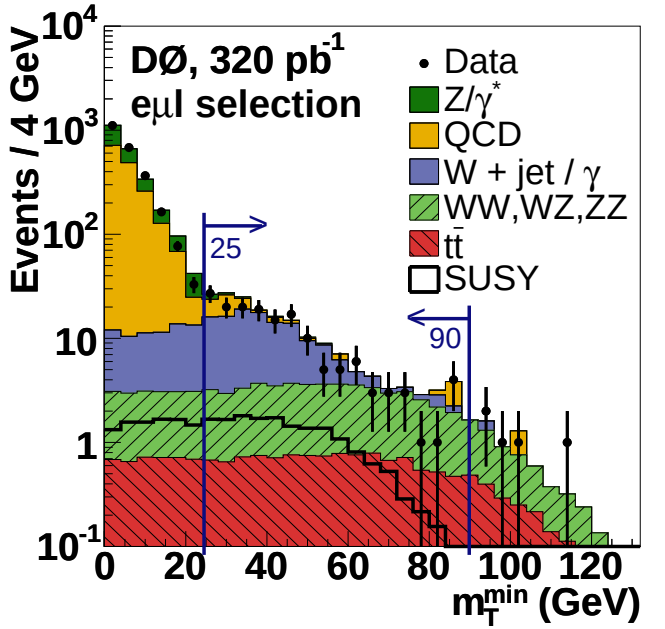
http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

Data Understanding in Different Analyses

exp./analysis		$p_\perp^{\ell 1}$	$p_\perp^{\ell 2}$	$p_\perp^{\ell 3}$ [GeV]
CDF	$ee+e/\mu$	20	8	5
	$\mu\mu+e/\mu$	20	8	5
	$ee\ell$	10	5	4
DØ	$ee\ell$	12	8	4
	$e\mu\ell$	12	8	7
	$\mu\mu\ell$	11	5	3
	$LS\mu\mu$	11	5	–



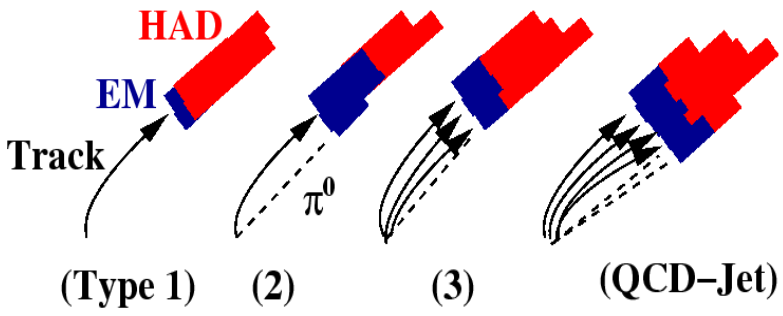


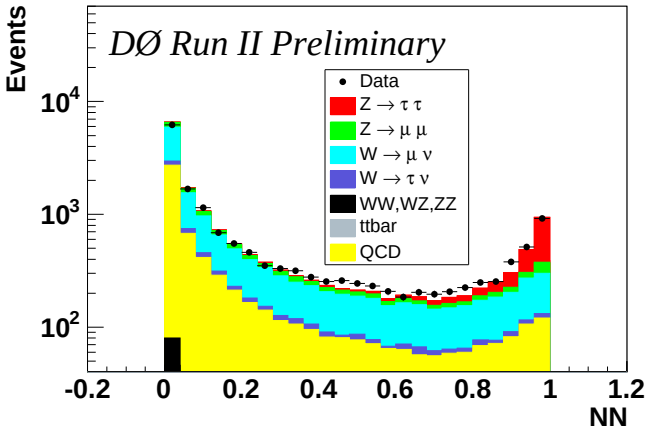


Identifying τ-leptons at DØ

65% of τ's decay hadronically $\rightarrow$ few tracks, narrow energy deposition!
Idea: Neural Nets (NN) to separate τ's from e/jets; one for each type

- Shower shape
  (transverse/longit.)
- Isolation
  (in dR $<$ 0.3/0.5 cones)
- EM-fraction
- $p_\perp^{\text{no } \tau\text{-tracks}} / p_\perp^{\text{tracks}}$

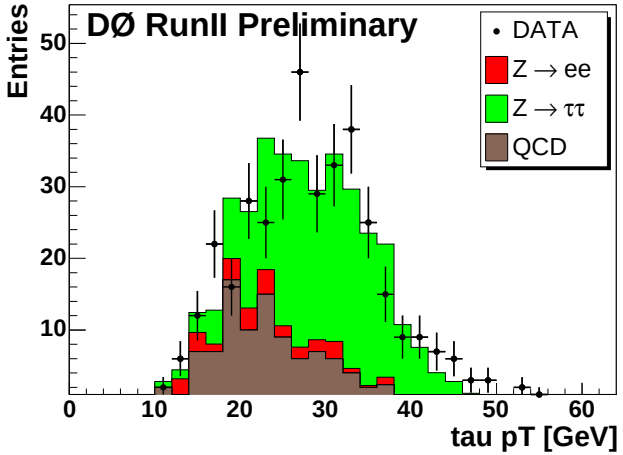


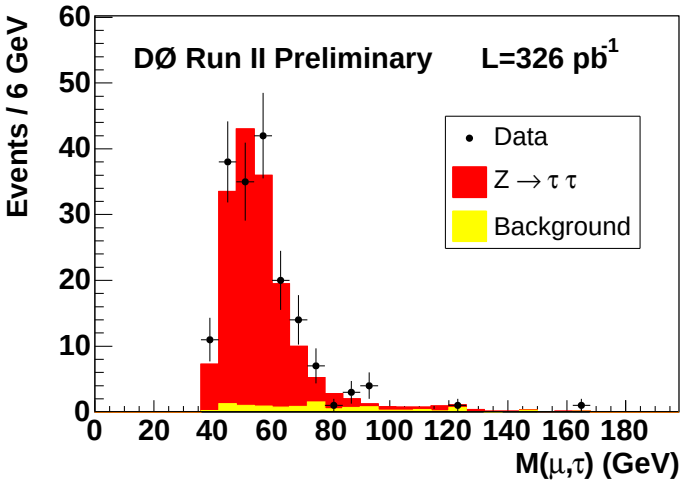


Reference signal:

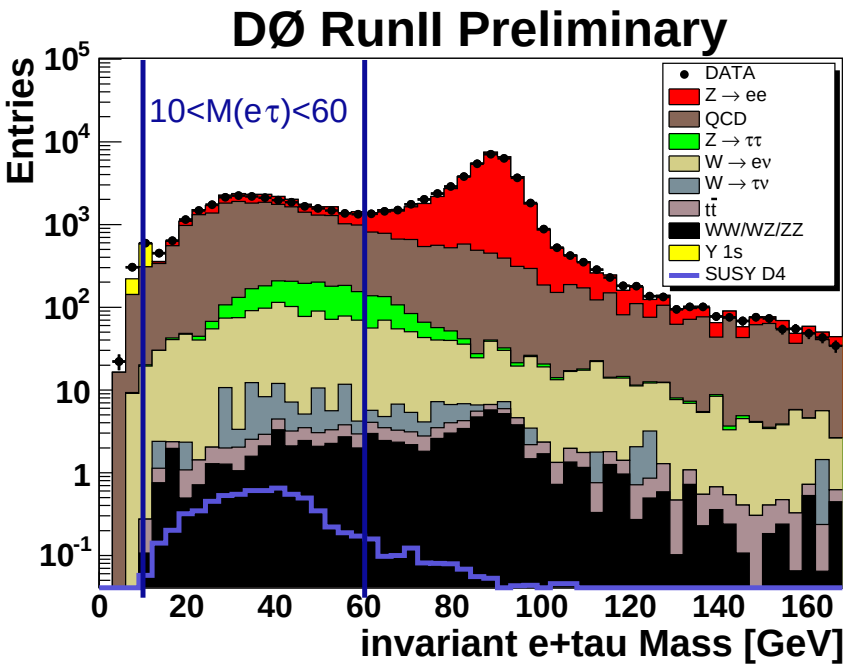
$Z \rightarrow \tau\tau_{\text{had}}$
$\rightarrow e/\mu\ \tau_{\text{had}}$

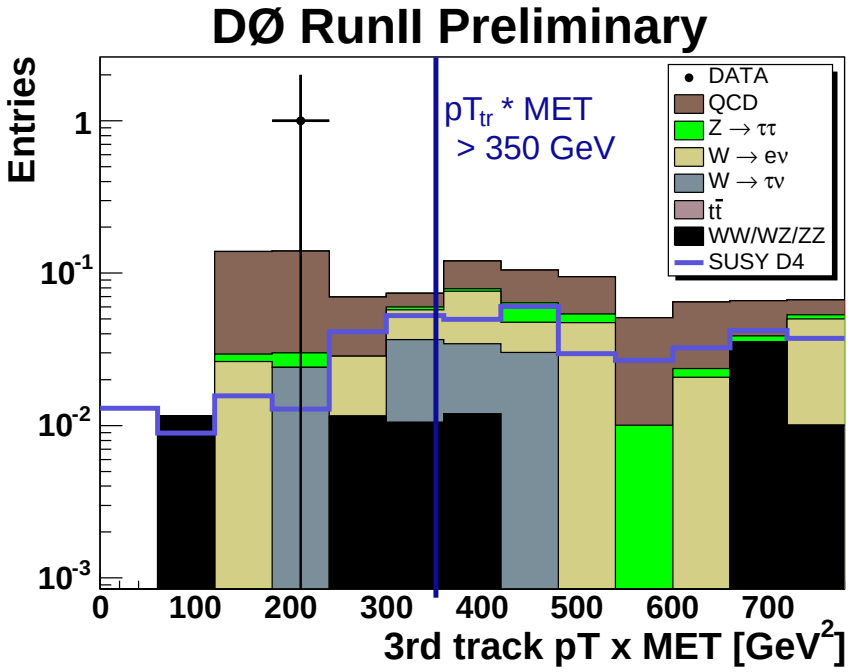
$\mu\tau\ell$: NN>0.90
$e\tau\ell$: NN>0.95





$e\tau\ell$ - analysis





leading leptons: $\mathbf{e}, \tau_{\mathbf{had}}$

$p_\perp^e > 8$ GeV

$p_\perp^\tau > 8$ GeV NN$_\tau$ >0.95

$p_\perp^{tr} > 5$ GeV iso. 3rd track

$p_\perp^\tau > 8$ GeV 2nd τ-cand.

additional cuts:

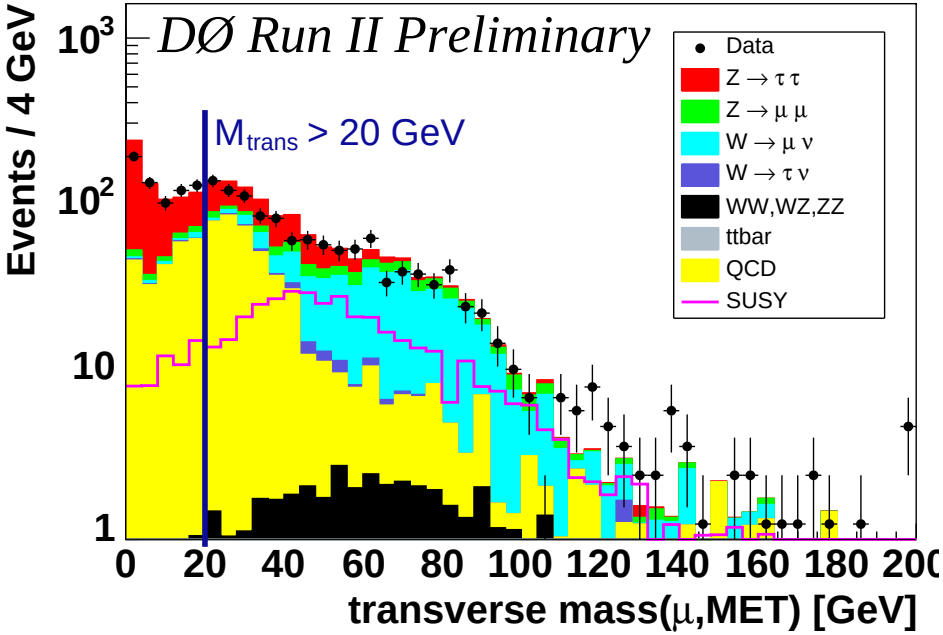
Z-veto: $10\text{ GeV} < M_{inv}^{(e,\tau)} < 60\text{ GeV}$ and $\Delta\phi_{(e,\tau)} < 2.9$

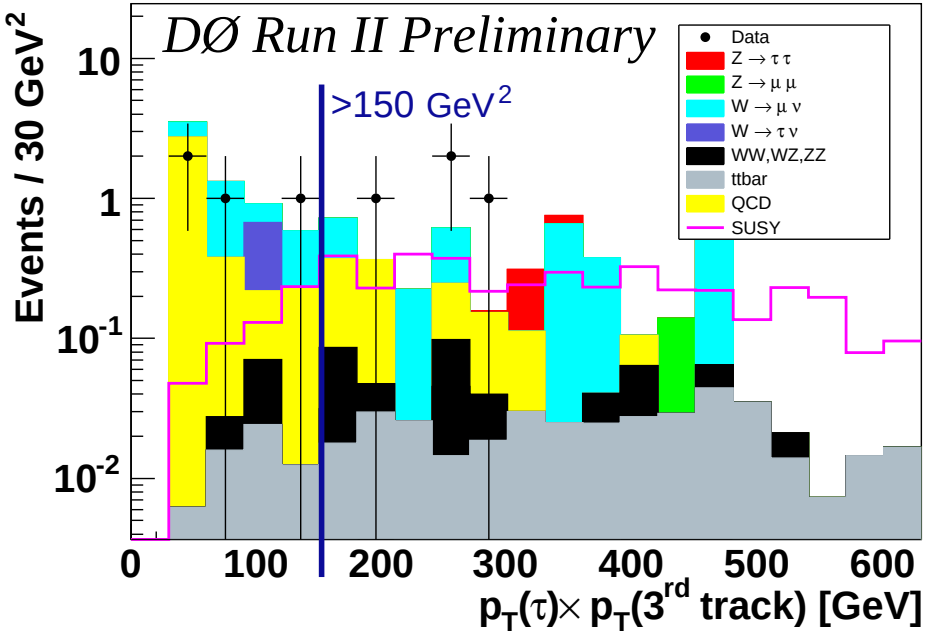
$t\bar{t}$-veto: $H_T = \sum p_\perp^{jet} < 60$ GeV

$\mathrm{Min}(M_{trans}^{e}, M_{trans}^{\tau}) > 10$ GeV

$p_\perp^{track} \cdot \not{E}_T > 350\text{ GeV}^2$

$\mu\tau\ell$ - analysis





distribution done with loose cuts

leading leptons: $\mu, \tau_{\mathbf{had}}$

$p_\perp^\mu > 14$ GeV

$p_\perp^\tau > 7$ GeV NN$_\tau$ >0.9

$p_\perp^{tr} > 4$ GeV iso. 3rd track

additional cuts:

Z-veto: $M_{inv}^{(\mu,\tau)} < 60$ GeV, $\Delta\phi_{(\mu,\tau)} < 2.9$

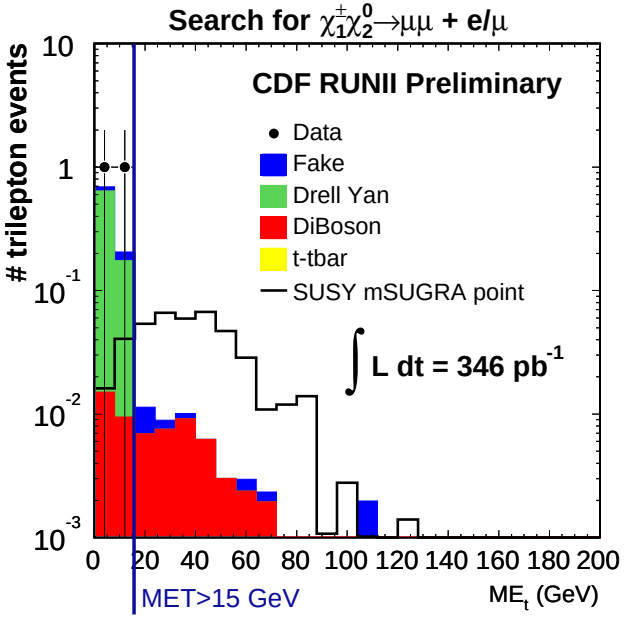
$t\bar{t}$-veto: $H_T = \sum p_\perp^{jet} < 80$ GeV

$M_{trans}^{\mu} > 20$ GeV, $M_{trans}^{\tau} > 8$ GeV

$p_\perp^\tau \cdot p_\perp^{track} > 150$ GeV^2

CDF Results ($\mathcal{L} \approx 220 - 350$ pb^{-1})

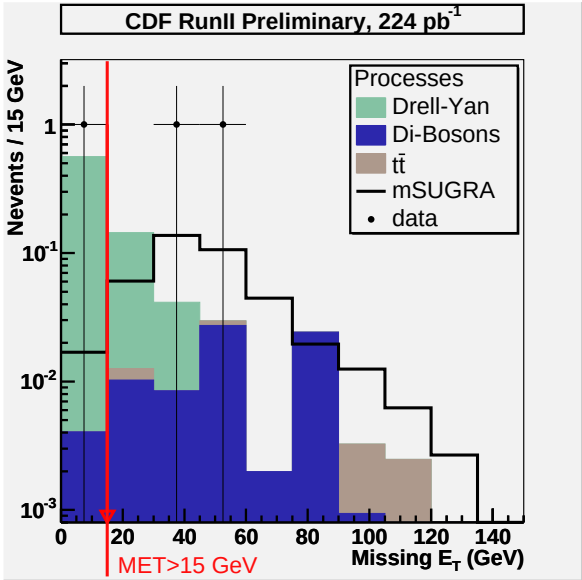
$\mu\mu$+e/μ (high $p_\perp$)

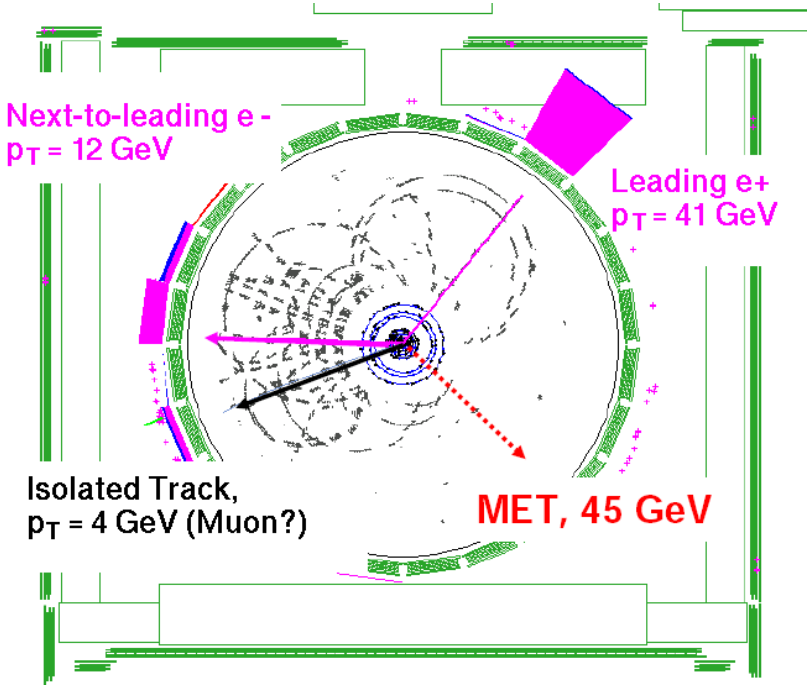


analysis	N_d	N_{bkg}^{SM}	N_{signal}
ee+e/μ	0	0.17 ± 0.05	0.49 ± 0.06
$\mu\mu$+e/μ	0	0.09 ± 0.03	0.37 ± 0.05
eeℓ	2	0.48 ± 0.07	0.36 ± 0.27

SUSY-point: $M(\tilde{\chi}_1^\pm) = 113$ GeV, $M(\tilde{\chi}_1^0) = 66$ GeV
$m_0 = 100$ GeV, $m_{1/2} = 180$ GeV, $\tan(\beta)$=5, $\mu > 0$, A_0=0

eeℓ (low $p_\perp$)

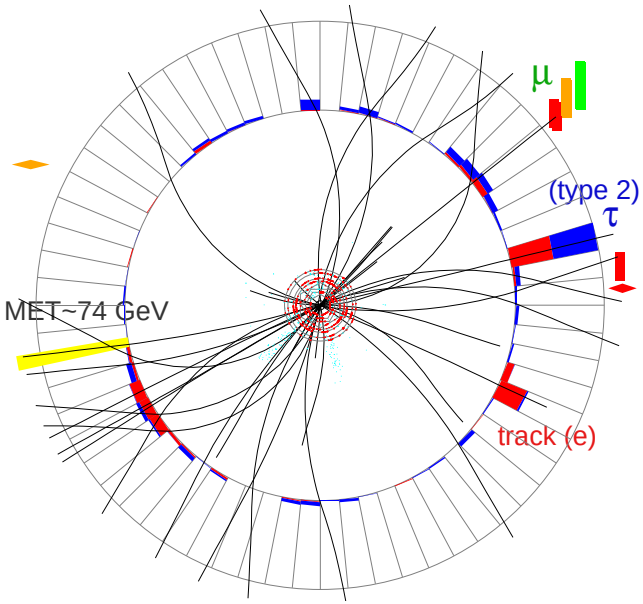




http://www-cdf.fnal.gov/physics/exotic/exotic.html

DØ Results ($\mathcal{L} \approx 320$ pb^{-1})

analysis	N_d	N_{bkg}^{SM}	N_{signal}
$ee\ell$	0	0.21 ± 0.12	2.15 ± 0.18
$e\mu\ell$	0	0.31 ± 0.13	1.47 ± 0.13
$\mu\mu\ell$	2	1.75 ± 0.57	0.65 ± 0.09
$LS\mu\mu$	1	0.64 ± 0.38	0.62 ± 0.16
$e\tau\ell$	0	0.58 ± 0.14	0.41 ± 0.04
$\mu\tau\ell$	1	0.36 ± 0.13	0.72 ± 0.06
comb.	4	3.85 ± 0.75	6.02 ± 0.30



SUSY-point (phenomenological model): $\sigma \times BR$**=0.231 pb**

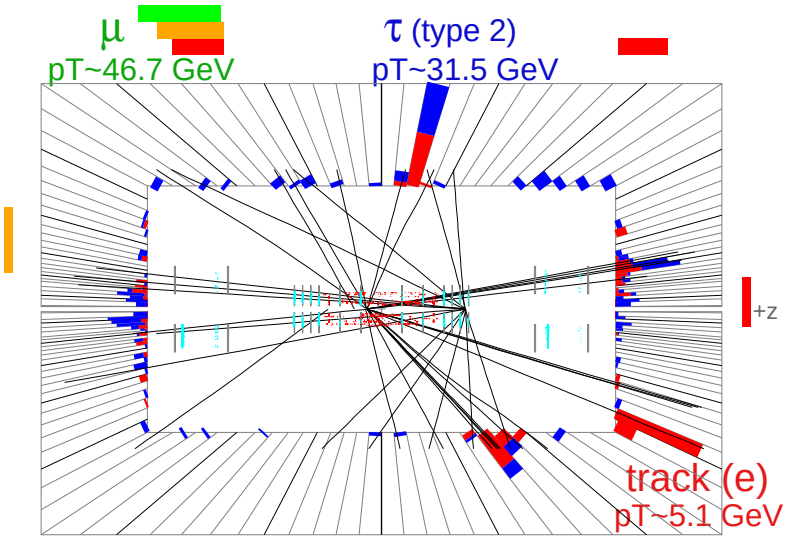
$M(\tilde{\chi}_1^{\pm}) = 114$ GeV, $M(\tilde{\chi}_2^0) = 114$ GeV, $M(\tilde{\ell})_R = 115$ GeV

Similar to the mSUGRA **point:** $\sigma \times BR$**=0.188 pb**

$M(\tilde{\chi}_1^{\pm}) = 110$ GeV, $M(\tilde{\chi}_2^0) = 114$ GeV, $M(\tilde{\ell})_R = 120$ GeV

$m_0 = 92$ GeV, $m_{1/2} = 180$ GeV, $\tan(\beta) = 3$, $\mu > 0$, $A_0 = 0$

http://www-d0.fnal.gov/results/publications_talks/thesis/

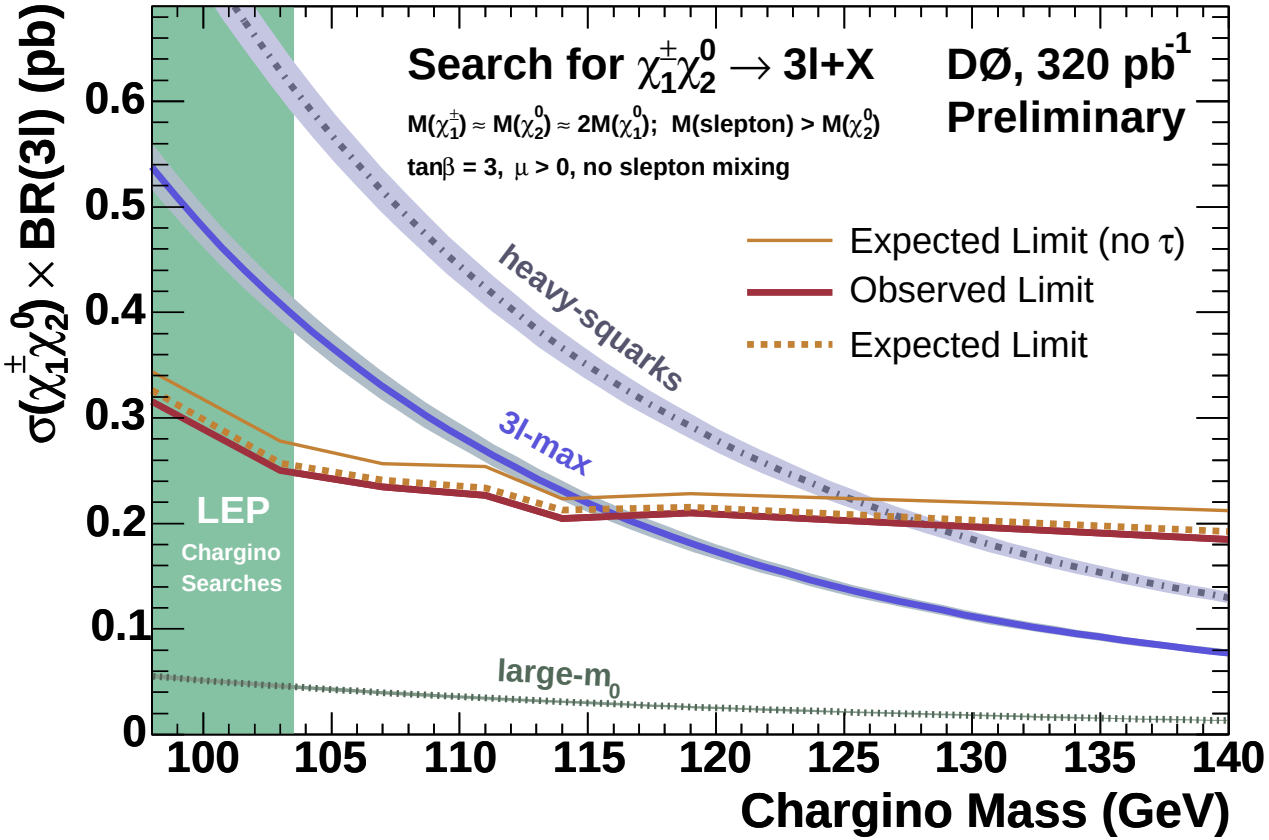


Interpretation in Different Scenarios

3ℓ-max: $M(\tilde{\ell}) \approx M(\tilde{\chi}_2^0)$
maximal leptonic BR due to dominating $\tilde{\ell}$-decays
$M(\tilde{\chi}^{\pm}) > 116$ GeV
no $\tilde{\ell}$-mixing assumed

Large-m_0: small lep.BR, $\tilde{\chi}_2^0$ mainly via W^*/Z^*

Heavy-Squarks:
$M(\tilde{\chi}^{\pm}) > 128$ GeV
(enhanced σ_{SUSY} due to relaxed mass unification and supressed t-channel interference)



Shaded bands: PDF and scale uncertainties

Nearly model independent cross section limits (assume certain mass ratios) $\longrightarrow$ interprete as mass limits in different benchmark scenarios (relax mass unification)!
The sensitivity extends beyond existing LEP limits at $M(\tilde{\chi}^{\pm}) > 103.5$ GeV.

Conclusions

- CDF and DØ have searched for associated $\tilde{\chi}^{\pm}\tilde{\chi}^{0}$ production in the challenging low mass region $\rightarrow$ very soft leptons
- Several different final states have been investigated, including hadronically decaying τ-leptons (at DØ)
- No evidence of signal (DØ) $\rightarrow$ combined trilepton analyses:

  $\approx$ **model independent σ-limits** (certain mass ratios)
  M($\tilde{\chi}_1^{\pm}$) > 116 GeV in the "3ℓ-max" scenario
  no limits from CDF yet, but many more analyses in progress...

- Analyses presented are based on: $\mathcal{L}_{\mathbf{rec}} \approx$ **220-350 pb^{-1}**
- Experiments have on tape about: $\mathcal{L}_{\mathbf{del}} \approx$ **1000 pb^{-1}**
- New data will allow extended coverage of SUSY par. space
  $\Longrightarrow$ **potential for discoveries**

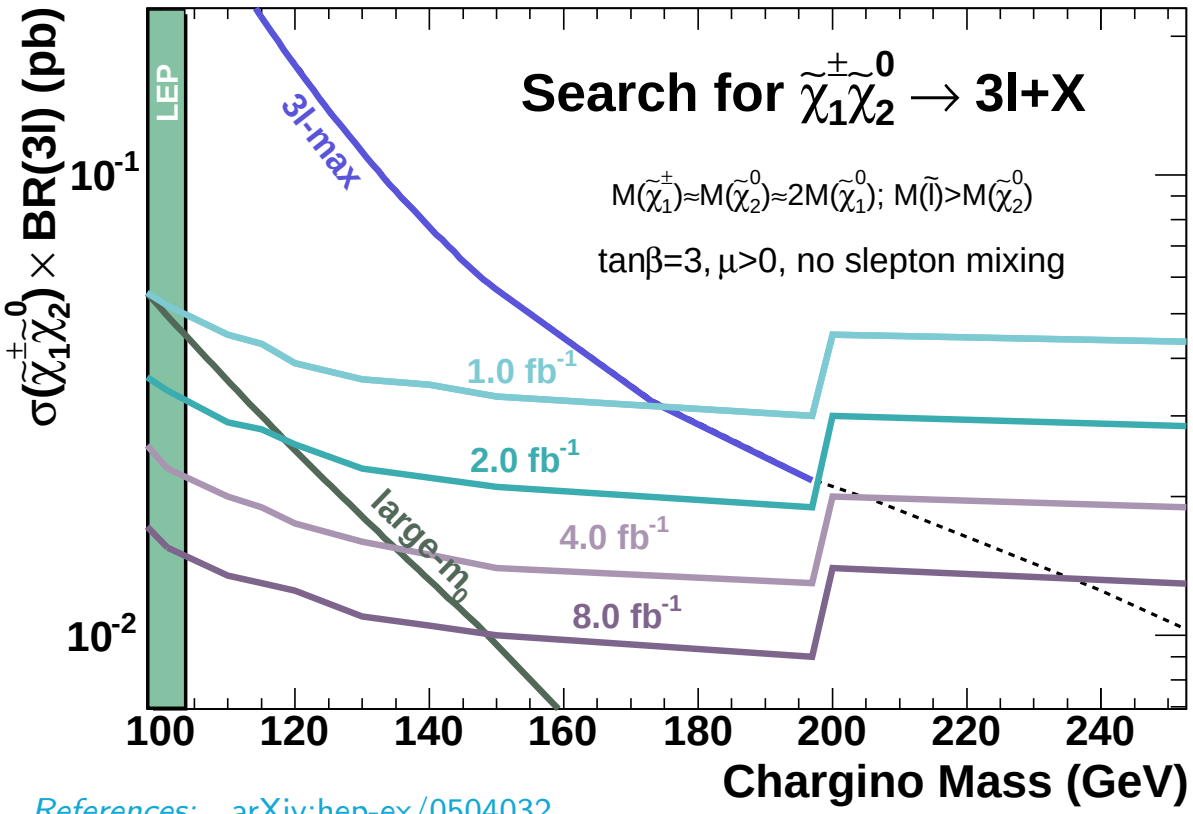
BACKUP slides

Outlook - SUSY Reaches

Assumptions:

- background reduction of 50% in each channel
- same backgr.-level in $\mu\mu\ell$-channel as in $ee\ell$
- fractional error in the exp. backgr.: $\approx 10\%$

Upper limits correspond to integrated luminosities of 1, 2, 4 and 8 fb^{-1} per exp.

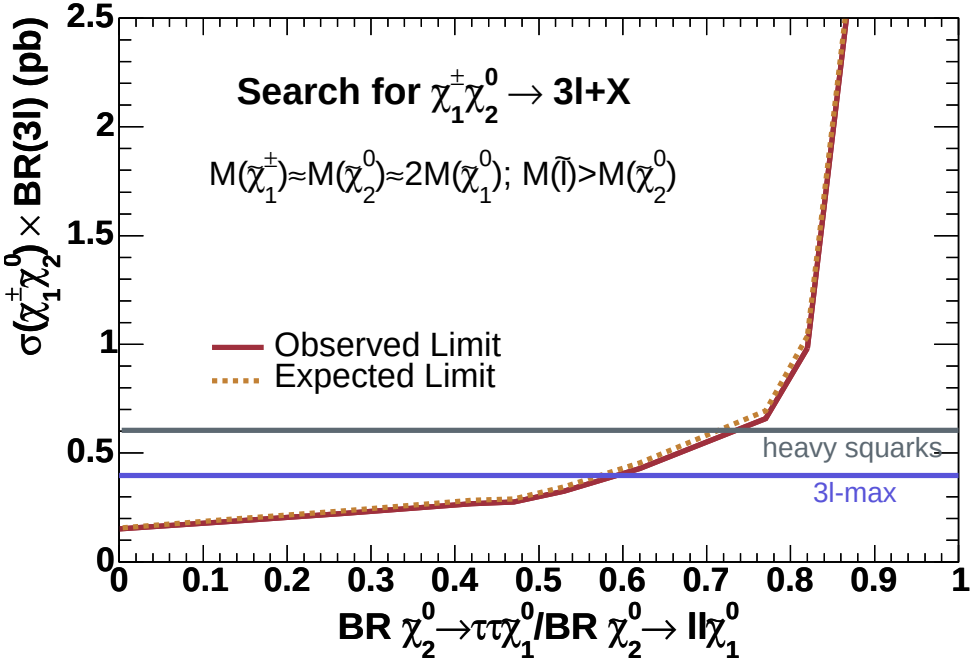


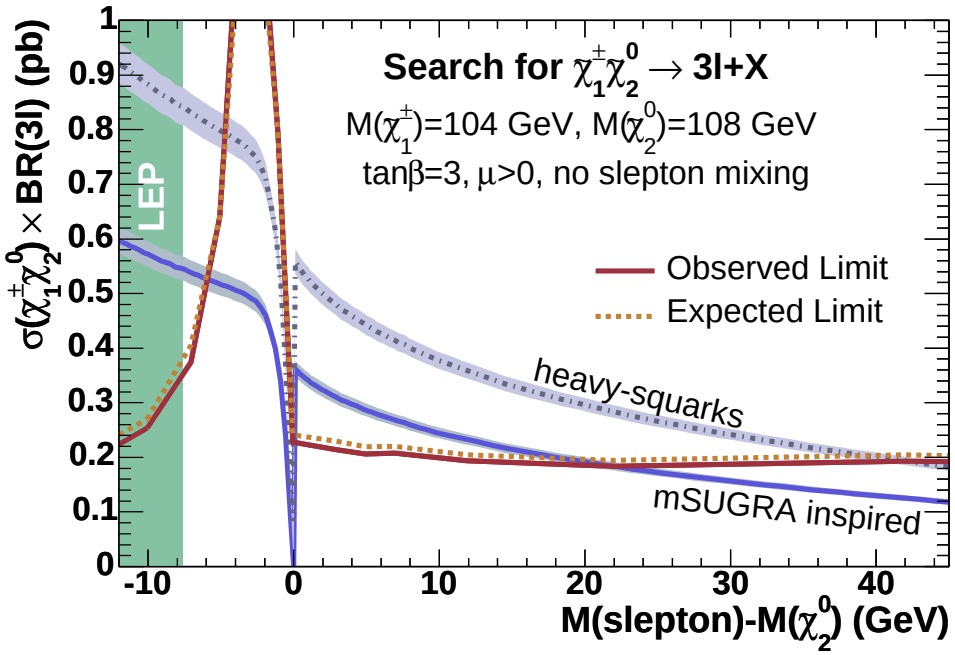
References: arXiv:hep-ex/0504032

http://www-cdf.fnal.gov/physics/projections/

The mSUGRA-inspired phenomenological SUSY-models have trilepton total cross sections, $\sigma\times$BR(3ℓ), between the 3ℓ-max and the Large-m_0 scenario.
$\rightarrow$ discovery potential up to $M(\tilde{\chi}^{\pm}) \approx$250 GeV.

Further Interpretation of Results





Slepton mixing: Exclude $M(\tilde{\chi}^\pm)$ of 104 GeV for τ-fractions of:

3ℓ-max: up to 59%

Heavy Squarks: up to 73%

cMSSM models: no $\tilde{\ell}$-mixing

Excluded $\tilde{\ell}$-mass ranges:

$M(\tilde{\chi}_2^0) < M(\tilde{\ell}) < M(\tilde{\chi}_2^0)$+20 GeV

$M(\tilde{\chi}_2^0) < M(\tilde{\ell}) < M(\tilde{\chi}_2^0)$+40 GeV

Sensitivity in 2-body domain:

$M(\tilde{\ell}) < M(\tilde{\chi}_2^0)-6$ GeV / $M(\tilde{\chi}_2^0)-4$ GeV

Systematics at CDF and DØ

Systematics include:

- Luminosity
- PDF/scale uncertainties of the SM cross sections

- Lepton ID criteria
- $\mathrm{e}/\mu \quad \mathrm{p}_\perp$-resolutions / smearing
- τ identification (many variables, NN)

- Fake rates
- Jet Energy Scale