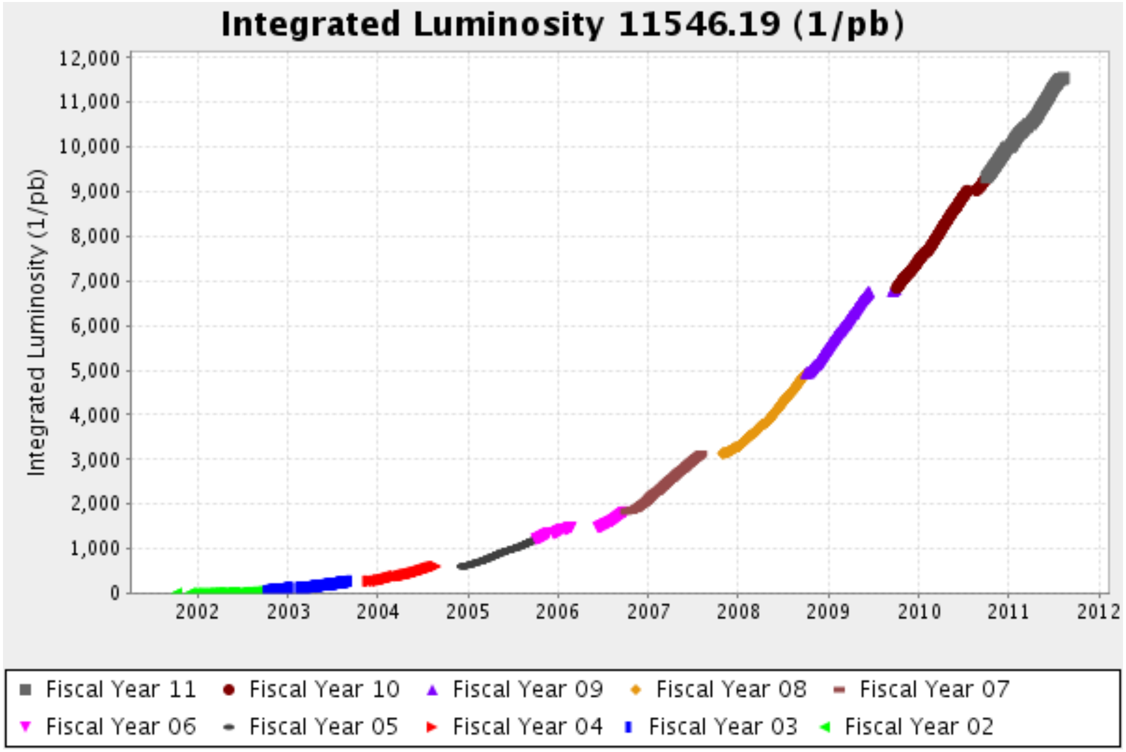
SUSY Results from the Tevatron

SUSY 2011
28 Aug – 2 Sept, Fermilab

Leo Bellantoni, FNAL

The Tevatron

11~12 fb^{-1} delivered per experiment

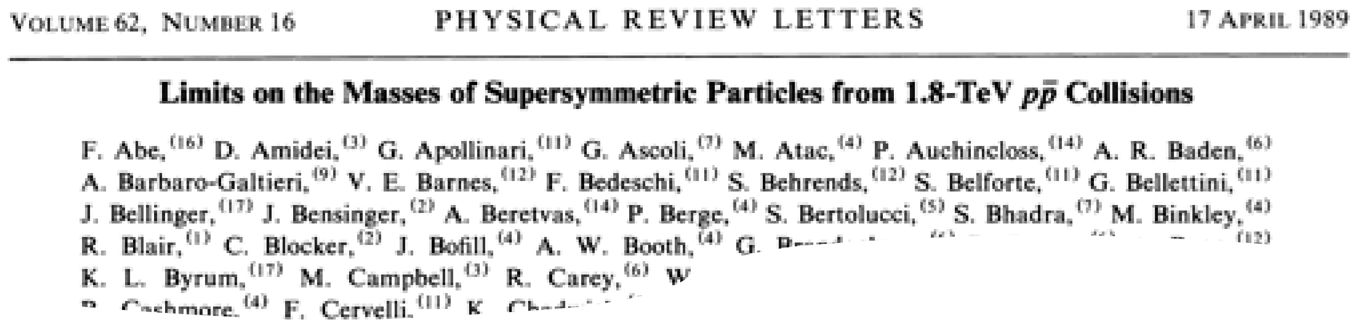


Both CDF & D0 detectors measure e, μ, γ, jets, τ well and tag b, c with vertex detectors

After so many years, these are well-understood detectors

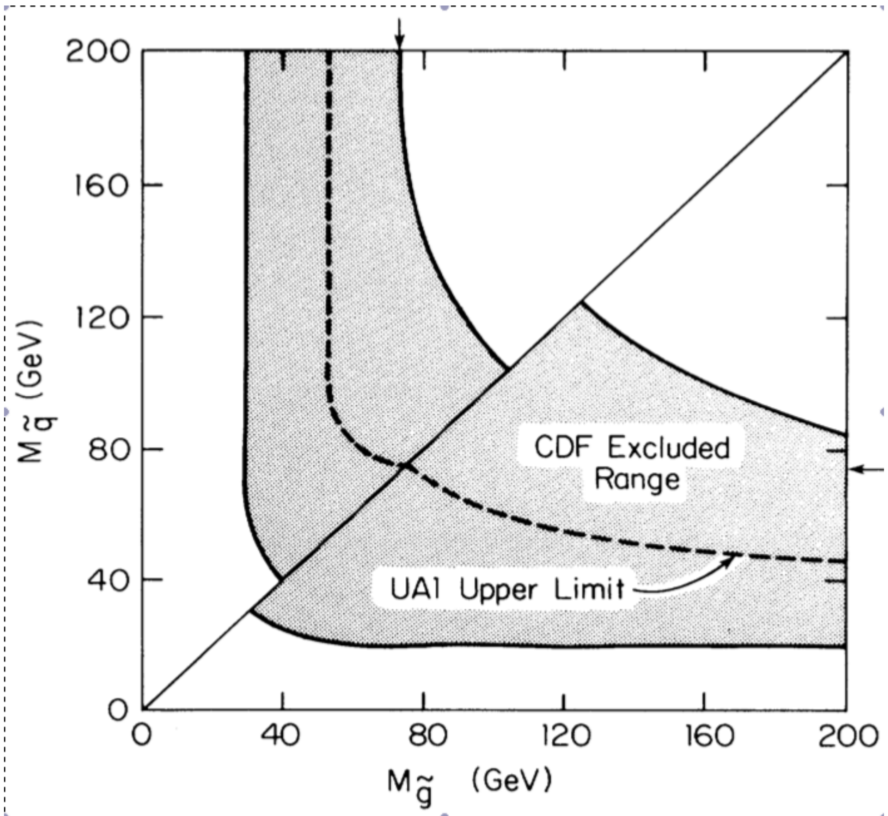
http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

A Glance Back


VOLUME 62, NUMBER 16 PHYSICAL REVIEW LETTERS 17 APRIL 1989

Limits on the Masses of Supersymmetric Particles from 1.8-TeV $p\bar{p}$ Collisions

F. Abe,[16] D. Amidei,[3] G. Apollinari,[11] G. Ascoli,[7] M. Atac,[4] P. Auchincloss,[14] A. R. Baden,[6] A. Barbaro-Galtieri,[9] V. E. Barnes,[12] F. Bedeschi,[11] S. Behrends,[12] S. Belforte,[11] G. Bellettini,[11] J. Bellinger,[17] J. Bensinger,[2] A. Beretvas,[14] P. Berge,[4] S. Bertolucci,[5] S. Bhadra,[7] M. Binkley,[4] R. Blair,[1] C. Blocker,[2] J. Bofill,[4] A. W. Booth,[4] G. ...
K. L. Byrum,[17] M. Campbell,[3] R. Carey,[6] W ...
... F. Cervelli,[11] K. ...

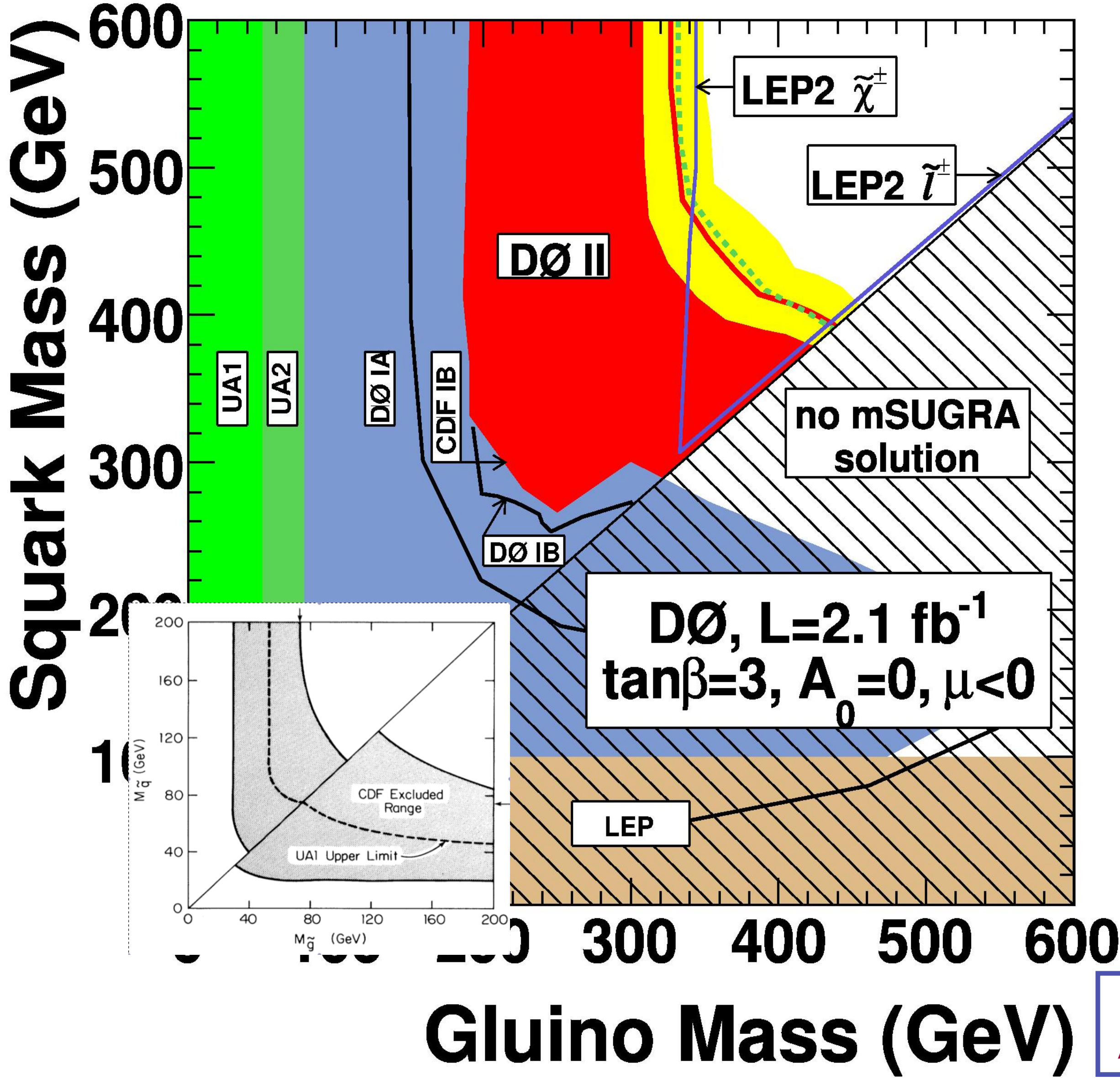


squarks and gluinos
in jets + Missing E_T
25.3 nb^{-1}

$W \rightarrow \tau\upsilon, Z \rightarrow \upsilon\upsilon$

HF production backgrounds estimated from Monte Carlo alone

A Glance Back



$\mathcal{O}[10^2]$ as much data

Background models now include diboson production, top pair production, and QCD rates from data, not MC

Analysis techniques now much more advanced:

- ***Combined selection criteria***
- ***Multivariate discriminant***
- ***Limit setting procedures***

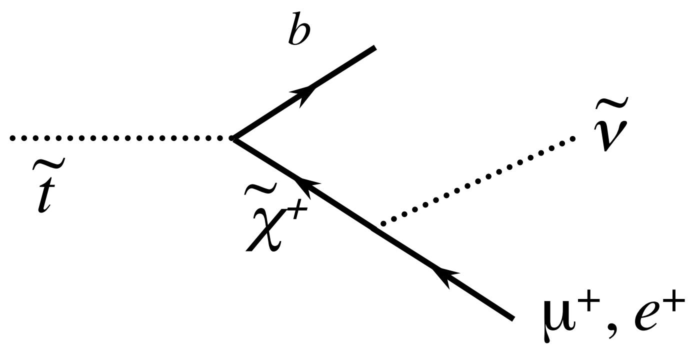
Abazov, etal, Phys.Lett.B660,449(2008)
Abazov, etal, Phys.Lett.B680,24(2009)
Aaltonen etal, Phys.Rev.Lett. 102 (2009) 121801

Table of Contents

- **Recent results**
  - **stop & sneutrino in $e\mu$**
  - **like sign dileptons**
  - $B_s \rightarrow \mu\mu$
  - **GMSB in $\gamma\gamma$**
  - **SUSY & Dark Photons**

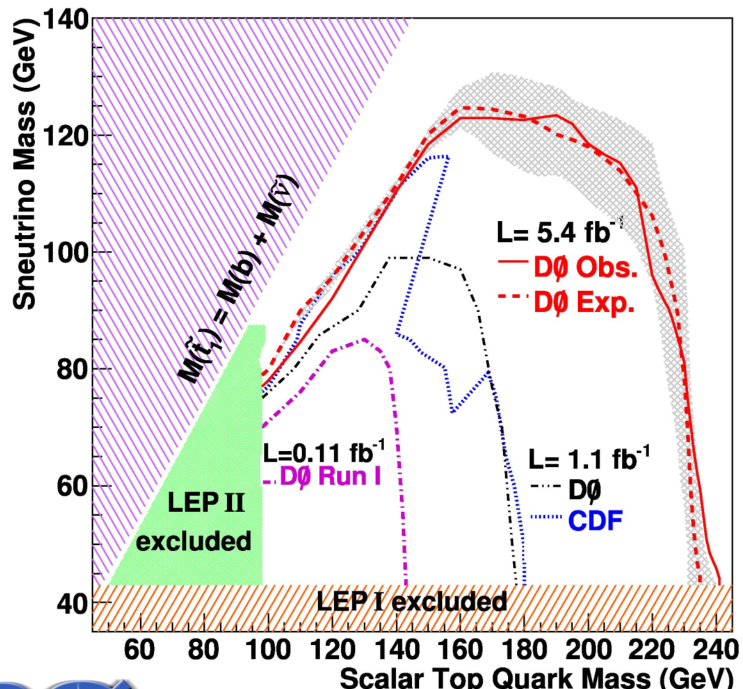
- **Looking forward**
  - **charm tagging**
  - **tau tagging**
  - **a few words about pp vs $p\bar{p}$**

$\tilde{t}$ pairs in $e\,\mu\,\not{E}_T$



Backgrounds are

$p\bar{p} \to Z/\gamma^* \to \tau^+\tau^- \to e^+\mu^- 4\nu$
occurs at relatively low $\not{E}_T$, $p_T(\ell^\pm)$ (< 20 GeV) and large opening angle ($\Delta\phi > 2.8$) in the transverse plane



$p\bar{p} \to t\bar{t}$ is basically the same thing without the SUSY; it can be suppressed with MVA methods

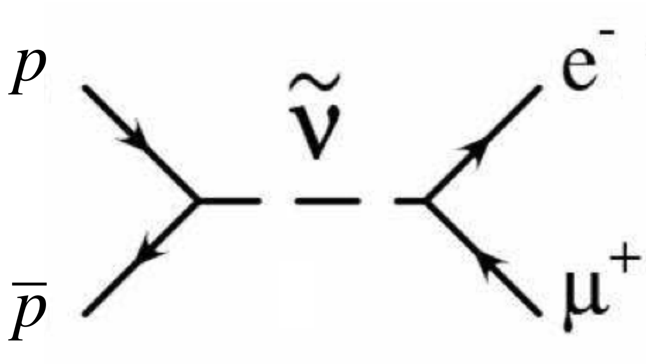
WW likewise

Abazov et.al., Phys.Lett. B696,321(2011)
Aaltonen et al. Phys. Rev. D82, 092001 (2010)

Other stop searches:

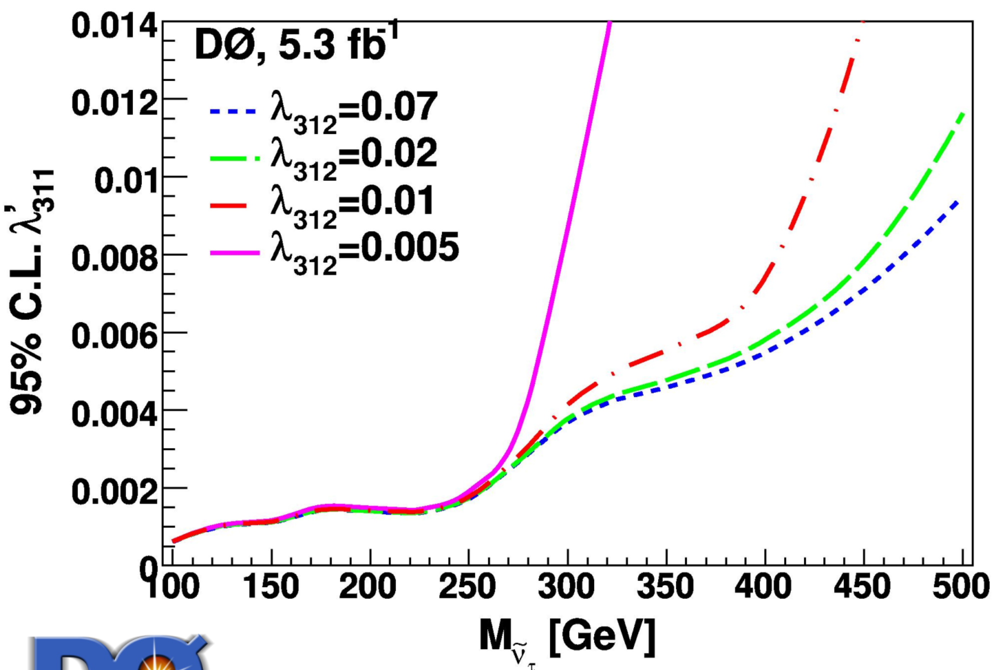
- top-like $\ell\ell$
  Aaltonen etal, Phys.Rev.Lett. 104,251801(2010)
  Abazov etal, Phys.Lett. B675,289 (2009)
- top-like ℓ+*jet* Abazov Phys.Lett.B674,4(2009)

$\tilde{\nu}$ in $e\ \mu$



A search for $e\mu$ resonances
Parameterized in terms of
R-Parity violating sneutrino:

$$L = -\lambda_{312}(\tilde{\nu}_L)[\bar{\mu}_R e_L + \bar{e}_R \mu_L] - \lambda'_{311}(\tilde{\nu}_L)[\bar{d}_R d_L] + h.c.$$



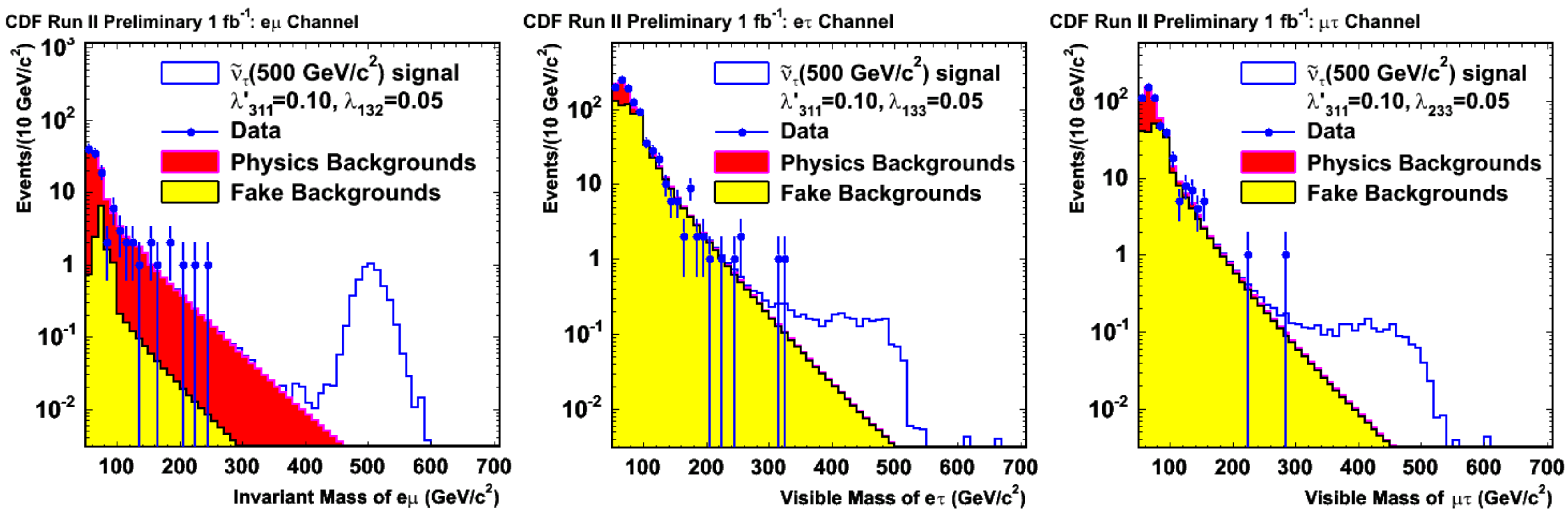
Similar to the $\tilde{t}$ search,
but select low-$\not{E}_T$ events:

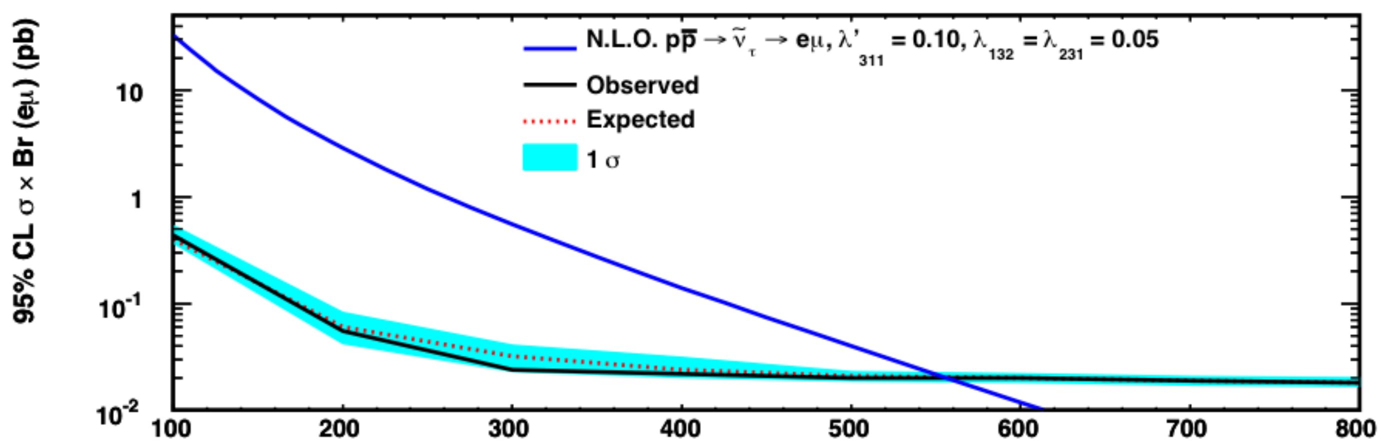
20 GeV < $\not{E}_T$
0.7 < $\phi\,(\mu, \not{E}_T) < 2.3$

Jet veto reduces $t\ \bar{t}$

Abazov et.al.,
Phys.Rev.Lett. 105:191802 (2010)

$\tilde{\nu}$ in $e\mu$, $e\tau$ and $\mu\tau$





$M(\tilde{\nu})$ GeV

Aaltonen et.al., Phys.Rev.Lett. 105:191801 (2010)

Like Sign Dileptons I

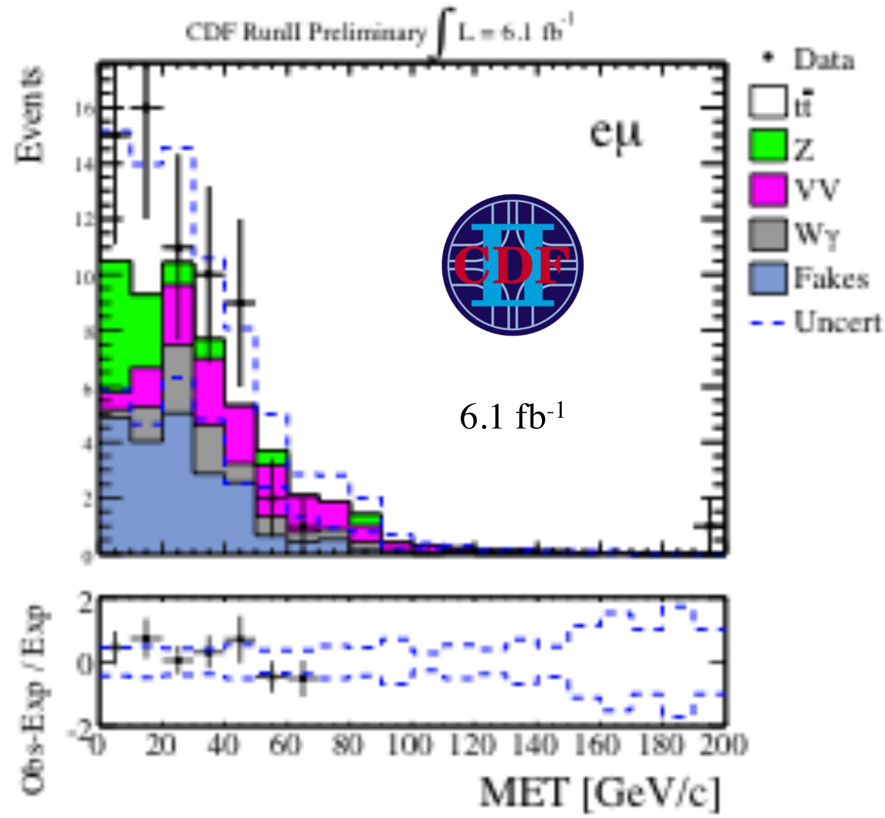
2 high p_T leptons of same (non-zero) charge is rare in $p\bar{p}$ collisions: $\sigma(p\bar{p} \to WZ/ZZ \to \ell^\pm\ell^\pm) \sim$ few pb

This makes an excellent signature for many BSM extensions: SUSY, Universal Extra Dimensions, heavy Majorana ν, 4th generation fermions, H^{++}

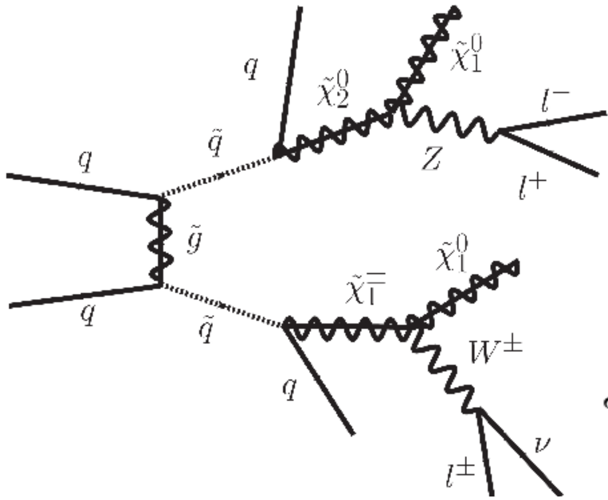
1st step: model-independent search for isolated same-charge same-vertex $e^\pm$ or $\mu^\pm$

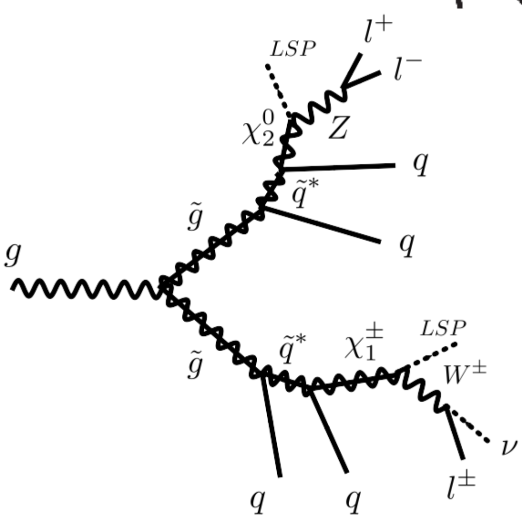
$p_T^{(1)} > 20$ GeV $|\eta| < 1.1$
$p_T^{(2)} > 10$ GeV $|\eta| < 1.1$
Veto 86GeV $< m(\ell^+\ell^-) <$ 96GeV
Veto 86GeV $< m(e^+e^-) <$ 96GeV

CONF Note 10464



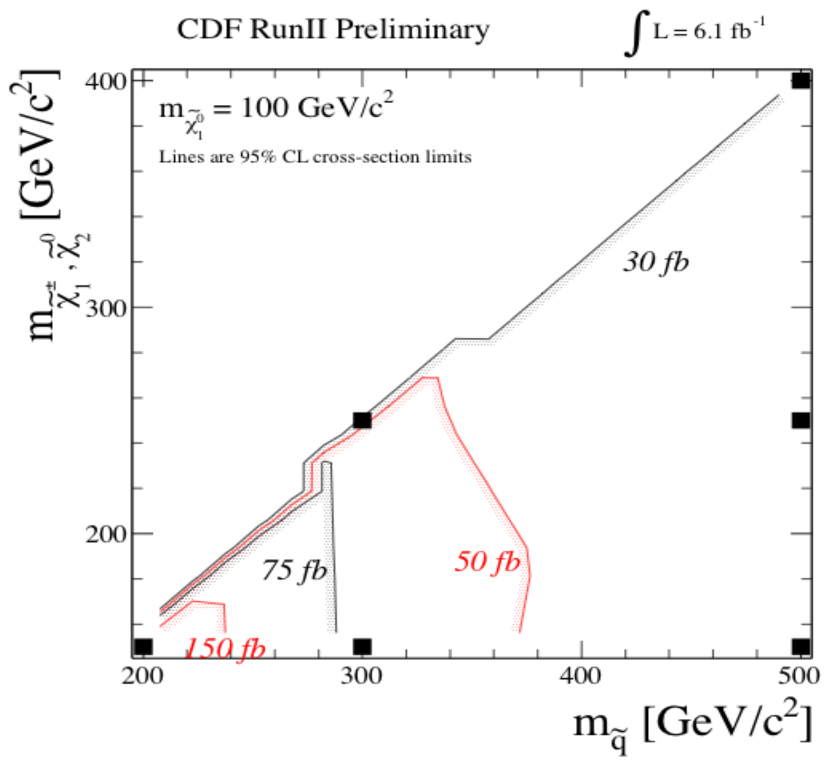
Like Sign Dileptons II





2nd step: Require 1 or more jets in addition to the model-independent selection

Set limits on production cross-sections times decay branching ratios as function of
$m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_2^0)$ *and* $m(\tilde{q}), m(\tilde{g})$



6.1 fb^{-1}

CDF Note 10465

Using $Br(\tilde{q} \to q\tilde{\chi}_1^\pm) = Br(\tilde{q} \to q\tilde{\chi}_2^0) = 1/2$
and parameterization of Alwall, Schuster & Toro, Phys.Rev. D79,075020(2009)

Like Sign Dileptons III

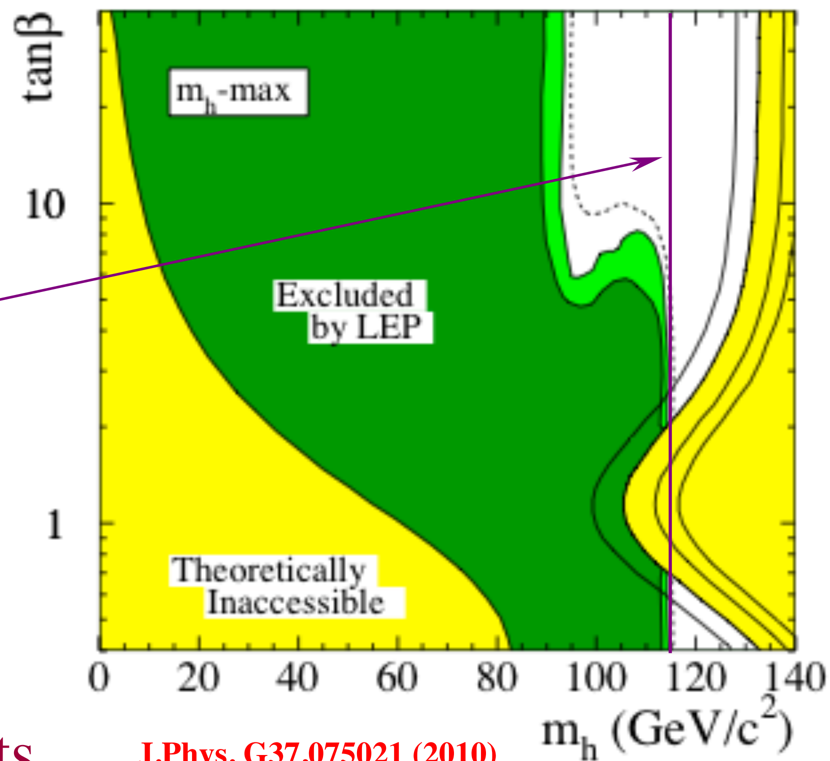
Minimal Supersymmetry has 5 Higgs bosons; lightest is CP-even scalar h

With radiative corrections $m_h \leq 135\text{GeV}$ for all $\tan\beta$ (lower for $\tan\beta \approx 1$)

Existing limit is close to this bound!

In mSUGRA, the SM Higgs bound $m_h \leq 114\text{GeV}$ applies

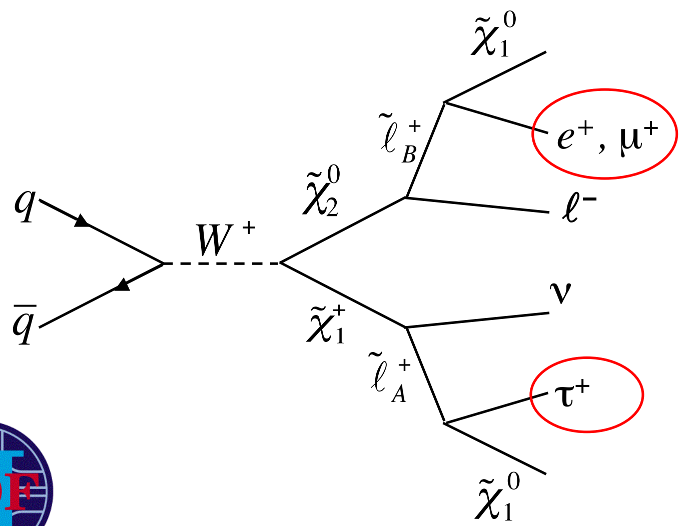
Favors high $\tan\beta$ - which means, processes that decay to τ are of particular interest

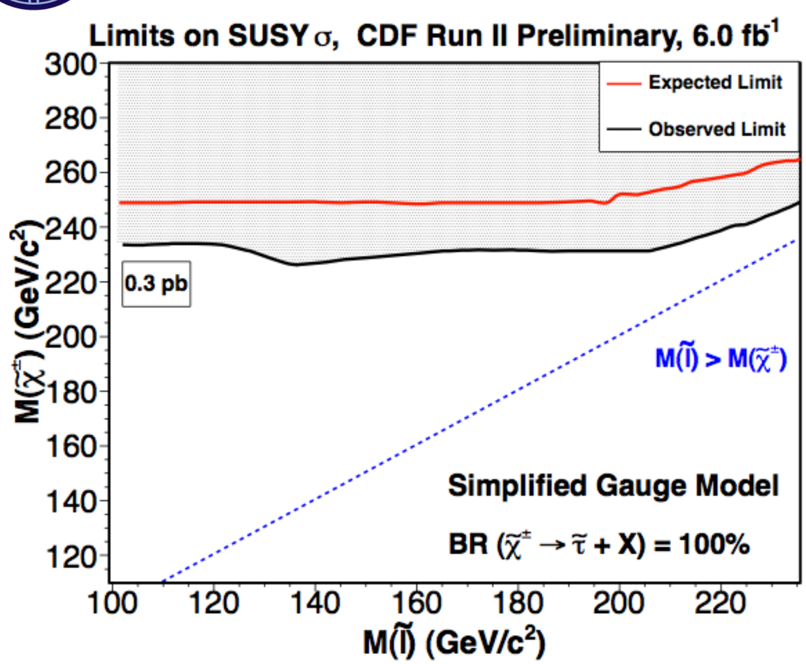


J.Phys. G37,075021 (2010)

3rd step: look for τe, $\tau\mu$ events in same-sign sample

Like Sign Dileptons III





Look for a hadronically decaying τ with μ or e of the same charge

"Simplified gravity" model 1:

$$Br\left(\tilde{\chi}_2^0 \to \tilde{\tau}^{\pm}\tau^{\mp}\right) = Br\left(\tilde{\chi}_1^{\pm} \to \tilde{\tau}^{\pm}\nu\right) = 1$$

$$Br\left(\tilde{\ell}^{\pm} \to \ell\tilde{\chi}_1^0\right) = 1$$

$$m(\tilde{\chi}_2^0) = m(\tilde{\chi}_1^{\pm})$$

"Simplified gravity" model 2:

Similar, but

$$Br\left(\tilde{\chi}_2^0 \to \tilde{\tau}^{\pm}\tau^{\mp}\right) = Br\left(\tilde{\chi}_1^{\pm} \to \tilde{\tau}^{\pm}\nu\right) = 1/3$$

$$Br\left(\tilde{\ell}^{\pm} \to \ell\tilde{\chi}_1^0\right) = 1, \textit{ flavor conserving}$$

"Simplified gauge" model:

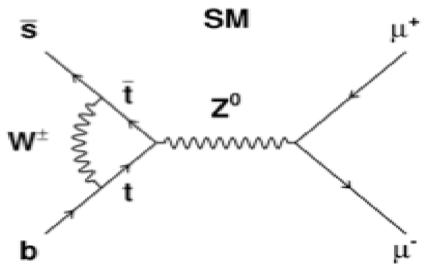
$$Br\left(\tilde{\chi}_2^0 \to \tilde{\tau}^{\pm}\ell^{\mp}\right) = 1/3$$

$$Br\left(\tilde{\chi}_1^{\pm} \to \tilde{\tau}^{\pm}\nu\right) = 1 \qquad m(\tilde{\chi}_1^0) \approx 0$$

$$Br\left(\tilde{\ell}^{\pm} \to \ell\tilde{\chi}_1^0\right) = 1, \textit{ flavor conserving}$$

CDF Note 10611

$B_S \to \mu\mu$



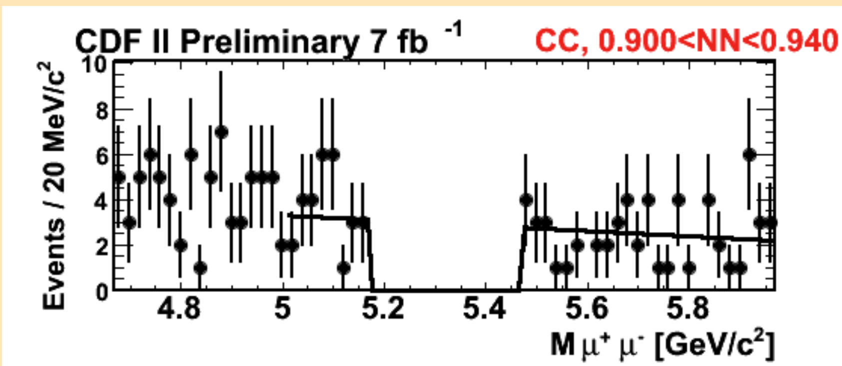
$Br(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$
$Br(B_d \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$
A. J. Buras et al., JHEP 1010:009,2010

Normalize to $B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+$

In MSSM $Br(B_s \to \mu^+\mu^-) \propto \tan^6(\beta)$

Continuum backgrounds are:
- $b \to c\, \mu^- X$; $c \to (s,d)\, \mu^+ X$
- $Z/\gamma^* \to \mu^+ \mu^-$ and (wrong) large impact parameter
- $p\bar{p} \to b\bar{b} \to \mu^+ \mu^- X$
- Fake muons

Fit $M(\mu\mu)$ to a line outside signal region



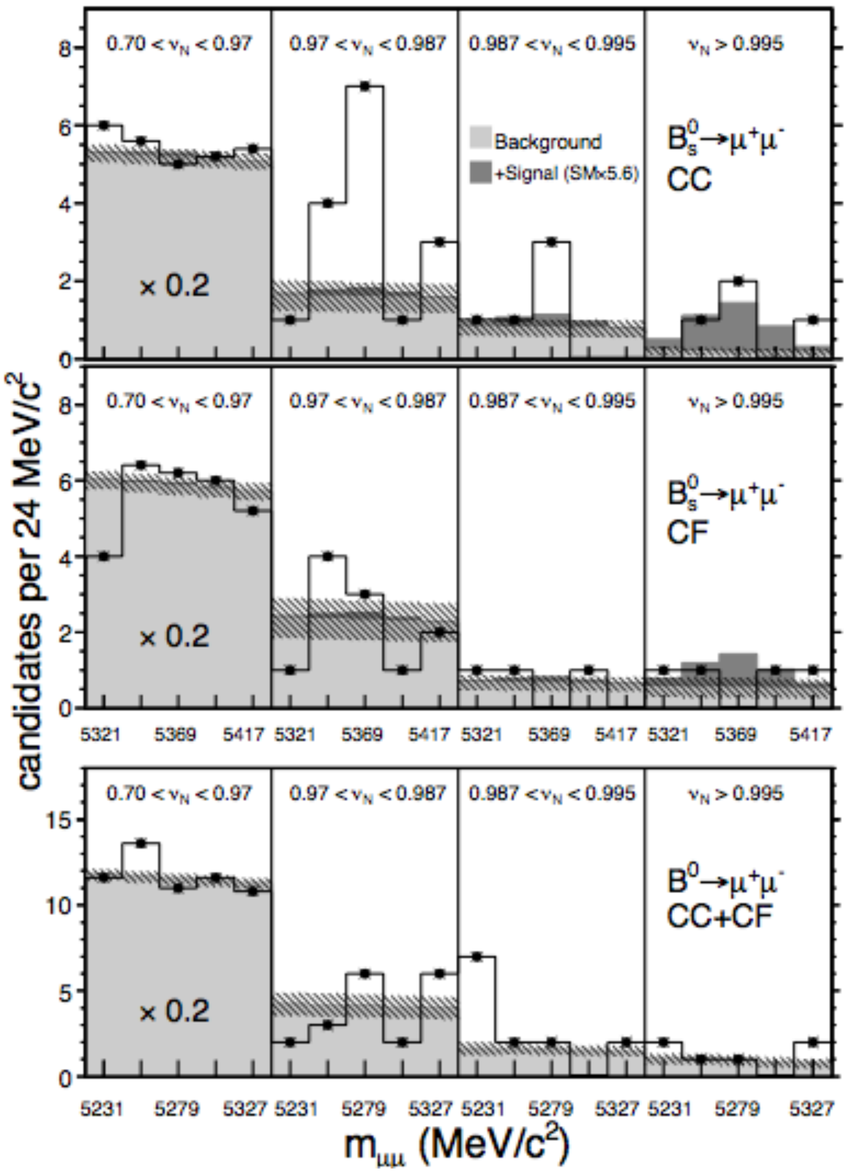
Non-continuum background:
$B_S \to$ 2 hadrons which are mis-identified as muons

Estimated in D^{*+} tagged $D^0 \to K^-\pi^+$ data

For 0.995 < NNet < 1 (most pure sample)

0.92 ± 0.21 events in B_d window
0.11 ± 0.11 events in B_s window

$B_S \to \mu\mu$



Likelihood fit includes all bins in $M(\mu\mu)$, NN

Systematic uncertainties included as nuisance parameters, modeled as Gaussian

Including S.M. contribution as background, p-value is 1.9% for B_S box, >23% for B_d box.

$$Br\left(B_d \to \mu^+\mu^-\right) < 5.0 \times 10^{-9} \quad 90\%\ C.L.$$
$$4.6 \times 10^{-9} < Br\left(B_s \to \mu^+\mu^-\right) < 39 \times 10^{-9}$$

Central value for S corresponds to 5.6 times SM rate

7 fb^{-1}

arXiv:1107.2304

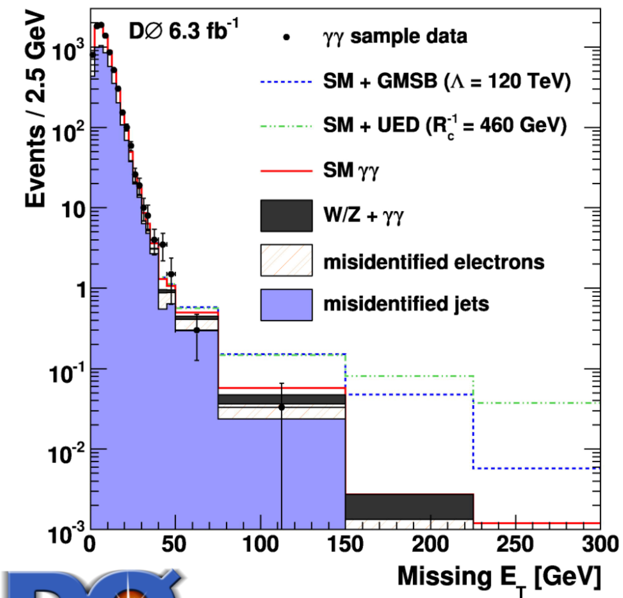
But later CMS result on 1.14fb^{-1} (arXiv:1107.5834) was $Br(B_S \to \mu^+\mu^-) < 19 \times 10^{-9}$

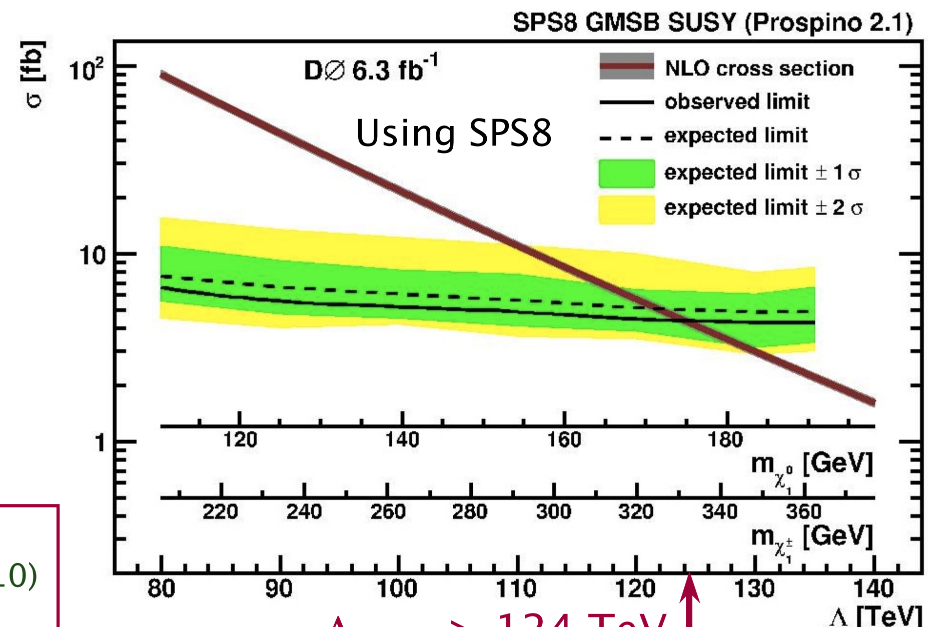
GMSB in $\gamma\gamma\not{E}_T$

In Gauge Mediated Supersymmetry Breaking, gravitino is LSP
Gravitino is dark matter candidate if m_G < few keV

$p\bar{p}$ collisions produce SUSY particles
cascade down to NLSP & then to gravitino
Phenomenology determined by NLSP

One clean signature is when last decay in the chain is $\tilde{\chi}^0\tilde{\chi}^0 \rightarrow \gamma\tilde{G}\gamma\tilde{G}$





Λ_{GMSB} > 124 TeV

$$m\left(\tilde{\chi}_1^0\right) > 175\,GeV,\ m\left(\tilde{\chi}_1^\pm\right) > 331\,GeV$$

UED limits also found
Abazov et.al. PRL 105, 221802 (2010)

Aaltonen et al. (CDF Collaboration), Phys. Rev. Lett.104, 011801 (2010).

SUSY & Dark Photons

PAMELA, ATIC, Fermi LAT, INTEGRAL, HEAT, AMS-01, WMAP ('haze') all have results that *could* be interpreted as dark matter annihilation to e^+e^- near the center of the Milky Way

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Arkani-Hamed & Weiner JHEP 0812:104 (2008)
Arkani-Hamed, Finkbeiner, Slatyer & Weiner
     Phys.Rev.D 79,015014 (2009)
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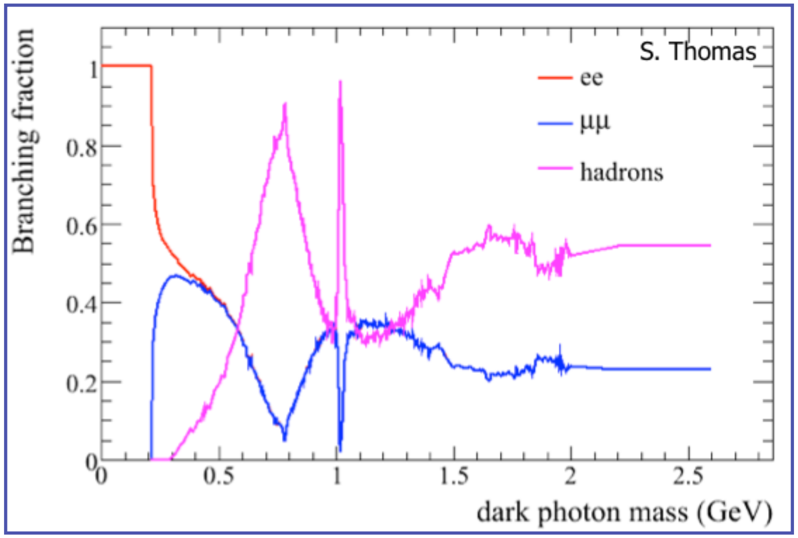
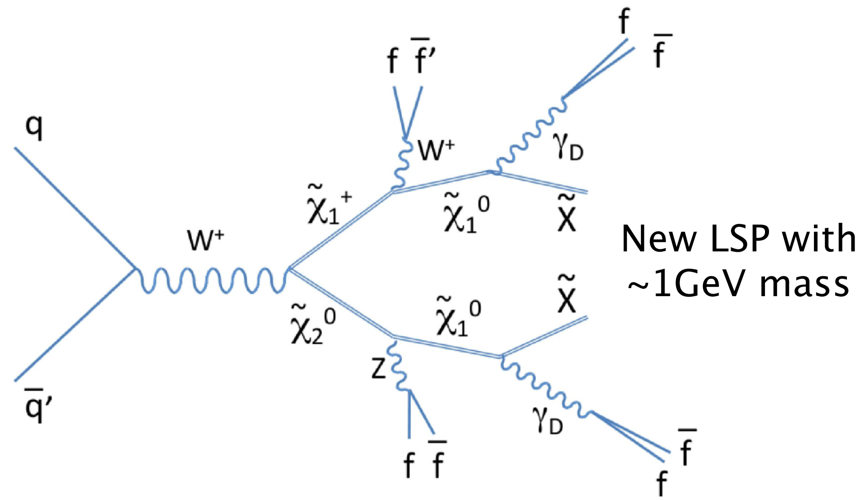
⇨ **try to fit them all into 1 model (along with DAMA results)**

- *Dark matter is on* 0.5 - 0.8 TeV *mass scale and annihilates to SM particles with sizeable cross sections*
- *Perhaps some new symmetry prevents the decay of these states*
- *These massive states might couple to* $\mathcal{O}$[1GeV] *"dark photons" which is part of a new sector of matter (a Hidden-Valley model)*
- *This picture of dark matter can be implemented with GMSB SUSY*

SUSY & Dark Photons



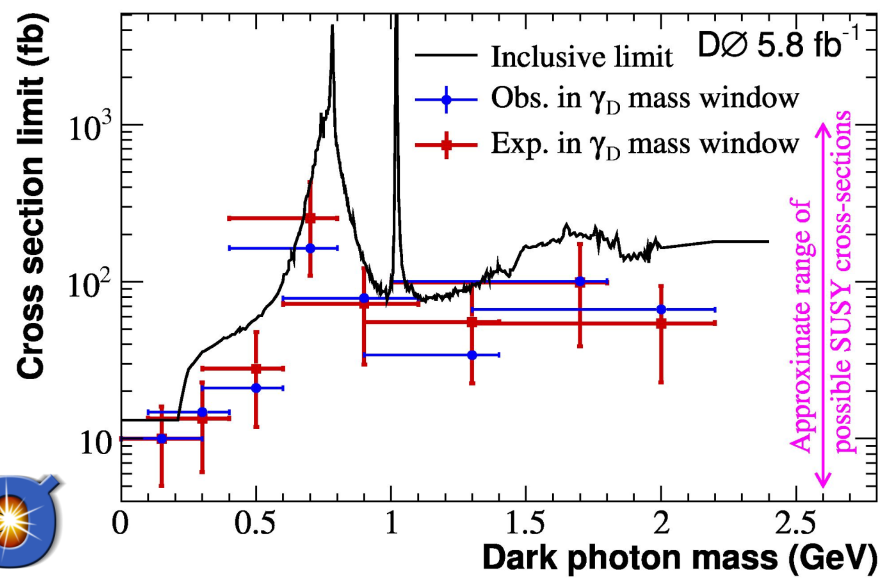


Look for 2 e^+e^-, $\mu^+\mu^-$ pairs with small opening angles – need to develop new isolation cuts

Don't require $\ell^+\ell^-$ pairs to come from primary $p\bar{p}$ vertex to allow up to $\mathcal{O}[1\mathrm{cm}]$ decay length

$E_T > 30$ GeV

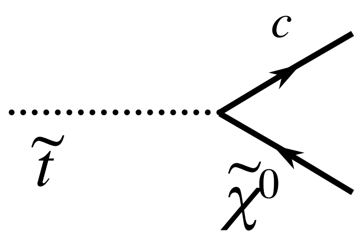
Abazov etal. Phys.Rev.Lett. 105,211802 (2010)

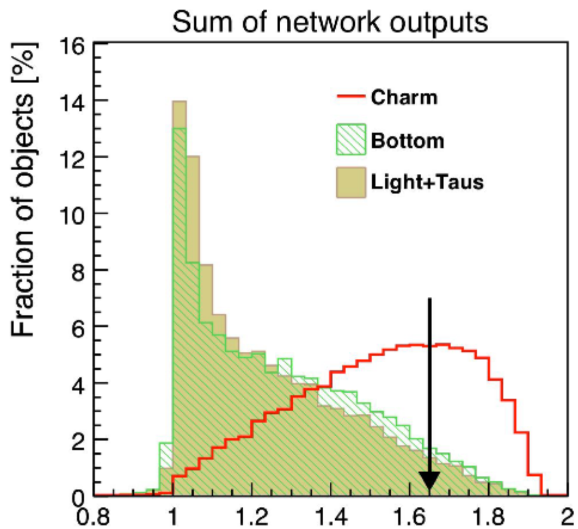


Looking Forward: charm tagging

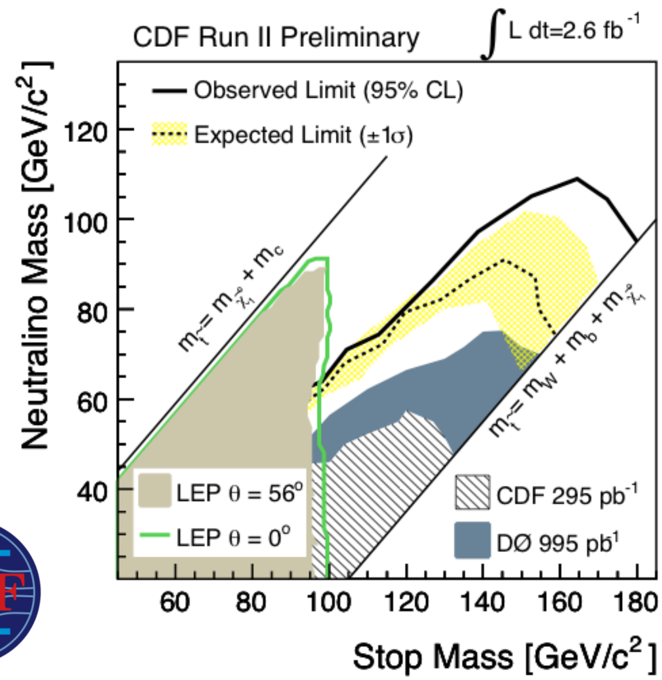
Charm is hard to find with just vertex detectors

Typically $\tau(b$ hadrons$) > \tau(c$ hadrons$)$
$\Rightarrow$ no high-purity selection





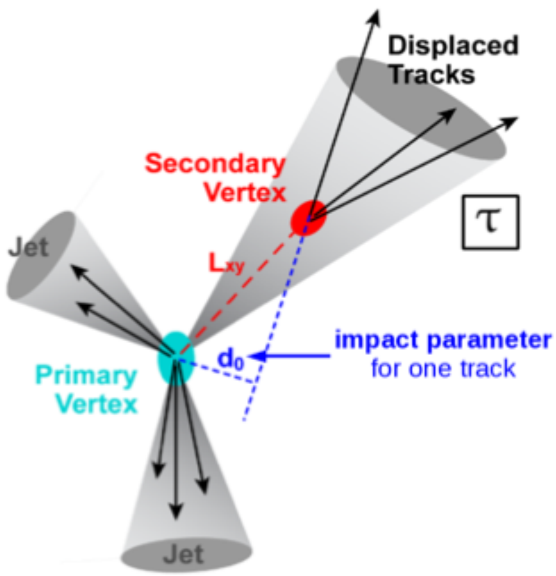
2 output, 22 input Neural Net



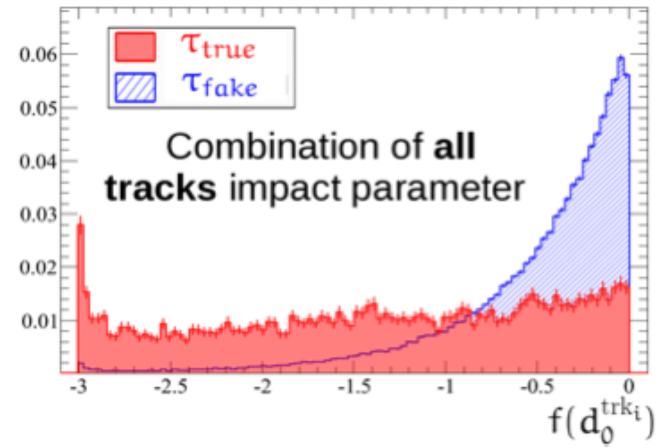
CDF CONF Note 9834

Looking Forward: tau tagging

τ is a long lived particle



Use impact parameter to remove jets faking τ more efficiently.
(large $c\tau_{life} \Rightarrow$ large d_0)

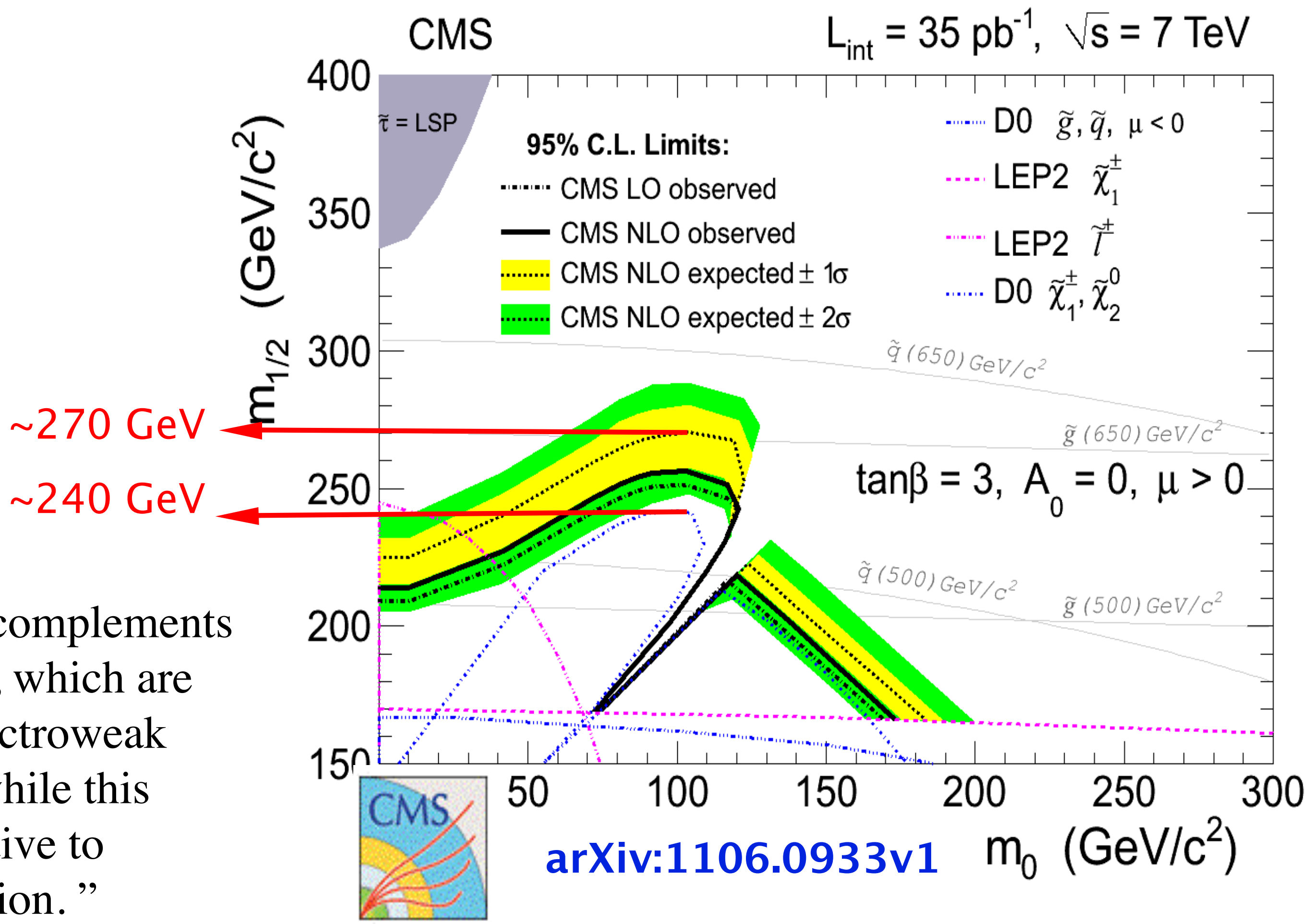


After adding these variables in the NN **clear improvement** was observed :
~ 10% more signal for the same bkg

3 prong τ_{had}

Romain Madar (CEA/Irfu/SPP) Tau Lepton Workshop - 09/16/2010

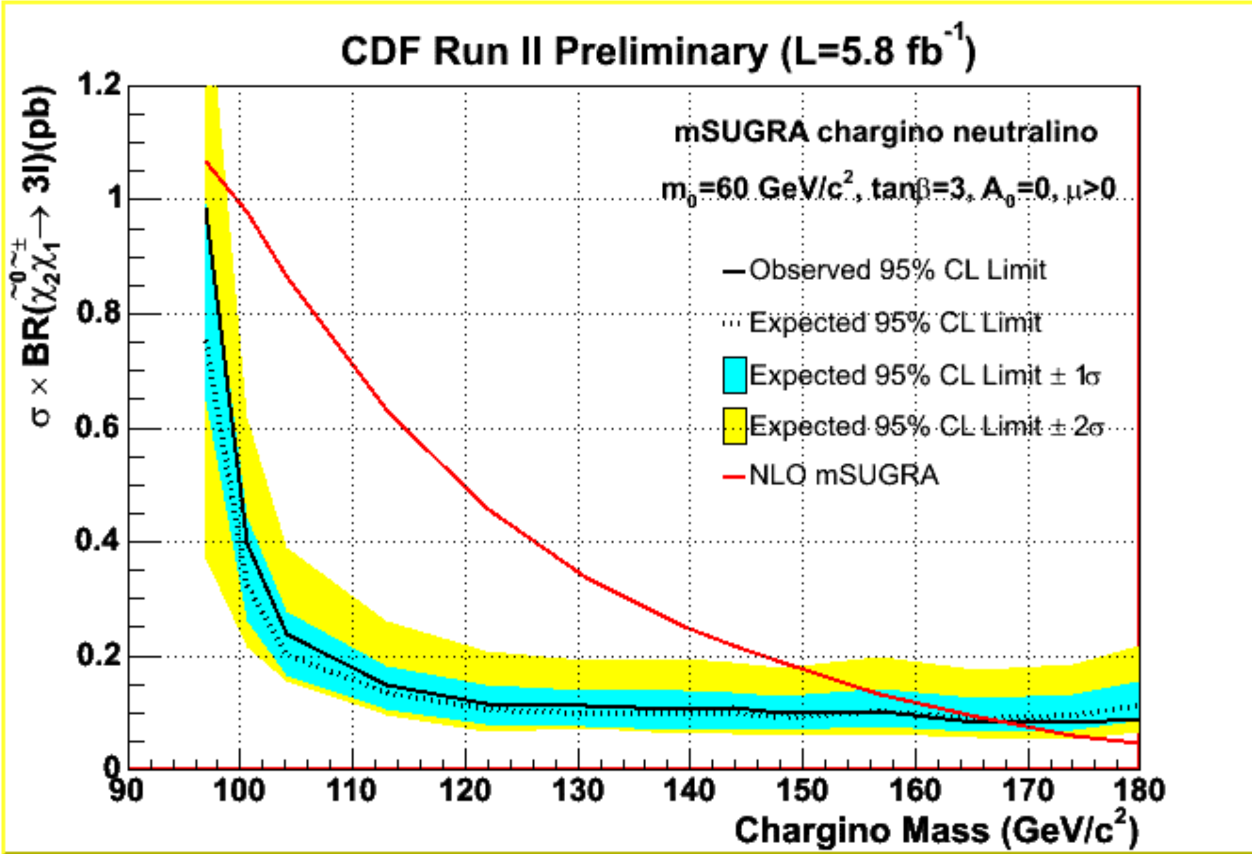
Looking Forward: *pp* vs *p$\bar{p}$*



" Overall, this search complements the Tevatron searches, which are mostly sensitive to electroweak gaugino production, while this search is mostly sensitive to squark-gluino production. "

This Just In

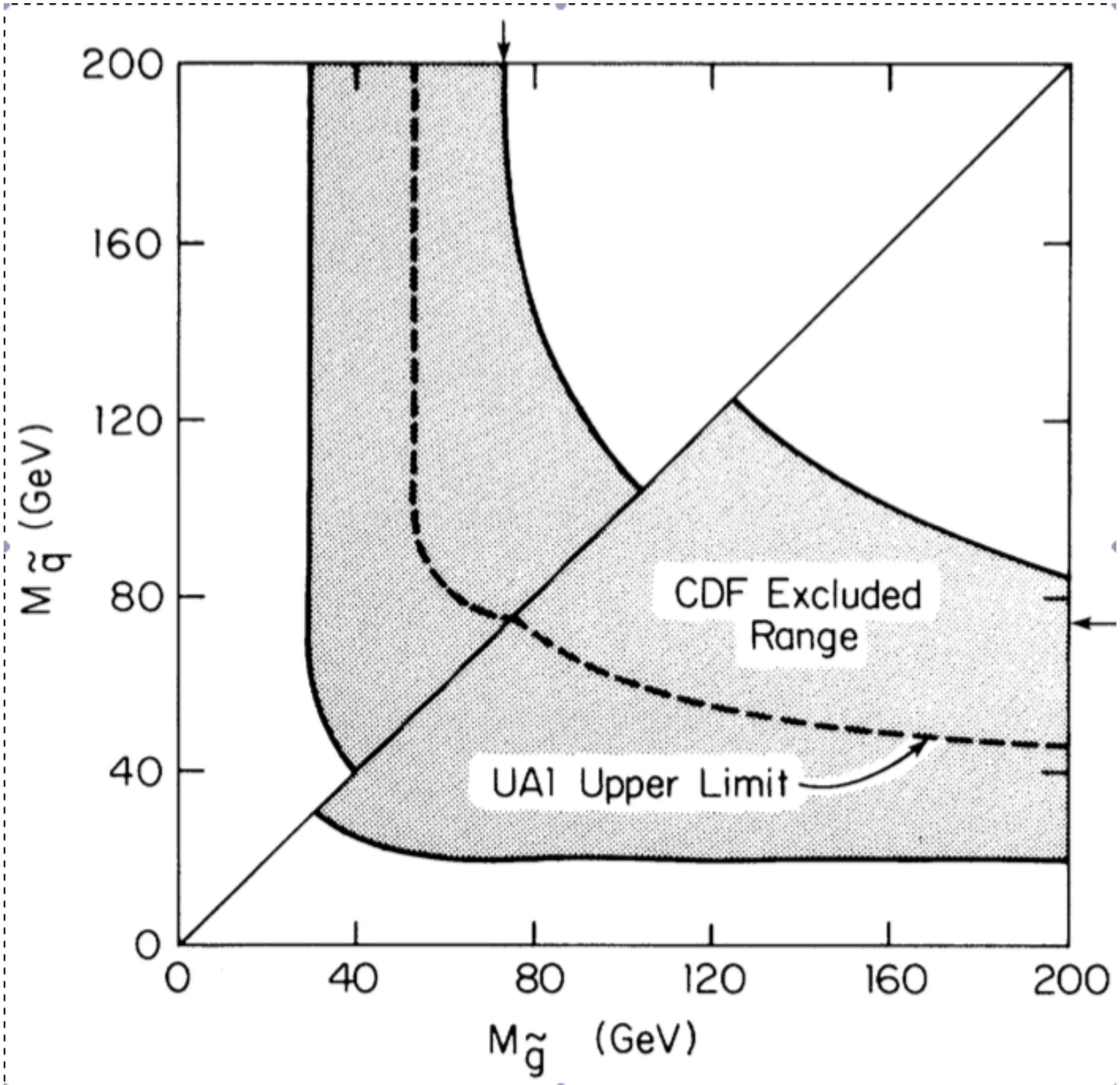
New result in SUSY search in trileptons from CDF:



Marcel Vogel presentation 235 in Room F (Wilson Hall 3NE)
Monday 29 Aug 11:35 AM

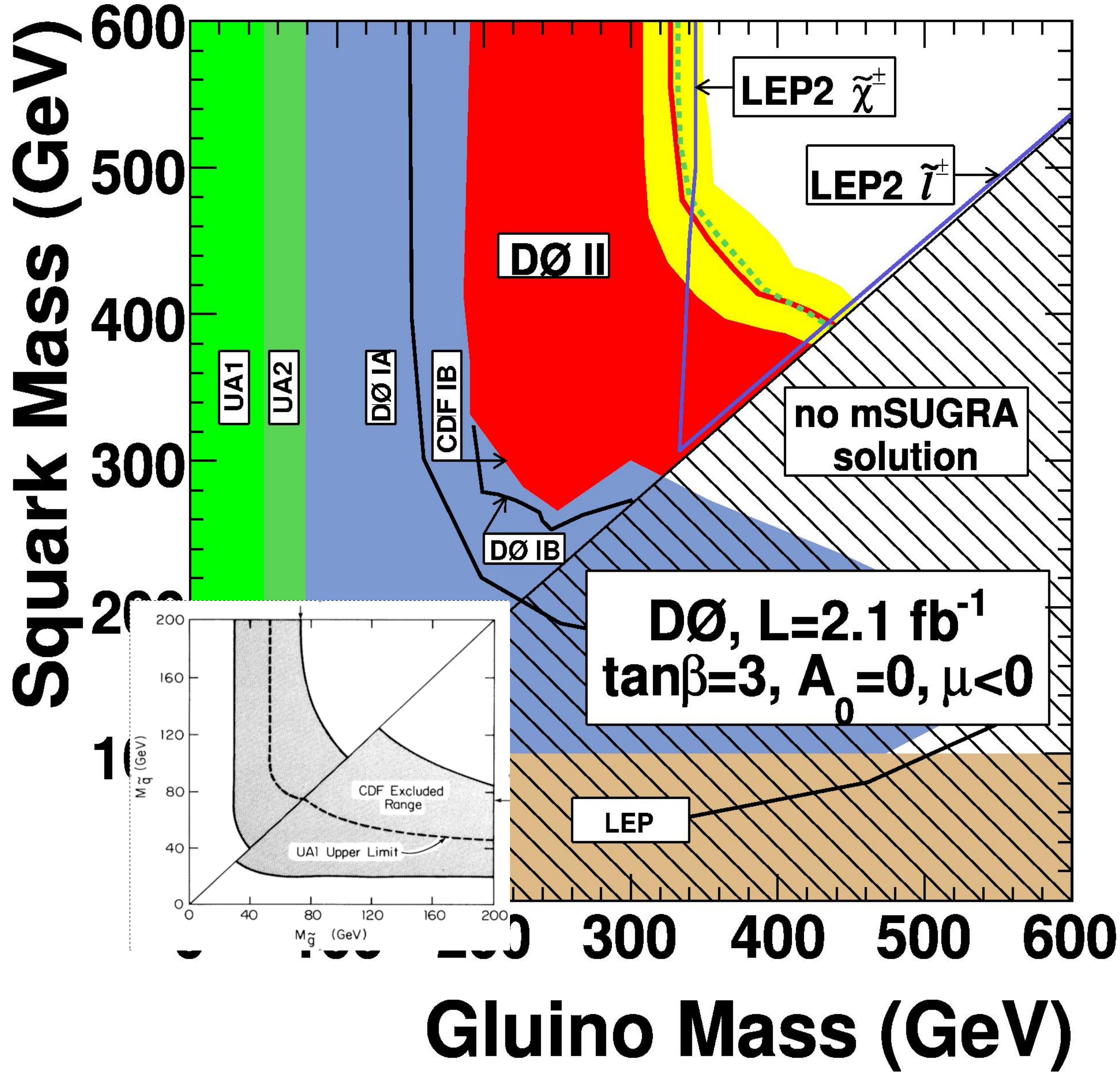
CDF Note 10636

Closing



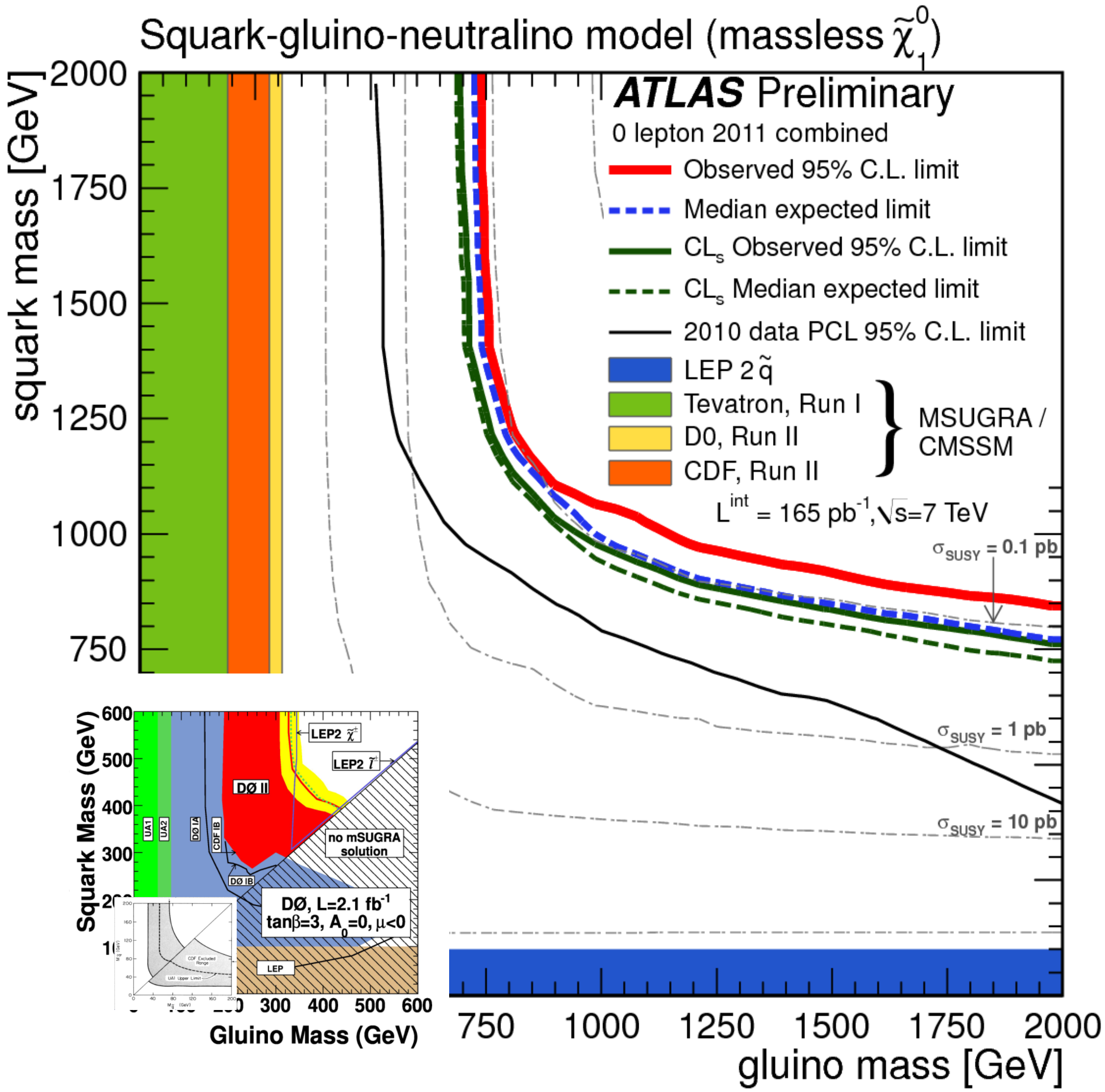
200
160
120
80
40
0
0
40
80
120
160
200
$M_{\tilde{q}}$ (GeV)
$M_{\tilde{g}}$ (GeV)
CDF Excluded Range
UA1 Upper Limit

Closing



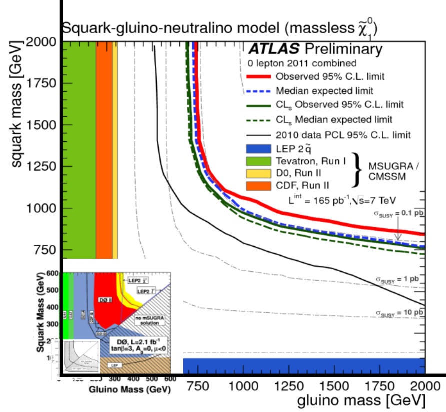
Squark Mass (GeV)
600
500
400
300
Gluino Mass (GeV)
300
400
500
600
LEP2 $\tilde{\chi}^{\pm}$
LEP2 $\tilde{l}^{\pm}$
DØ II
UA1
UA2
DØ IA
CDF IB
DØ IB
no mSUGRA solution
DØ, L=2.1 fb^{-1}
tanβ=3, A_0=0, μ<0
LEP
CDF Excluded Range
UA1 Upper Limit
$M_{\tilde{q}}$ (GeV)
$M_{\tilde{g}}$ (GeV)

Closing



Squark-gluino-neutralino model (massless $\tilde{\chi}_1^0$)
ATLAS Preliminary
0 lepton 2011 combined
Observed 95% C.L. limit
Median expected limit
CL_s Observed 95% C.L. limit
CL_s Median expected limit
2010 data PCL 95% C.L. limit
LEP 2 $\tilde{q}$
Tevatron, Run I
D0, Run II
CDF, Run II
MSUGRA / CMSSM
L^{int} = 165 pb^{-1}, $\sqrt{s}$=7 TeV
σ_{SUSY} = 0.1 pb
σ_{SUSY} = 1 pb
σ_{SUSY} = 10 pb
squark mass [GeV]
gluino mass [GeV]
Squark Mass (GeV)
Gluino Mass (GeV)
DØ II
LEP2 $\tilde{\chi}^{\pm}$
LEP2 $\tilde{l}^{\pm}$
no mSUGRA solution
DØ, L=2.1 fb^{-1}
tanβ=3, A_0=0, μ<0
LEP
UA1
UA2
DØ IA
CDF IB
DØ IB

Closing



Squark-gluino-neutralino model (massless $\tilde{\chi}_1^0$)
ATLAS Preliminary
0 lepton 2011 combined
Observed 95% C.L. limit
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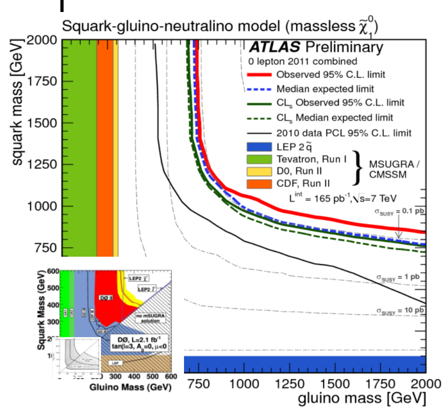
CL_s Median expected limit
2010 data PCL 95% C.L. limit
LEP 2 $\tilde{q}$
Tevatron, Run I
D0, Run II
CDF, Run II
MSUGRA / CMSSM
L^{int} = 165 pb^{-1}, $\sqrt{s}$=7 TeV
σ_{SUSY} = 0.1 pb
σ_{SUSY} = 1 pb
σ_{SUSY} = 10 pb
squark mass [GeV]
gluino mass [GeV]
2000
1750
1500
1250
1000
750
750
1000
1250
1500
1750
2000
Squark Mass (GeV)
Gluino Mass (GeV)
DØ, L=2.1 fb^{-1}

Closing



Many thanks: Oscar Gonzalez, Mike Eads, Michel Jaffre, Rob Forrest, & Our Conference Organizers

Another Slide

sparticle masses ≠ SM particle masses

Few constraints on Lagrangian terms that could create this asymmetry ⇒ 105 "L_{SOFT}" terms

Different SUSY-breaking models simplify these 105 terms with various parameterizations

mSUGRA	
m_0	Common scalar mass
$m_{1/2}$	Common gaugino mass
tan β	Ratio of Higgs vev
A_0	Common trilinear term
μ	Higgsino parameter

GMSB	
Λ	SUSY breaking scale
M_m	Messenger mass scale
tan β	Ratio of Higgs vev
N_m	# of messenger fields
μ	Higgsino parameter
C_{grav}	Sets the NLSP lifetime

Just 2 of many possibilities