Beyond Standard Model Searches

American Physical Society
Division of Particles & Fields
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Leo Bellantoni
Fermi National Accelerator Lab

Introduction

19 preliminary, 6 submitted, 11 published searches for BSM physics in the first 6 months of 2009

- Not counting searches for anomalies in production or decay of already-known particles (eg. t, W/Z, Υ, K) or non-SUSY Higgs searches

Lee Roberts will speak on "Low Energy Searches for BSM Physics" tomorrow

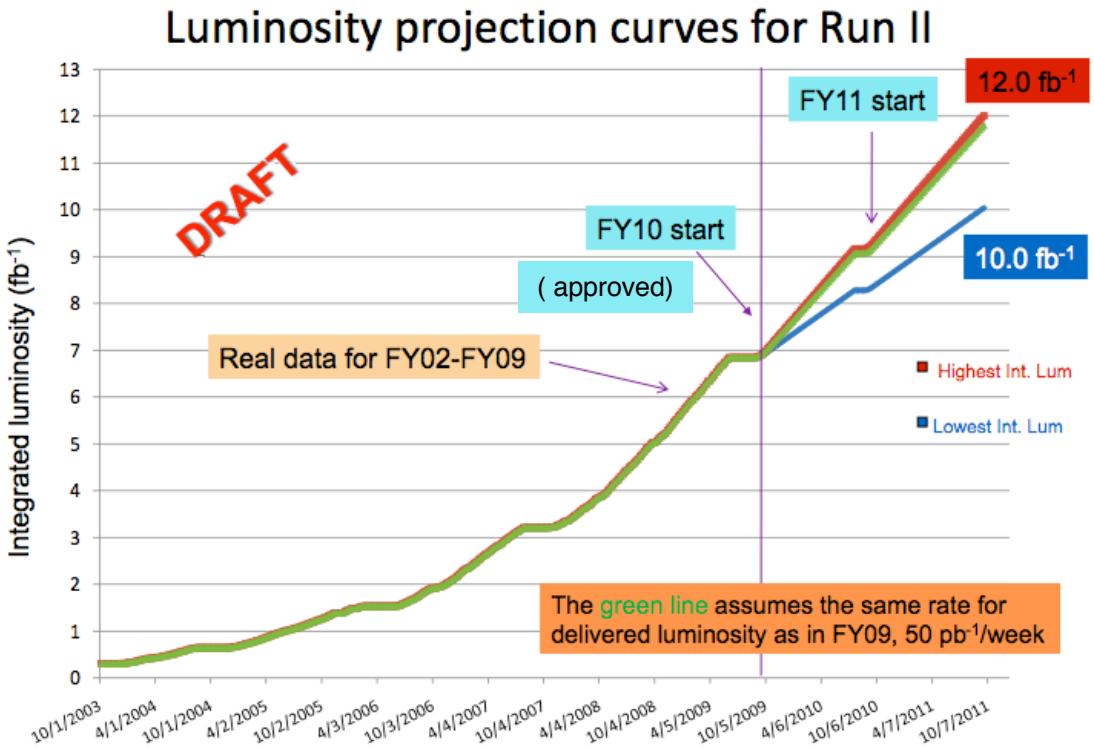
This talk covers only a selection of recent results

- ➢ Some SUSY results
- ➢ Some leptoquark results
- ➢ Hidden Valley models
- ➢ Model-independent searches

A TeVatron Primer

multi-fb^{-1} samples
multi-years running
⇒ CDF/D0 detectors
are well-understood

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



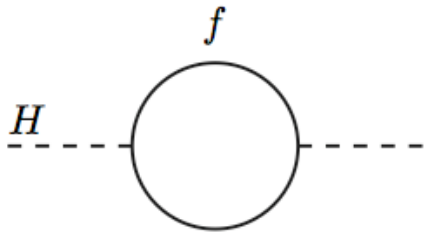
Initial state p_Z unknown - Missing momentum perpendicular to beam (E_T^{MISS}) also done well at both experiments

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

About SUSY

SUSY provides solutions to several SM dilemmas

The m_H problem:



1-loop fermion contribution from $-\lambda H \bar{f} f$ in Lagrangian to $(m_H)^2$ is

$$\Delta m_H^2 = -\frac{|\lambda|^2}{8\pi^2}\Lambda_{UV}^2$$

and we have no new physics to define Λ_{UV} cutoff until the Plank scale

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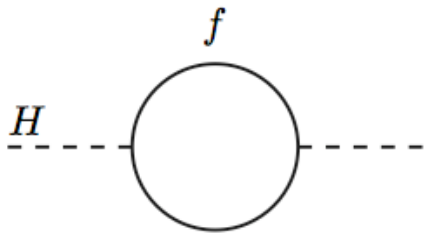

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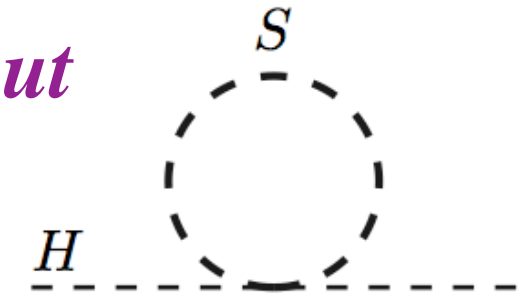
but



Lagrangian of $-\lambda|H|^2|S|^2$ introduces

$$\Delta m_H^2 = \frac{\lambda_S}{16\pi^2}\left[\Lambda_{UV}^2 - 2m_S^2 \ln(\Lambda_{UV}/m_S) + \ldots\right]$$

About SUSY

sparticle masses ≠ SM particle masses

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

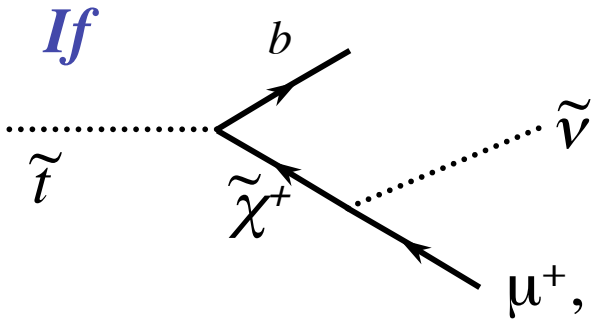
Different SUSY-breaking models simplify these 105 terms with various parameterizations

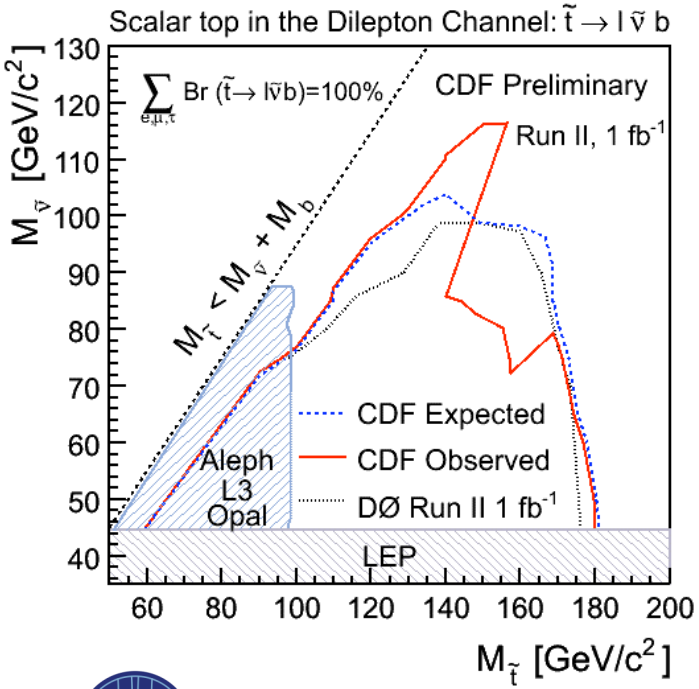
mSUGRA	
m_0	Common scalar mass
$m_{1/2}$	Common gaugino mass
tan β	Ratio of Higgs vev
A_0	Common trilinear term
μ	Higgsino parameter

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

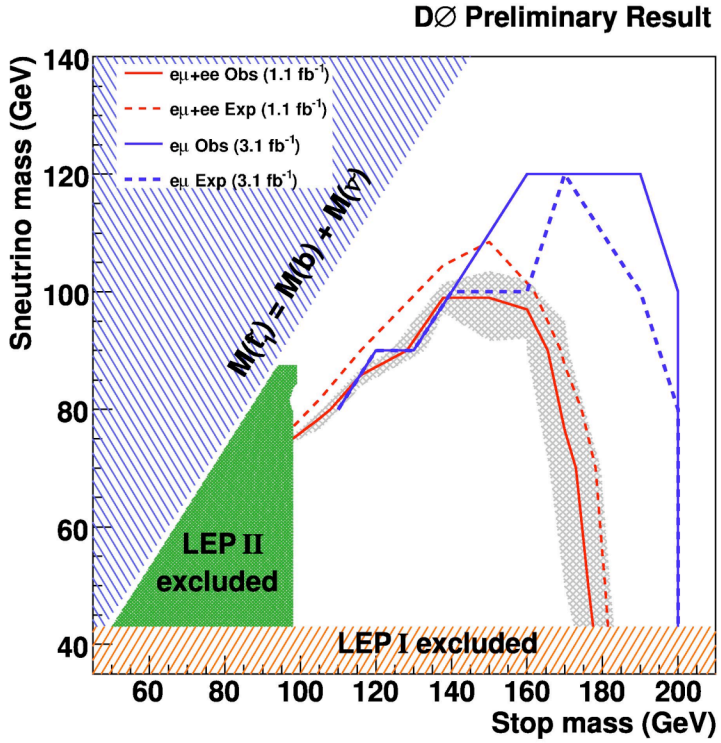
Pair-produced $\tilde{t}$



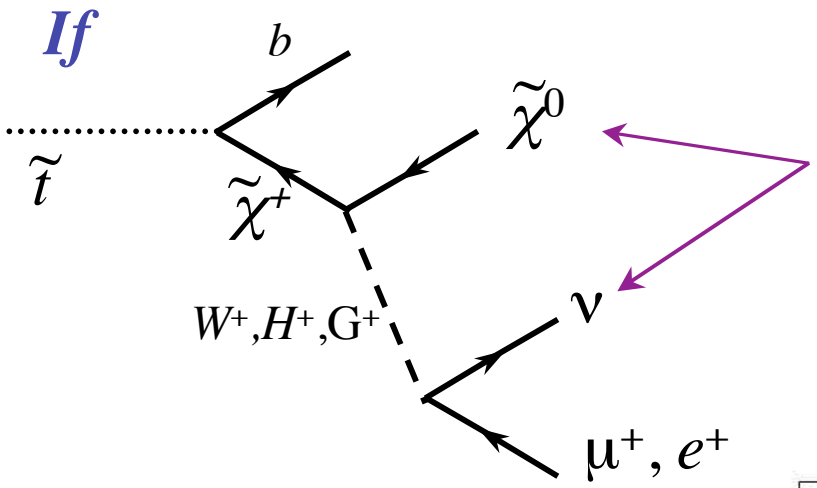


$ee, \mu\mu, 1\text{fb}^{-1}$

Look for $\ell^+\ell^-$ pairs with E_T^{MISS} from $\tilde{\nu}\,\bar{\tilde{\nu}}$



Pair-produced $\tilde{t}$

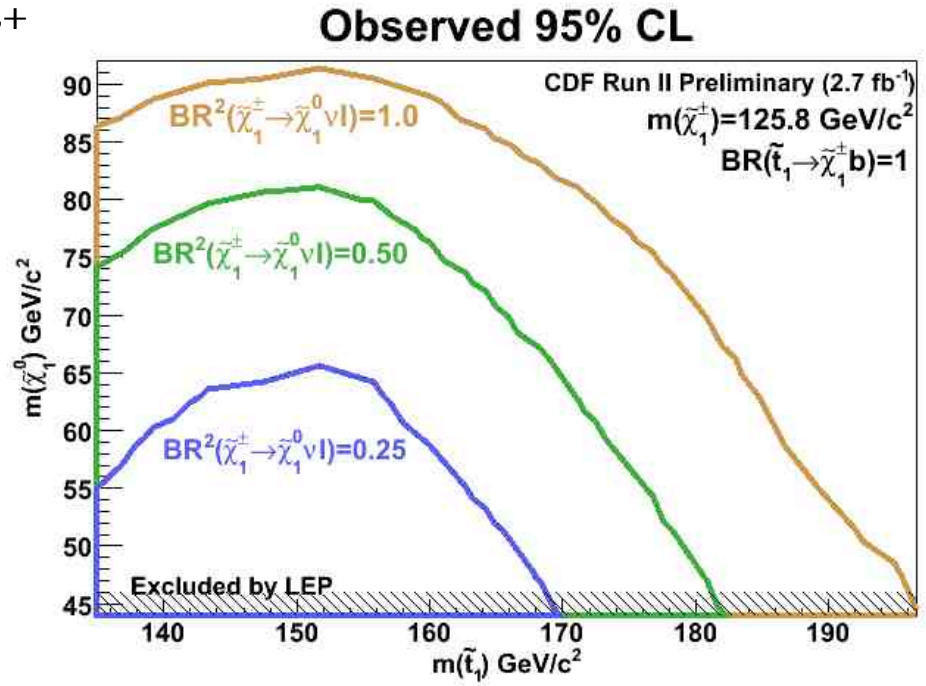


Looks a lot like $t\bar{t}$ to $\ell^+\ell^-$ + X

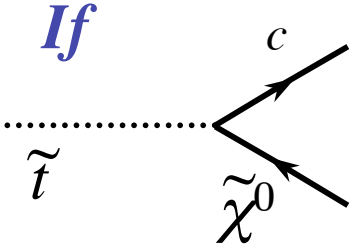
4-vector sum kinematically underconstrained
Use weighted sum of possible solutions to estimate stop mass

stop might even be less massive than top

top mass in dilepton channel would appear lower than in lepton-jets channel

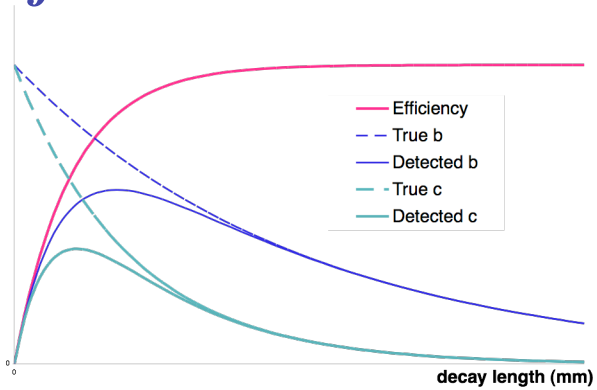


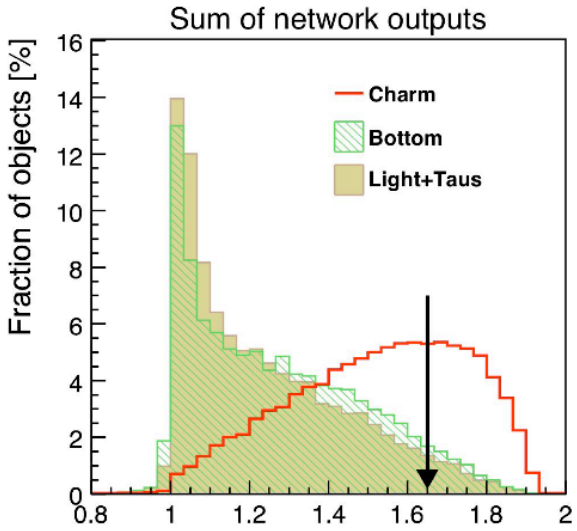
Pair-produced $\tilde{t}$



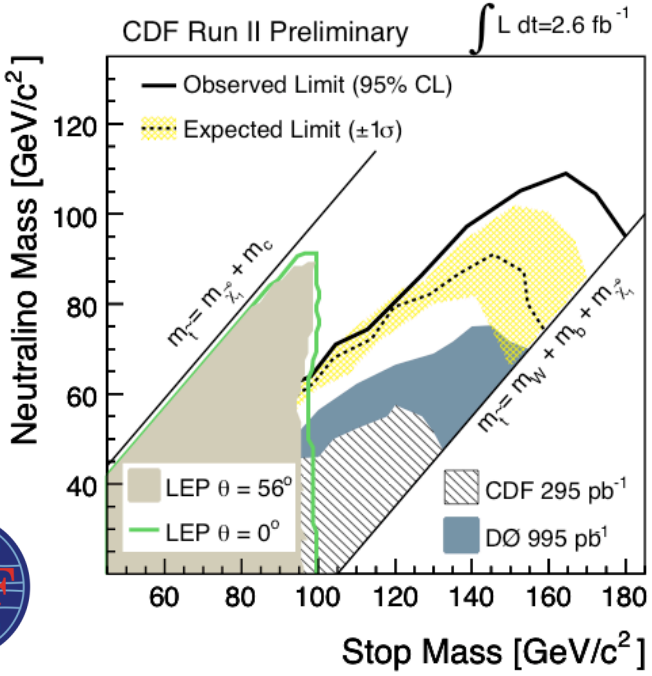
charm is hard to find with just vertex detectors

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

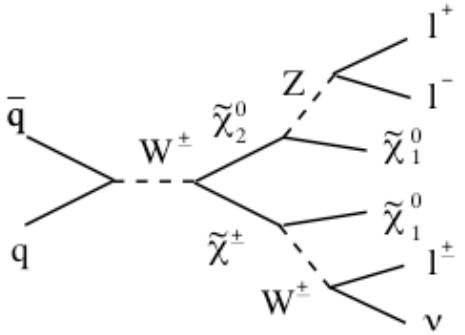


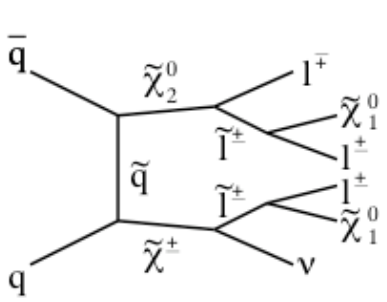


2 output, 22 input Neural Net



Trilepton Analyses

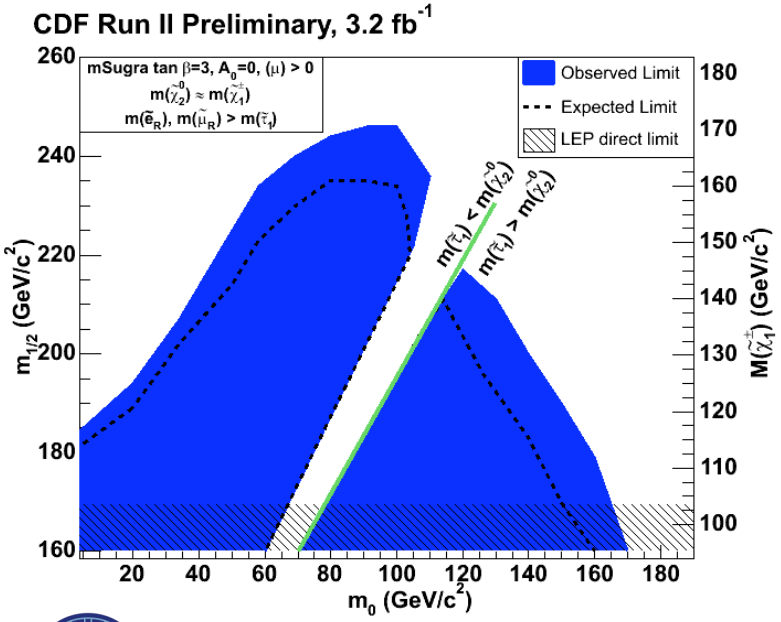


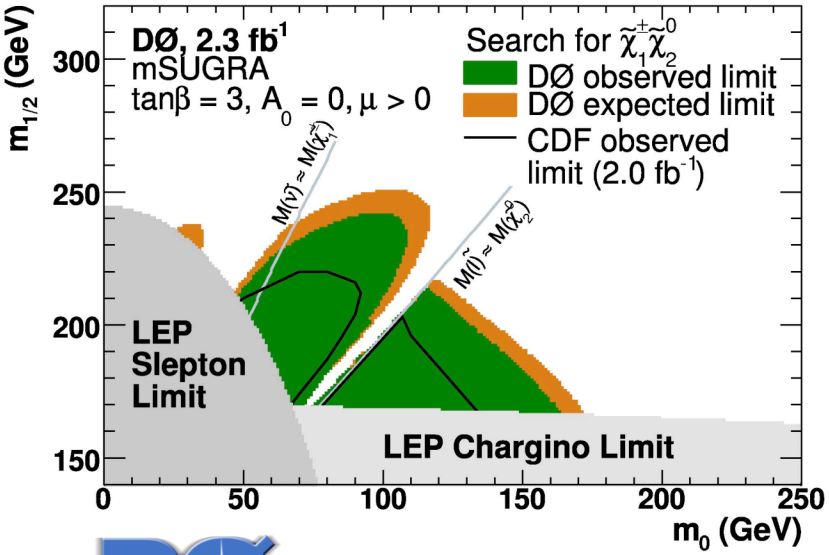


LSP

Small $M(\chi_2^0, \chi^\pm) - M(LSP)$
$\Rightarrow$ min p_T lepton is very low p_T
Or there might be a τ lepton

Look for 2 leptons & isolated track



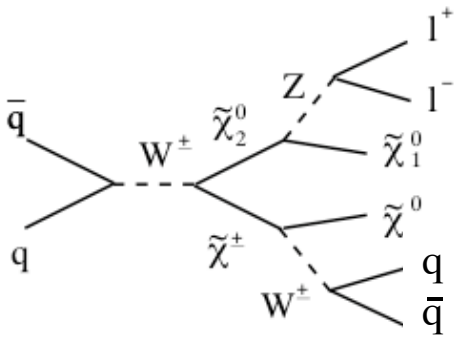


➪ ***Rob Forrest (CDF)***

➪ ***Todd Adams (D0)***

arXiv:0901.0646

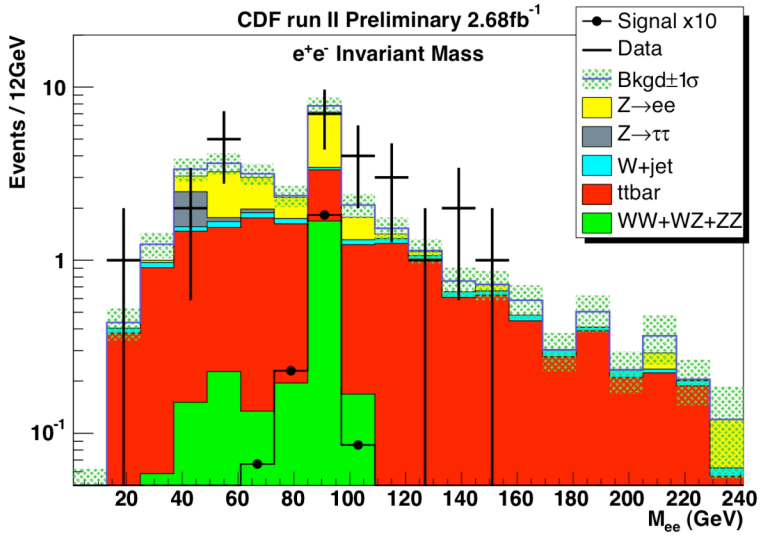
Another Trifermion Analysis

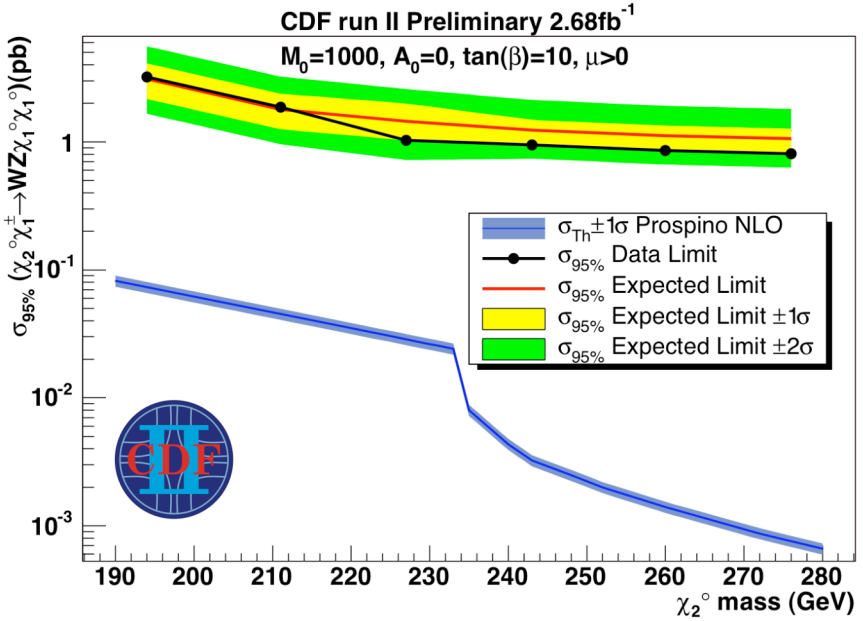


2 jets rather than ℓ E_T^{MISS}

- New, clean final state
- So far, only $Z \rightarrow e^+e^-$
- b-jet tagging not yet implemented, but $t\bar{t}$ is 2nd largest background
- 2.7fb-1

W Z E_T^{MISS} signature

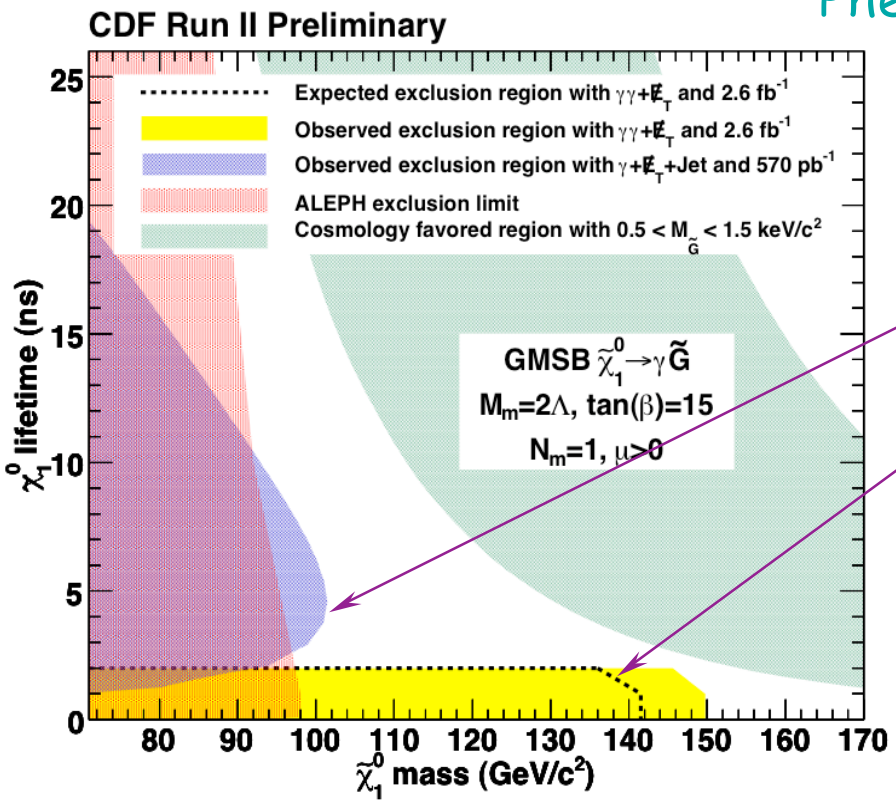




GMSB

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



Signatures:

γ_{DELAY} + jet + E_T^{MISS}

$\gamma\gamma + E_T^{MISS} + X$

Full TeVatron dataset should reach cosmologically interesting region

➪ ***Eunsin Lee***

Killing the MSSM

Science [sī-ən**s**] (n.) The systematic murder of elegant theories with merciless observations.

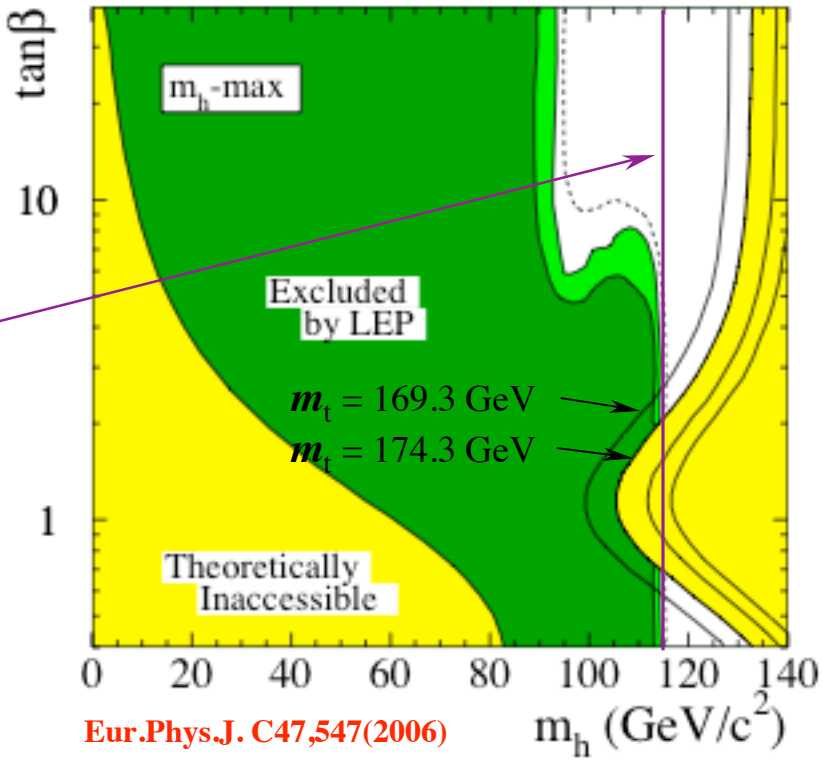
Minimal Supersymmetry has 5 Higgs bosons; lightest is CP-even scalar h

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

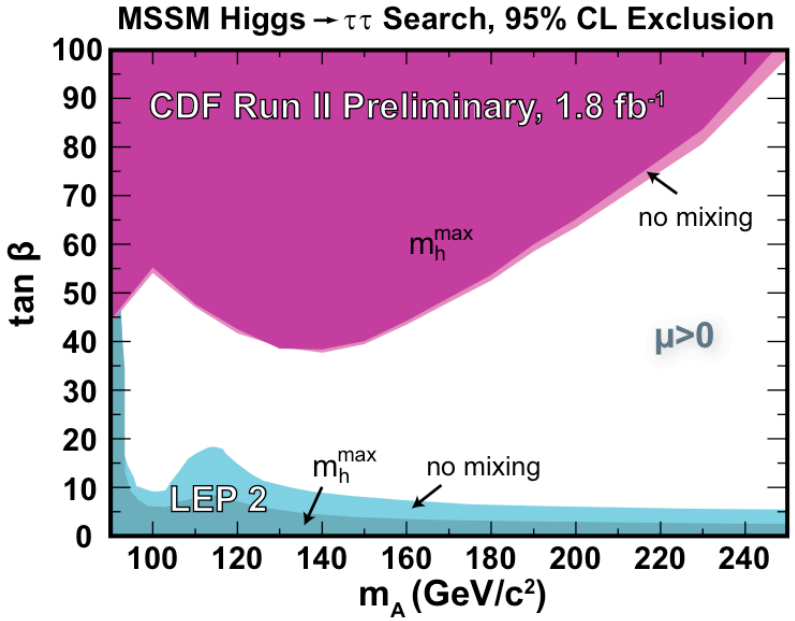
Favors high $\tan\beta$ -
see also Phys.Rev.Lett. 99, 251802 (2007)
JHEP 0708:083 (2007)
arXiv:0904.2548v2



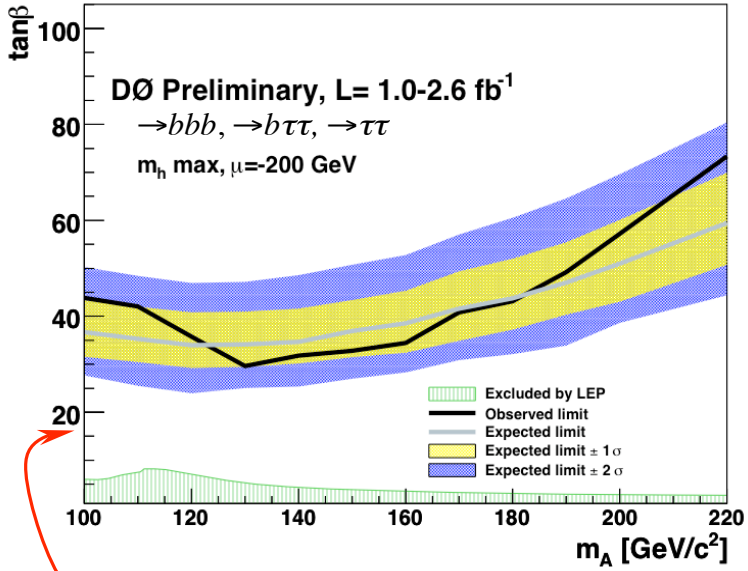
Eur.Phys.J. C47,547(2006)

Large *tan* β MSSM

Large *tan* β ⇒ *CP*-odd neutral Higgs *A* degenerate
with 1 of 2 *CP* - even *h*, *H*
At hadron colliders, decays →τ, →*b* limit max(tan β)



arXiv:0906.1014



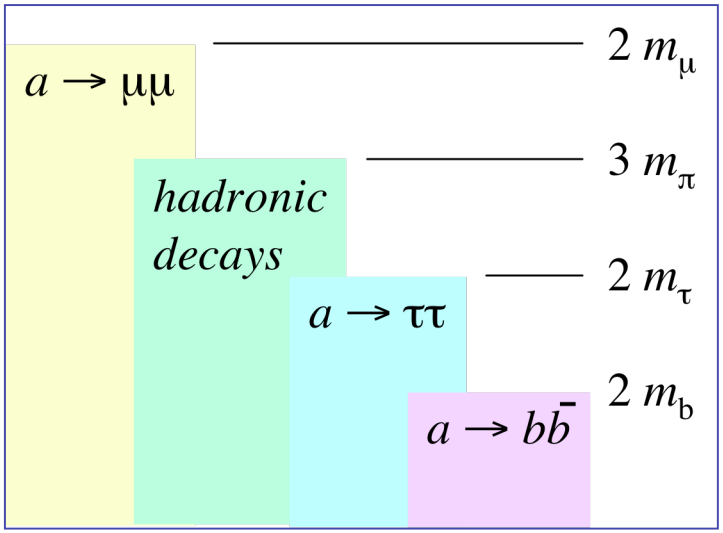
TeVatron combo might
get to *tan* $\beta < 20$

⇨ ***Mark Kruse's Higgs talk***

What's Next?

The Next-to-Minimal-SUSY model has also a pseudoscalar, a

Decay modes depend on m_a



$e^+e^- \to \Upsilon(3S) \to a\,\gamma$, $a \to \tau\tau$

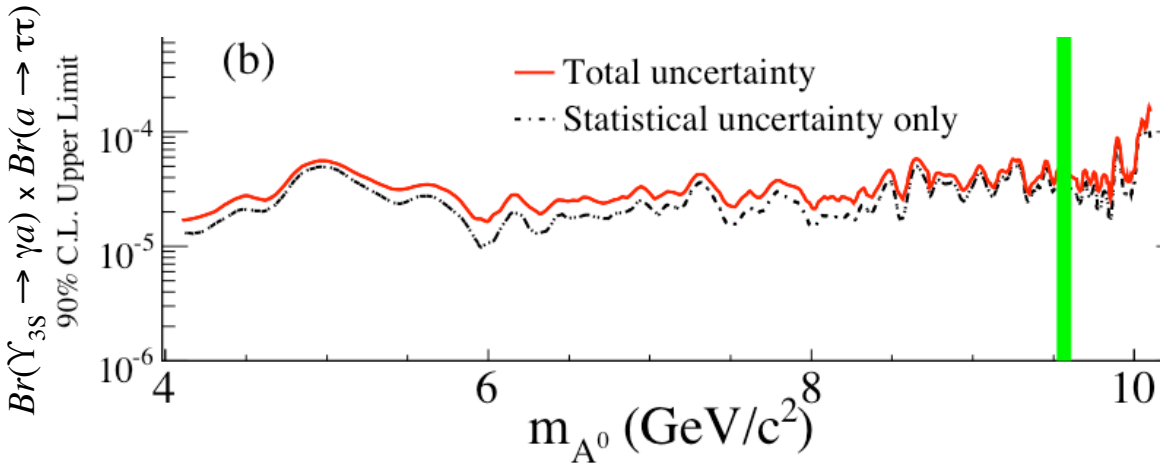
look for narrow peak in γ spectrum

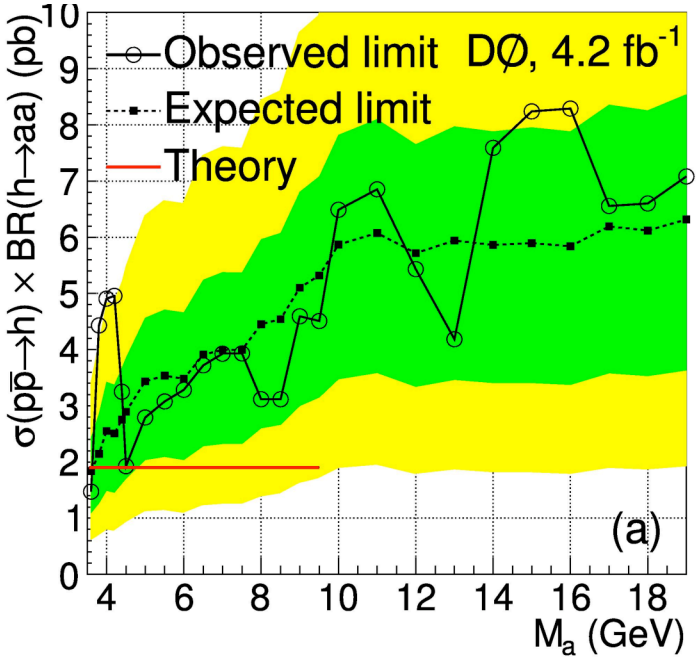
$m_h > 82$ GeV
LEP II (recoiling scalar)

$p\bar{p} \to h \to a\,a$, $a \to \mu\mu$ or $\tau\tau$

4μ is 2 collinear pairs
$Br(\mu\mu\tau\tau) \approx Br(\tau\tau\tau\tau)/100$
but cleaner signature

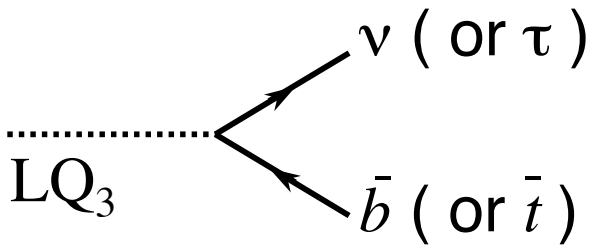
NMSSM results





BaBar arXiv:0906.2219
D0 arXiv:0905.3381

Leptoquarks (I)

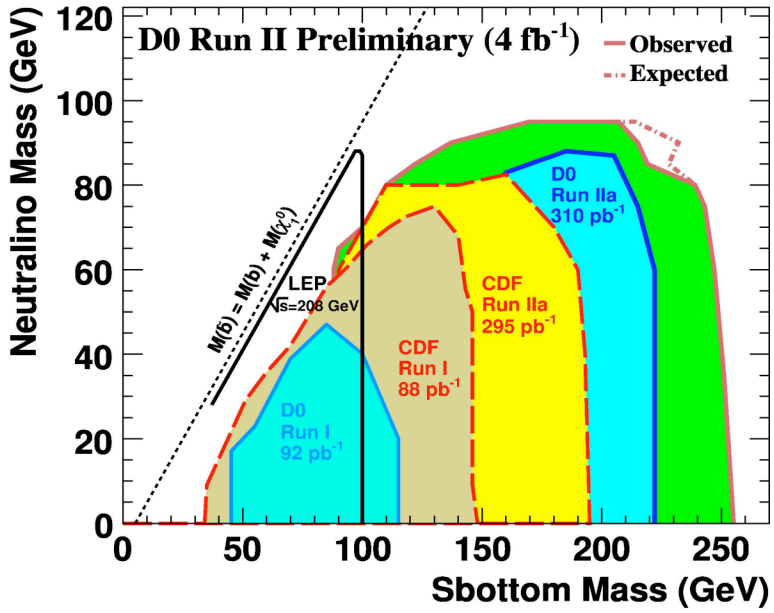


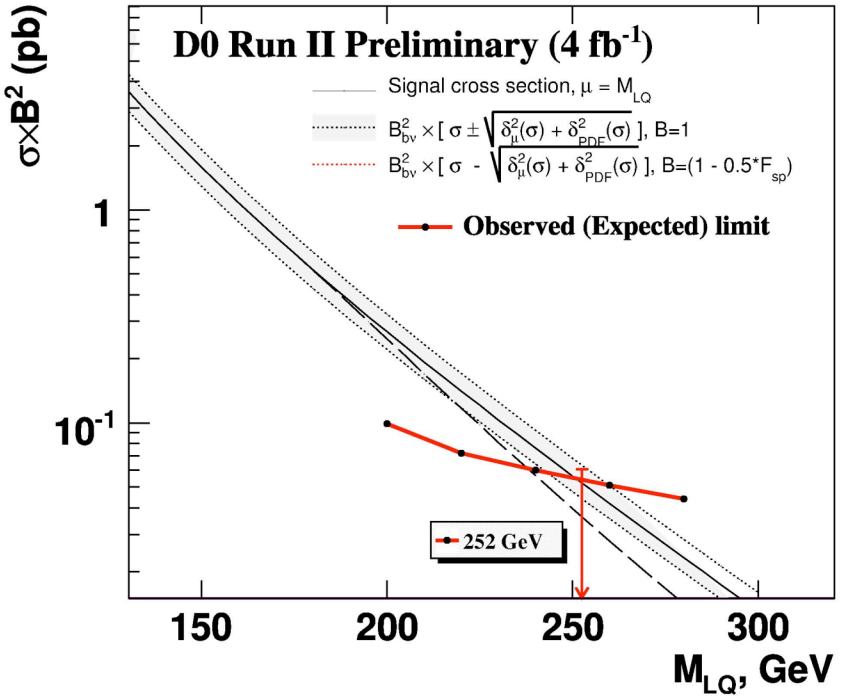
$$p\bar{p} \rightarrow LQ_3\,\overline{LQ_3} \rightarrow b\bar{b}\,\nu\bar{\nu}$$

Just the same as

$$p\bar{p} \rightarrow \tilde{b}_1\tilde{b}_1 \rightarrow b\bar{b}\,\tilde{\chi}_1^0\,\overline{\tilde{\chi}_1^0}$$

signal is 2 b jets with E_T^{MISS}





➪ ***Sergey Uzunan***

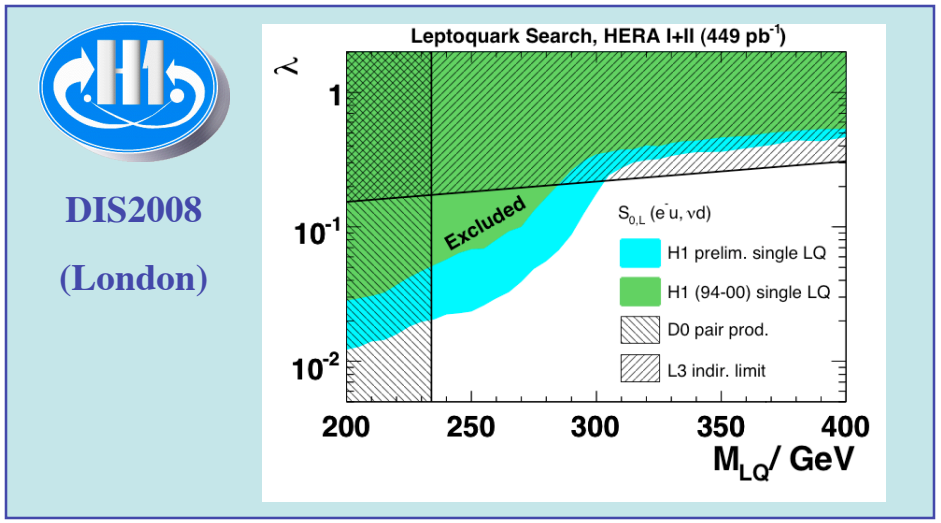
Leptoquarks (II)

HERA data: e^+p, e^-p ~0.5 fb^{-1} $\sqrt{s}$ = 300-319 GeV
~0.3 fb^{-1} with longitudinal $e^\pm$ polarization

$$a_{ij}^{eq}\left(\frac{\lambda_{LQ}}{M_{LQ}}\right)^2\left(\bar{e}_i\gamma^\mu e_i\right)\left(\bar{q}_j\gamma_\mu q_j\right)$$

$$for\ i,j = L,R \quad q = u,d$$

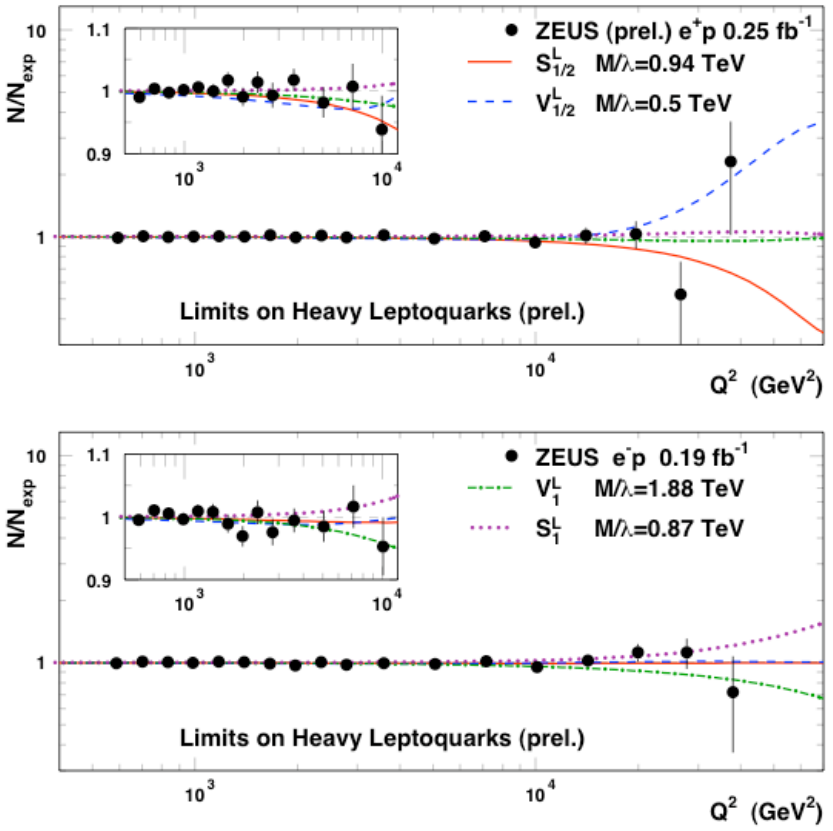
M_{LQ}/λ_{LQ} limits 0.5-1.9 TeV
Also limits on LED, contact interactions, quark charge radius



Leo Bellantoni, FNAL
APS / DPF 2009

ZEUS

EPS HEP 2009



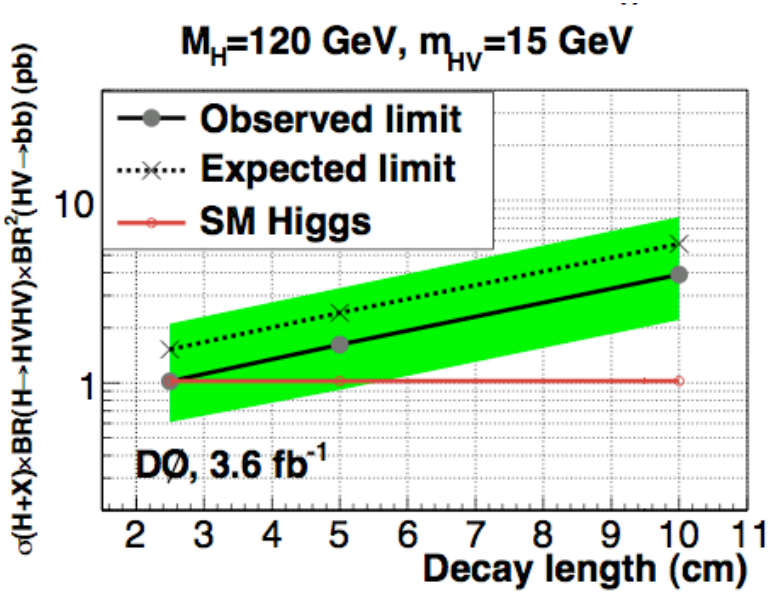
Hidden Valley → $b\bar{b}$

Novel unseen fields might have low mass quanta if couplings to SM fields are weak - mediators might be at higher masses

Confining "hidden valley" models have v-hadrons that decay to SM particles with observable lifetimes

BBN requires at least 1 v-hadron with $\tau << 1$ sec

Look for *b*-vertex with
$1.6\text{cm} < \rho < 20\text{cm}$
***b* decay provides μ for trigger**



arXiv:0906.1787

➪ ***Andy Haas Tuesday Higgs***

SUSY Hidden Valleys

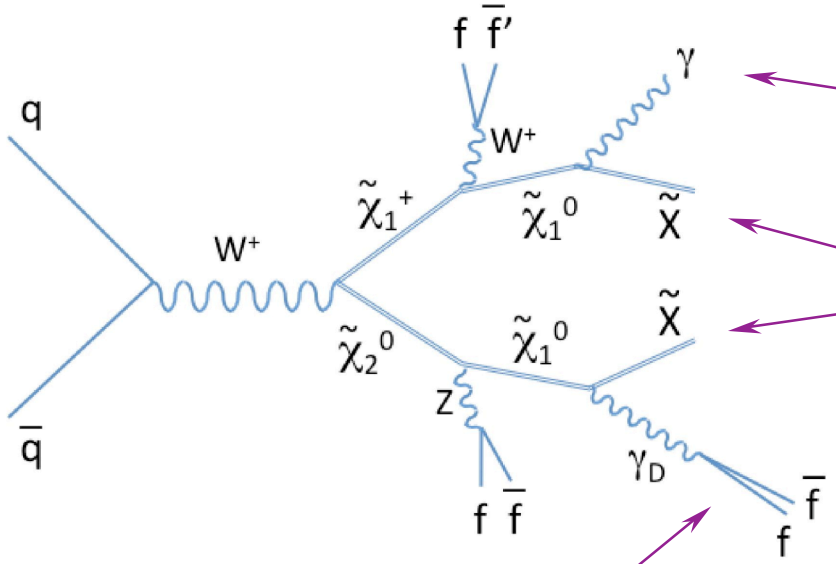
PAMELA, ATIC, Fermi LAT, INTEGRAL, HEAT, AMS-01, WMAP ('haze') all have results that *could* be interpreted as dark matter annihilation to e^+e^- near the center of the Milky Way

Arkani-Hamed & Weiner **JHEP** 0812:104 (2008)
Arkani-Hamed, Finkbeiner, Slatyer & Weiner
Phys.Rev.D 79,015014 (2009)

⇨ **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"***
- ***This picture of dark matter can be implemented with GMSB SUSY***

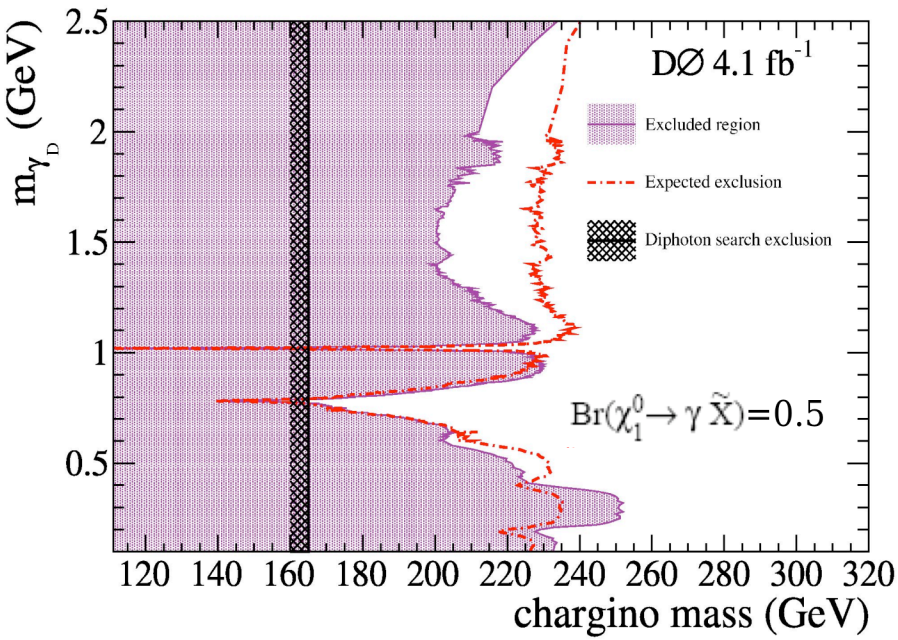
SUSY Hidden Valleys



$E_\gamma > 30$ GeV

E_T^{MISS}

Dark photon creates collinear fermion pair - search method much like the $a \rightarrow \mu\mu$ NMSSM search (also e^+e^-)



Model Independent Searches

Many aspects of the standard model are surprising
⇒ ALL of our models to extend it could be wrong
⇒ Try to look for new physics without reference to any model at all

Define (many) final states by particle content e.g. 'Two positrons and $\not\!\!E_T$'

Look for data in excess of standard model rates:

- Total number of events
- Distribution of kinematic variables
- Specific values of kinematic variables ("bumps")

N.B. Final states that require unusual reconstruction techniques, have low P_T particle content, or particles like K_S or D^{*+} neglected (so far)

Model Independent Searches

Looking just at event counts

CDF II 2.0 fb^{-1}		H1 0.5 fb^{-1}		DØ 1.1 fb^{-1}	
$\gamma\,\tau^{\pm}$	2.2σ	$\nu\,jjjj$	1 seen, 0.05±0.02 exp. $< 3.0\sigma$ (my #)	$\mu^{\pm}\,jj\,\not\!\!E_T$	9.3σ
$\mu^{\pm}\tau^{\pm}$	1.7σ	$e\,jjjj$	1 vs. 0.13±0.06 $< 2.4\sigma$ (my #)	$\mu^{\pm}\,j\gamma\,\not\!\!E_T$	6.6σ
$e^{\pm}\tau^{\pm}\,\not\!\!E_T$	1.7σ	eee	1 vs., 0.05±0.02 $\sim 2.0\sigma$ (my #)	$\mu^{+}\mu^{-}\,\not\!\!E_T$	4.4σ
-		$\mu\,\nu$	5 vs 2.8±0.5 $\sim 1.5\sigma$ (my #)	$\mu^{+}\mu^{-}\,\gamma$	4.4σ

➪ ***Jim Linneman (D0)***

$j\rightarrow\gamma$ fake rate, trigger modeling, μ P_T resolution

The LHC in BSM searches

The LHC in BSM searches

Replace this:

The LHC in BSM searches

With this:

Summary

Energy frontier collider searches not the only place to search for New Physics

Many interesting results and more to be expected from continued TeVatron operation

Standard model still in great shape

MSSM in less-good shape - Higgs sector is it's vulnerable spot

Prospects very bright at LHC (and elsewhere)

Apologies to all those whose work I couldn't squeeze in to this talk

Thanks to:

Todd Adams, Arnaud Duperrin, Andy Haas, Katjia Kruger, Monica D'Onofrio, Monica Turcato, Stefan Schmitt, Tom Wright DPF conference organizers