

# Tevatron New Phenomena Physics

E. Nagy (CPPM)  
for the  
CDF and D0  
Collaborations

This talk includes selected topics of searches on:

SUSY

Alternative EW Symmetry Breaking

Quark Lepton substructure

Extra Dimensions

GUT

Other exotics

At the Tevatron we are able to search for **all of them** with

- a well performing **collider**:  $> 4\text{fb}^{-1}$  luminosity delivered
- understood **detectors**
- advanced **analysis techniques**
- rigorous treatment of **systematics**

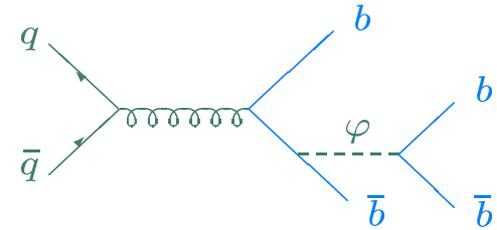
This makes us confident that a possible **excess** in rare event topologies of the SM (multiple jets, leptons, high ET, MET, HT, M) can reveal **evidence for new physics**

# BSM Higgs sector

Neutral MSSM Higgs bosons:  $h, H, A$

At high  $\tan\beta$ :  $\varphi = (h, A)$  if  $m_\varphi < 130$  GeV  
 $= (H, A)$  if  $m_\varphi > 130$  GeV

coupling to d-type fermion  $\tan\beta$  enhanced

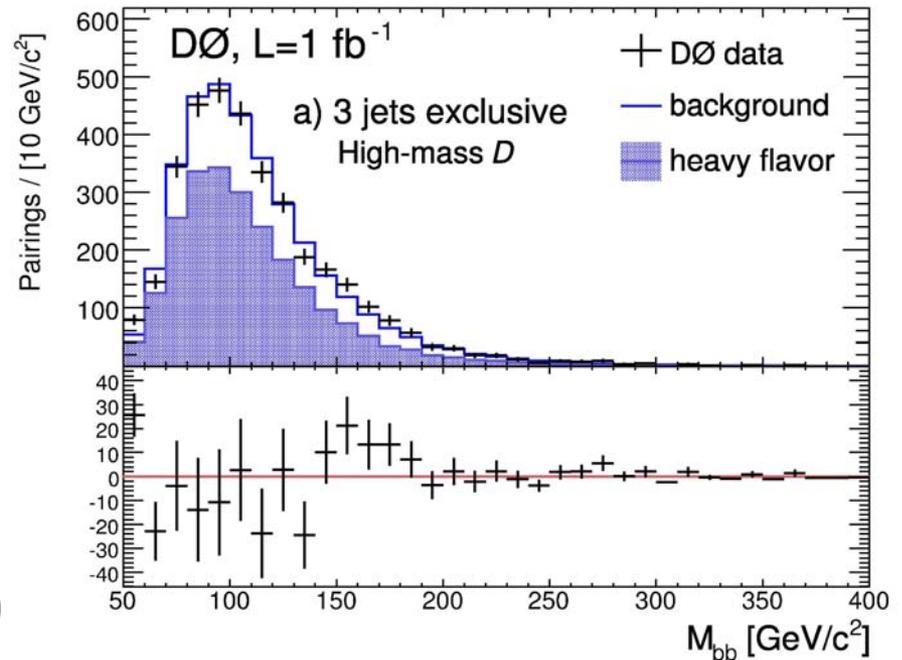
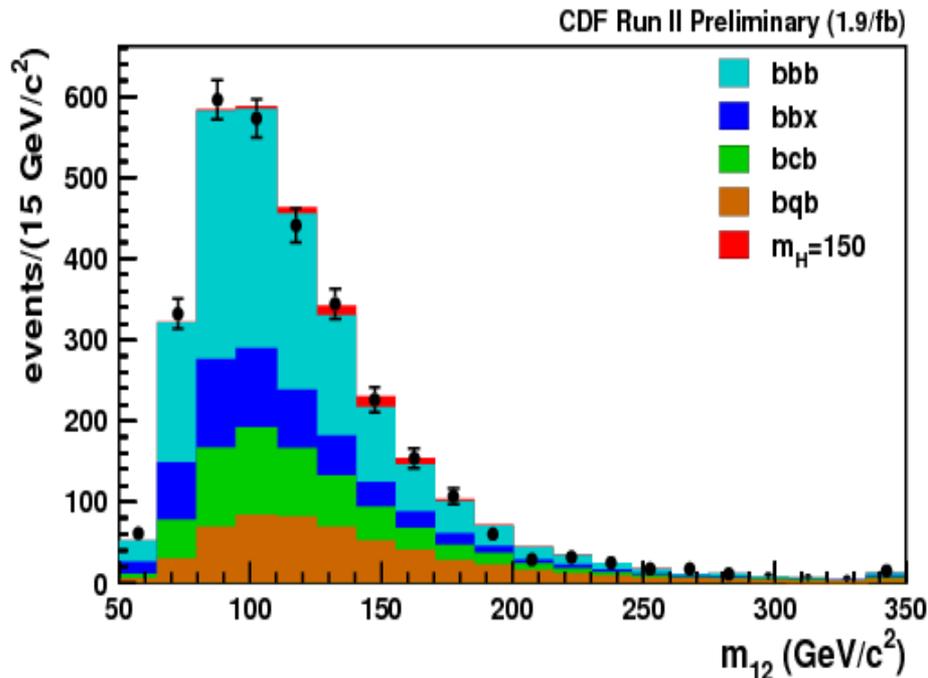


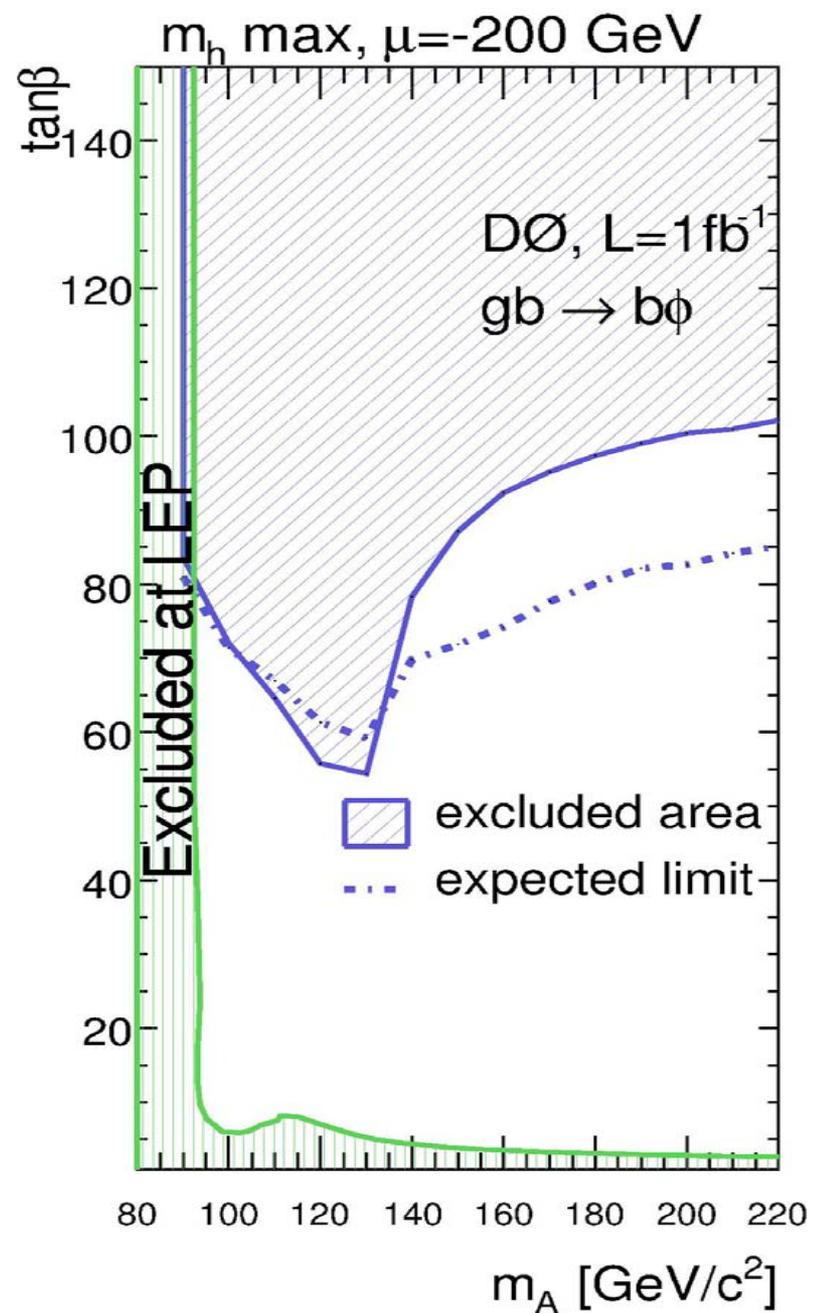
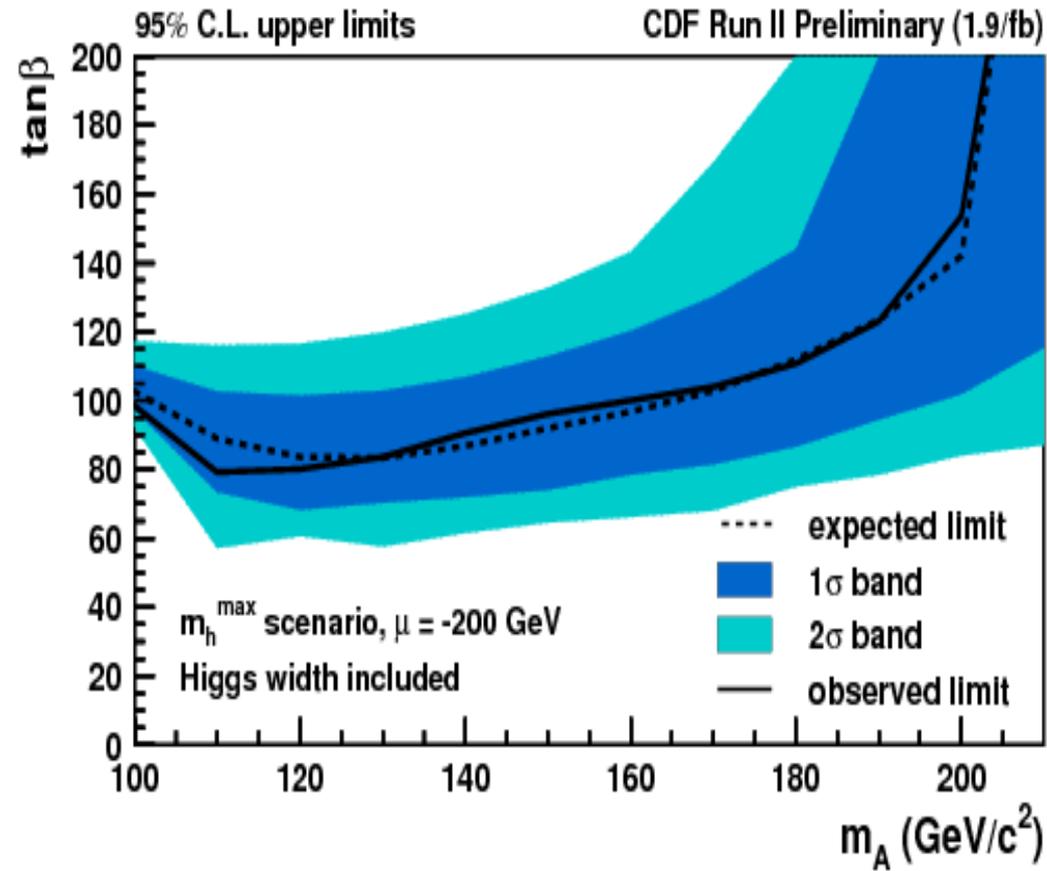
**Signal:** at least 3 tight b-tagged jet

Background: estimated from 2 b-tagged jet in data and simulation

Flavor composition: constrained using vertex mass in each jet (CDF)

HF tag-efficiencies for different jet multiplicities (D0)





$$\phi \rightarrow \tau\tau$$

The most sensitive search for the  $\phi$  boson

Small background and second highest BR ( $\sim 10\%$ ):

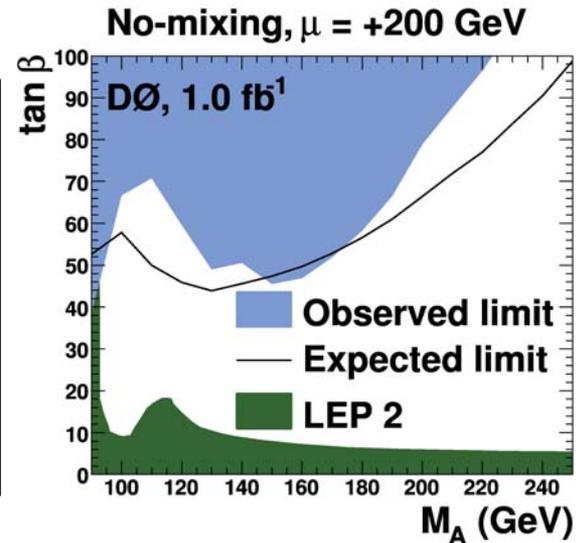
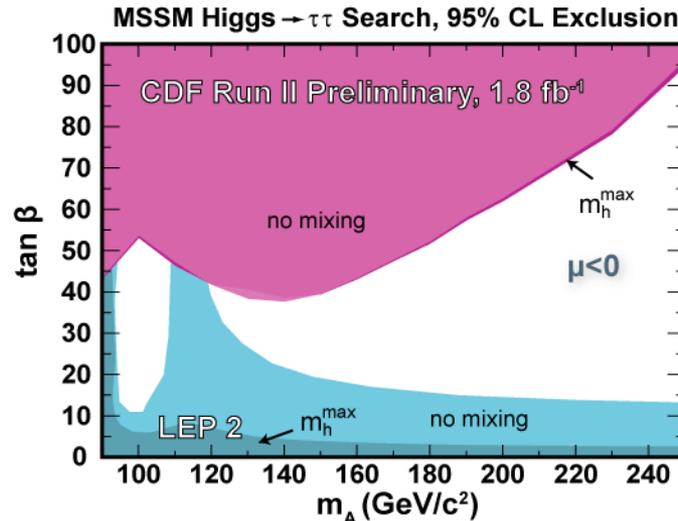
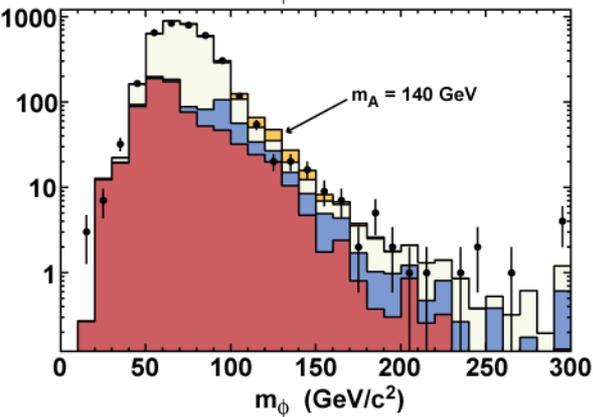
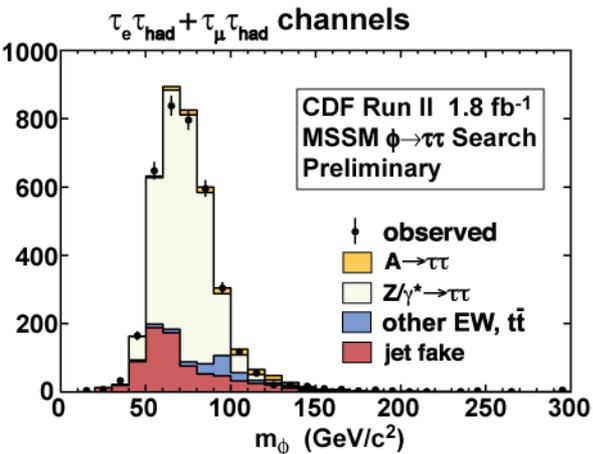
Signal:  $(e\tau_h)$   $(\mu\tau_h)$   $(e\mu)$  pairs + MET

$\tau_h$  narrow hadron jet (possible em component)

Background: mainly  $Z \rightarrow \tau\tau$  and jet fake

No excess in visible mass

Interpretation in MSSM:

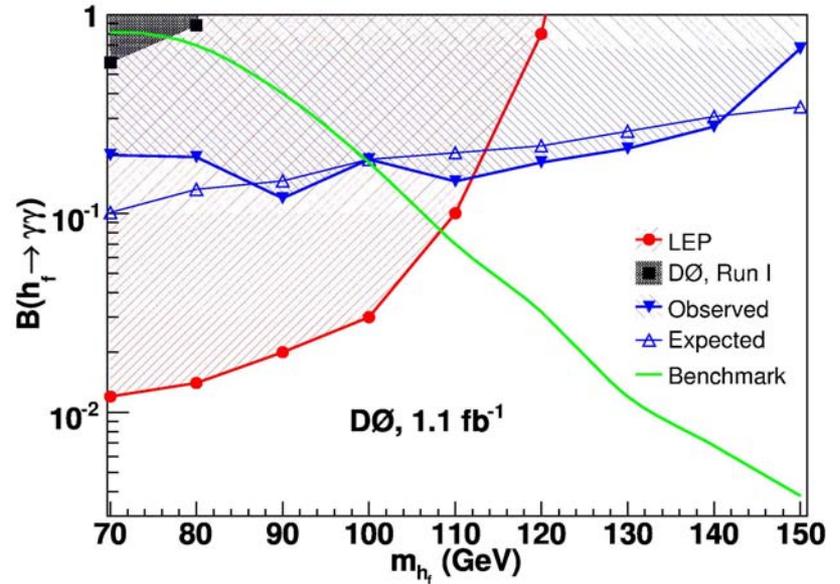
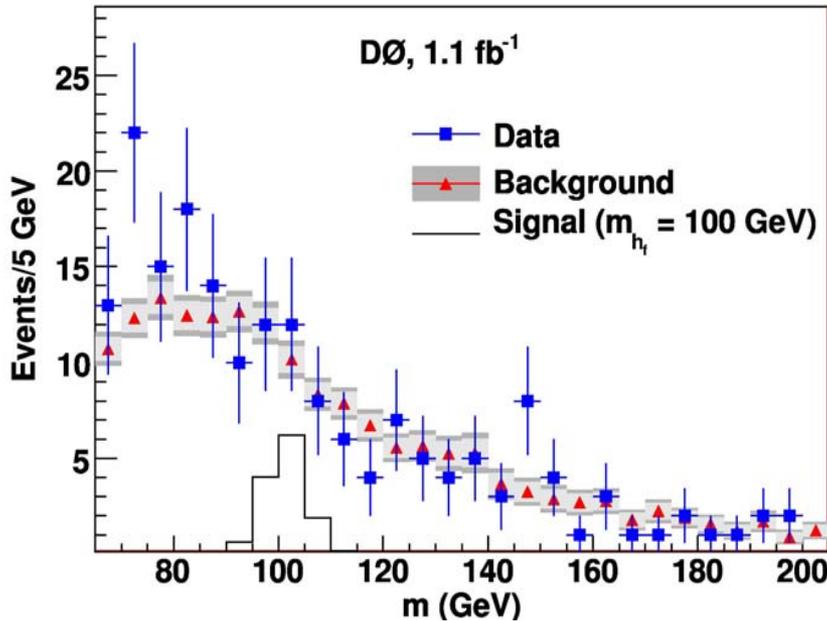


# Fermiophobic Higgs

In some extensions of the SM BR( $h \rightarrow \gamma\gamma$ ) can be  $\sim 1$  since only  $h \rightarrow VV$  ( $V=W,Z$ ) exists

DØ: searches for peaks in  $M_{\gamma\gamma}$

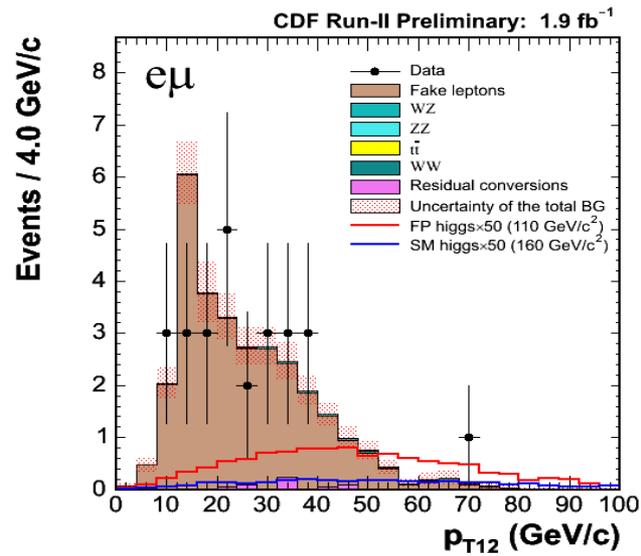
Background: jets faking photons separated by their shapes in the CPS



CDF: interpretes SM Higgs search in  $W+H(\rightarrow WW)$

Signal: 2 LS leptons

Bg: mainly fake leptons



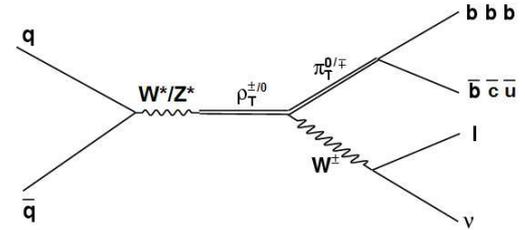
# Technicolor

an alternative way for EWSB

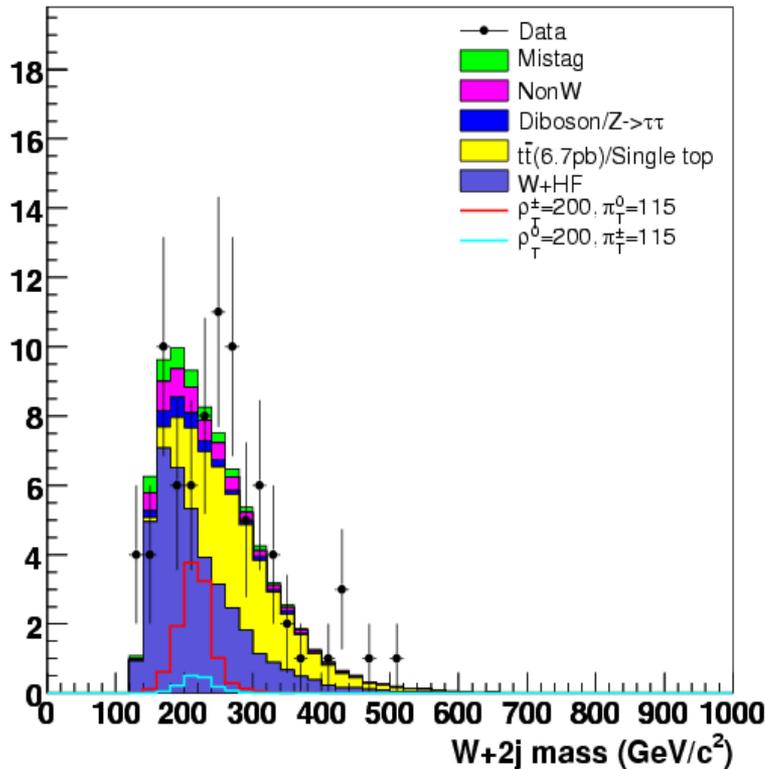
Large number of technihadrons predicted  
decaying into heavy (b,c) quarks

Search is focused in:  $m_W + m_{\pi_T} < m_{\rho_T} < 2m_{\pi_T}$

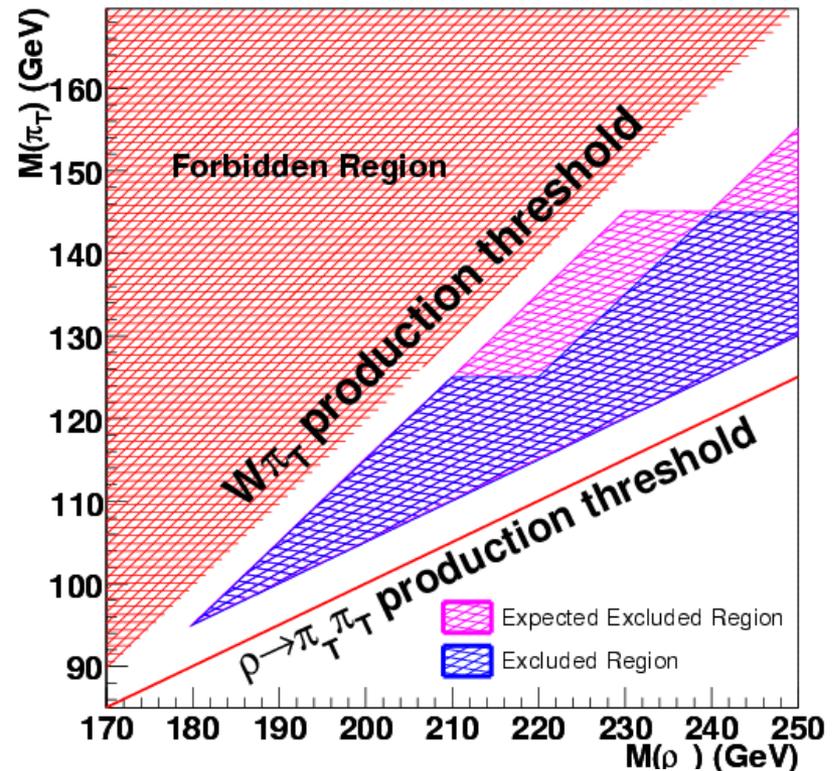
Signal:  $W(l(e,\mu)+MET)+b$ -tagged jet(s)  
similar in the  $WH_{SM}$  search



CDF Run II Preliminary (1.9 fb<sup>-1</sup>)



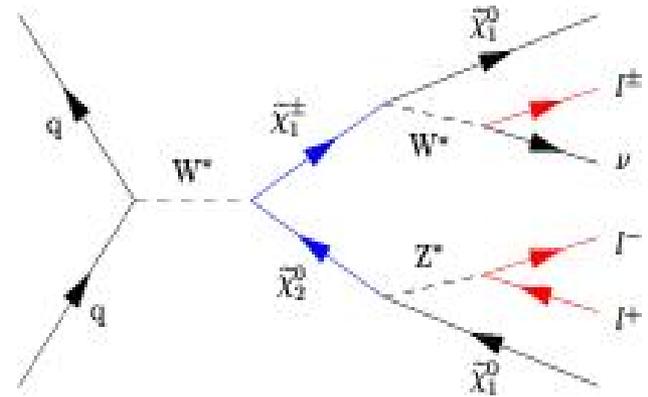
CDF Run II Preliminary (1.9 fb<sup>-1</sup>)



Large area of techniparticle masses  
newly excluded

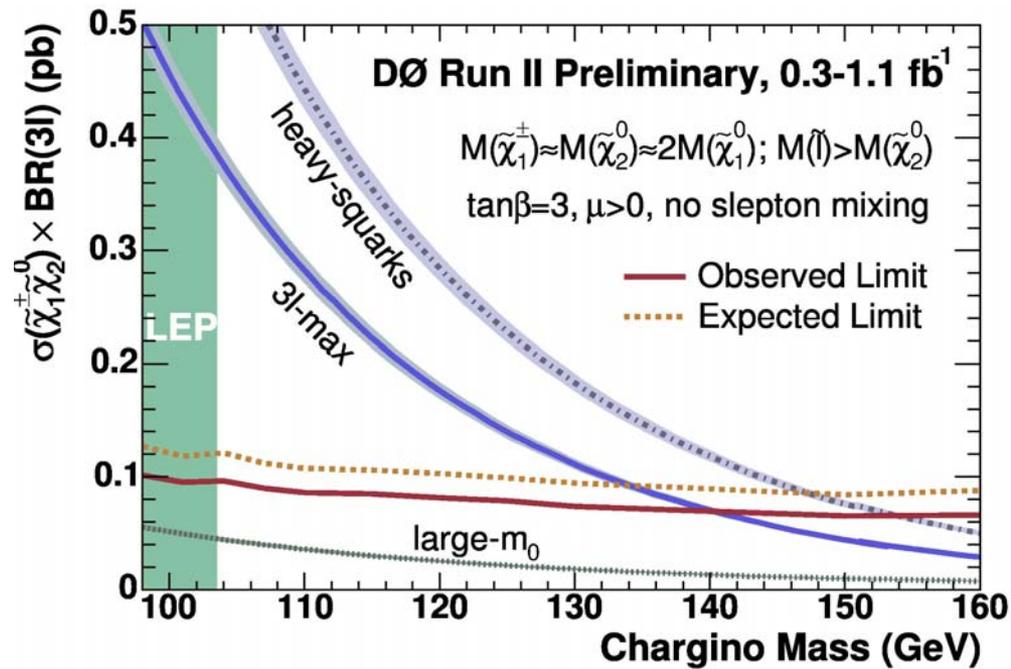
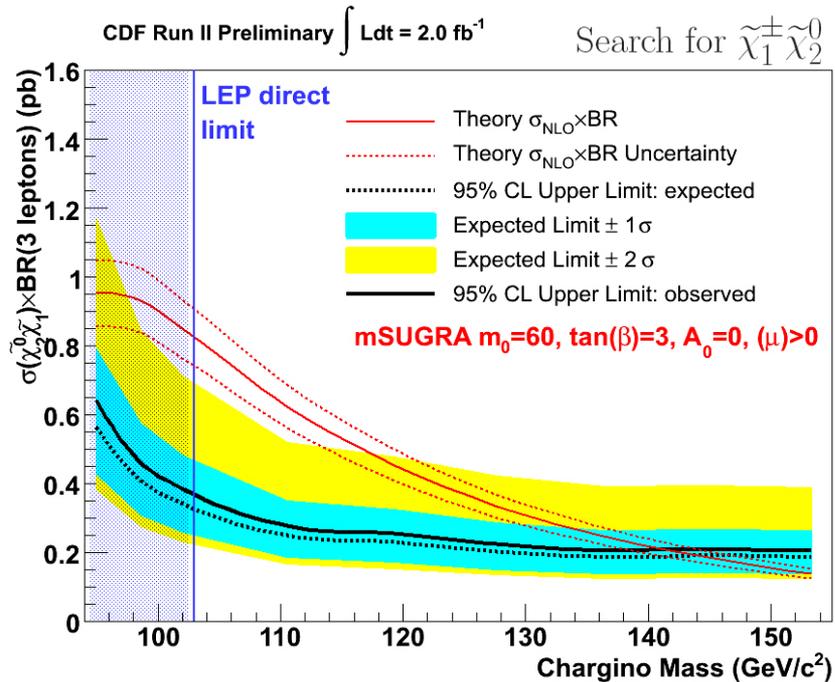
# SUSY particles

The “golden” signature:  
 chargino ( $\chi_{1^\pm}$ ) and neutralino ( $\chi_2^0$ ) pair production



3 leptons (or 2 leptons (ee, e $\mu$ ,  $\mu\mu$ ) + an isolated track) with MET from  $\chi_1^0$  and  $\nu$  or LS  $\mu, \mu$  pair is searched for

Limits set in the mSUGRA framework:  $m_0, m_{1/2}, A_0, \tan\beta, \text{sgn}(\mu)$   
 Typically, chargino masses up to 140 GeV excluded



# squarks and gluinos

Signal:  $n_j + \text{MET}$  ( $n = 2, 3, 4$ )

$$m_{\tilde{q}} < m_{\tilde{g}} : p\bar{p} \rightarrow \tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^0 q\tilde{\chi}_1^0$$

$$n = 2$$

$$m_{\tilde{q}} \sim m_{\tilde{g}} : p\bar{p} \rightarrow \tilde{q}\tilde{g} \rightarrow q\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$$

$$n = 3$$

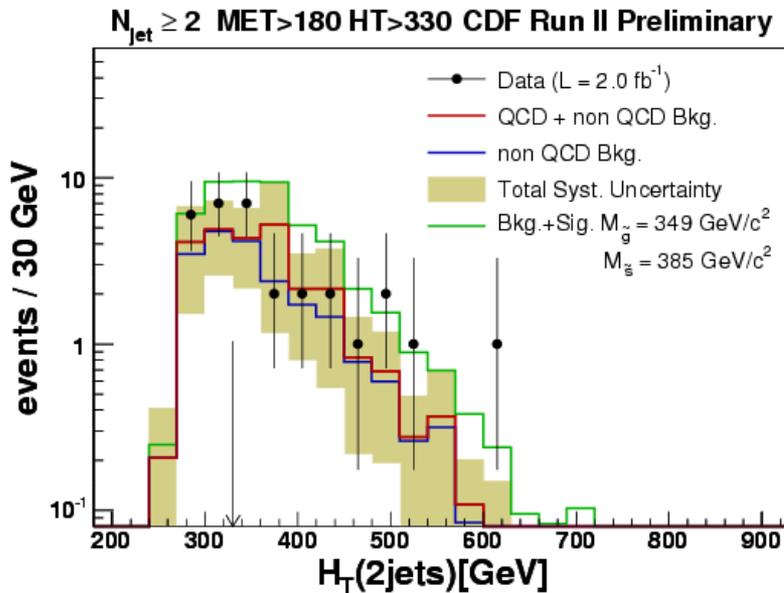
$$m_{\tilde{q}} > m_{\tilde{g}} : p\bar{p} \rightarrow \tilde{g}\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$$

$$n = 4$$

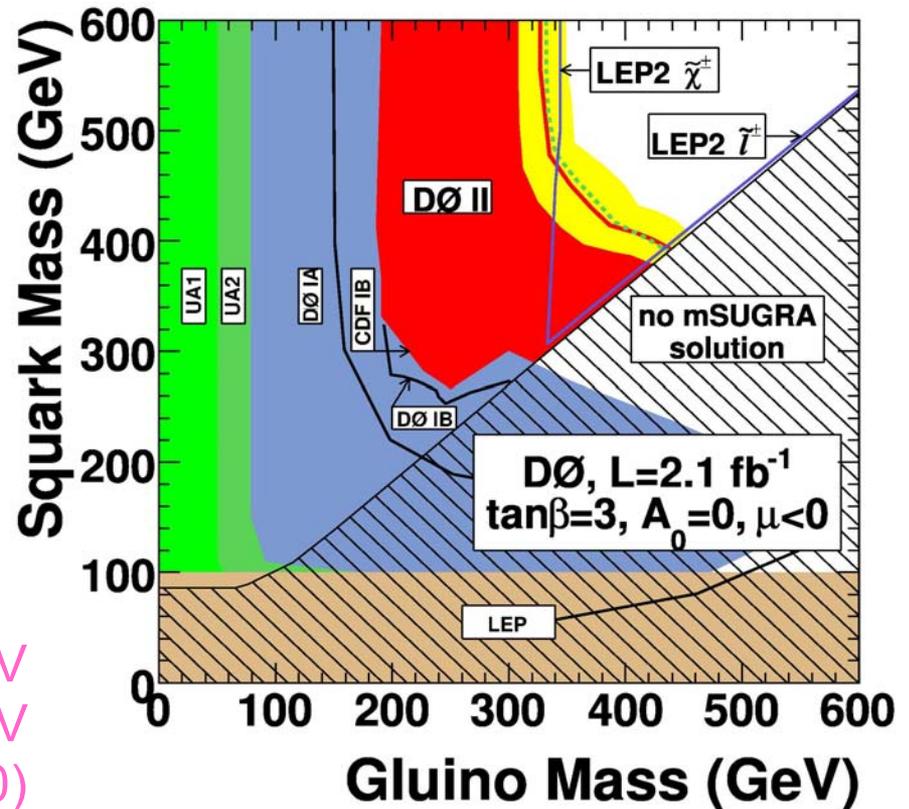
$p_T^j$  cut and lepton veto

Signal should show up  
in MET,  $H_T = \sum p_T^j$

D0 and CDF have  
comparable sensitivity



$m_{\tilde{q}} < 392 \text{ GeV}$   
 $m_{\tilde{g}} < 327 \text{ GeV}$   
 excluded (D0)



# stop quarks

may be the **lightest squark** due to **large mixing** thanks to a **large top mass**

1) 
$$p\bar{p} \rightarrow \tilde{t}_1\tilde{t}_1^* \rightarrow c\tilde{\chi}_1^0\bar{c}\tilde{\chi}_1^0$$

if  $m(c)+m(\chi_1^0) < m(st) < m(b)+M(W)+m(\chi_1^0)$

**Signal:** 2 acoplanar c-jets + MET  
**Background:** mainly V+(HF)jets

$m_{\tilde{t}} < 150 \text{ GeV}$  excluded for  $m_{\tilde{\chi}_1^0} < 65 \text{ GeV}$

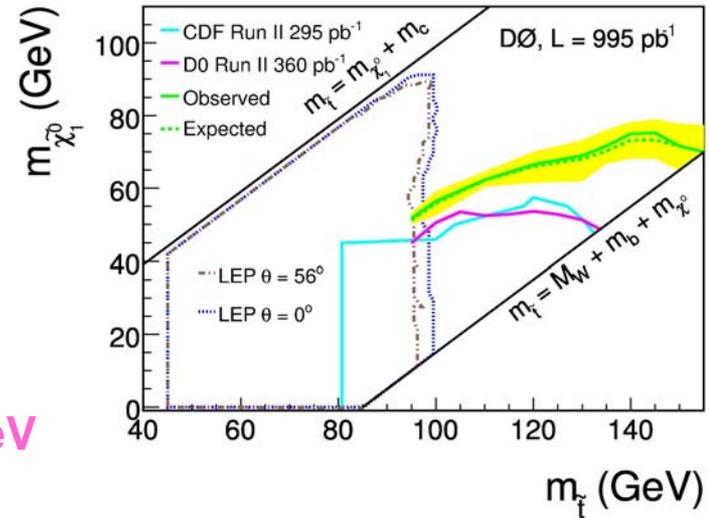
2) 
$$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm \rightarrow b\tilde{\chi}_1^0 l \nu$$

if  $m(b)+m(\chi_1^+) < m(st) < m(t)$ : ~ top decay  
 and  $m(\chi_1^+) < m(\chi_1^0)+m(W)$ : BR  $lv$  large

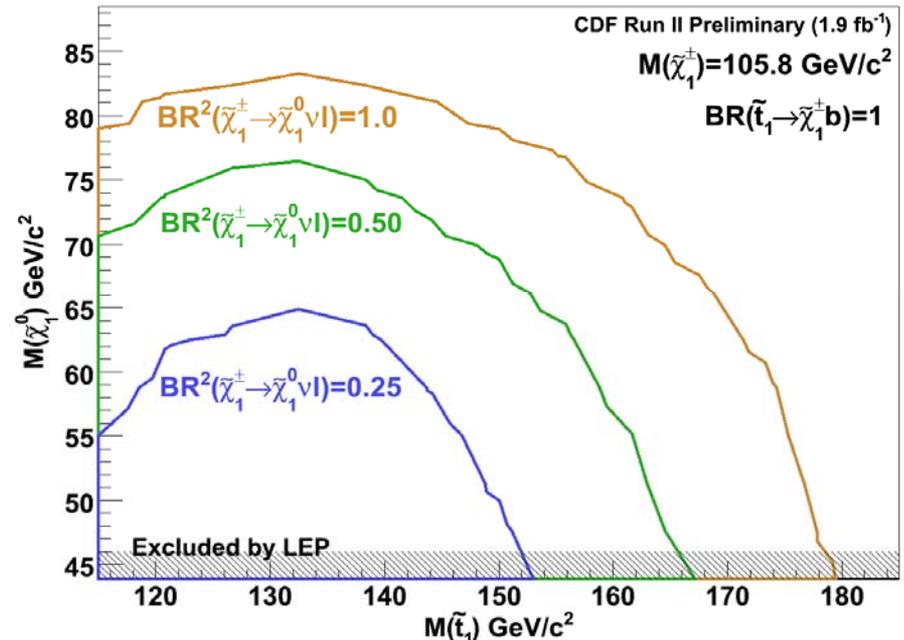
**Signal:** 2 leptons (1 isolated)  
 2 jets (1 btag)  
 MET

**Background:** mainly top

Reconstruct stop mass and **set limit**  
 based on absence of signal



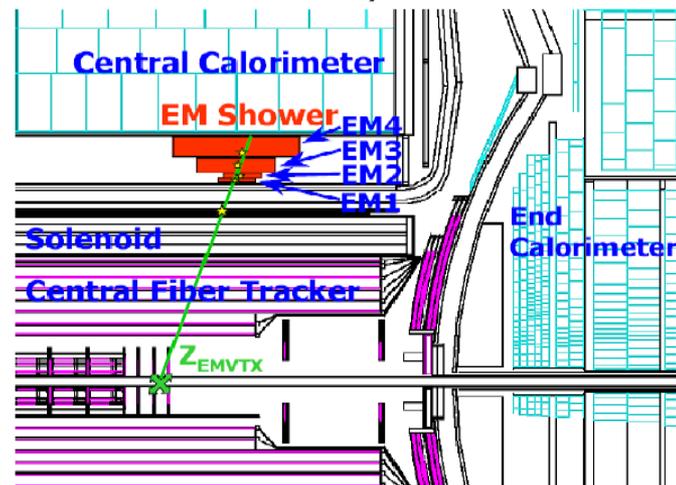
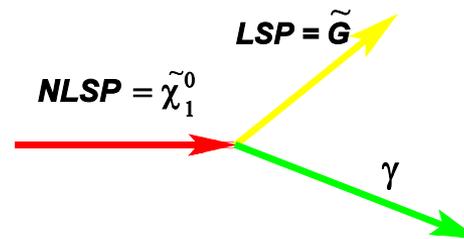
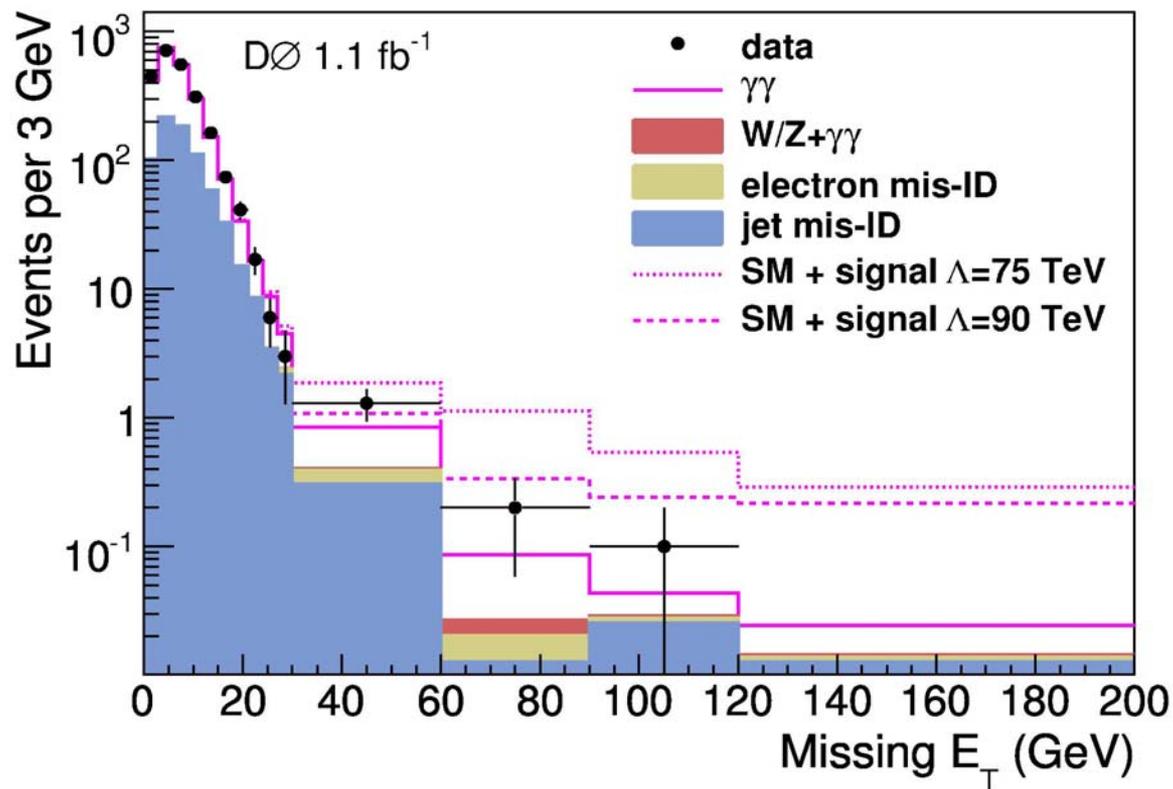
**Observed 95% CL**



# GMSB

Signal: 2 photons and MET  
 Background: mainly instrumental  
 mismeasured MET from  $\gamma\gamma$   
 jets faking photons

Photon pointing algorithm developed  
 helps choosing primary vertex



$m_{\tilde{\chi}_1^\pm} < 229$  GeV  
 $m_{\tilde{\chi}_1^0} < 125$  GeV  
 excluded

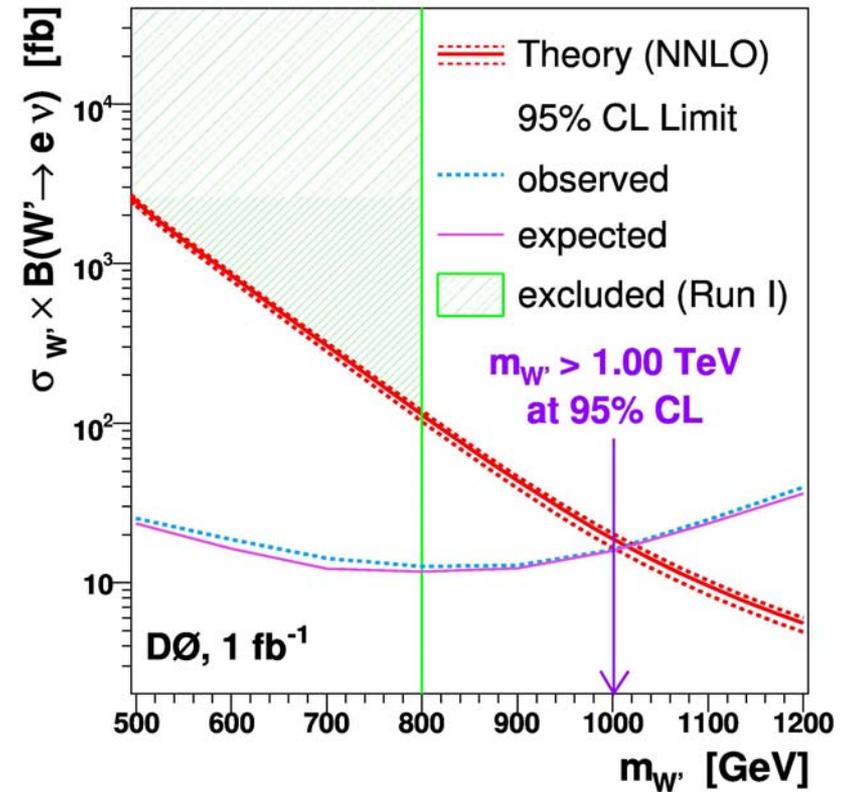
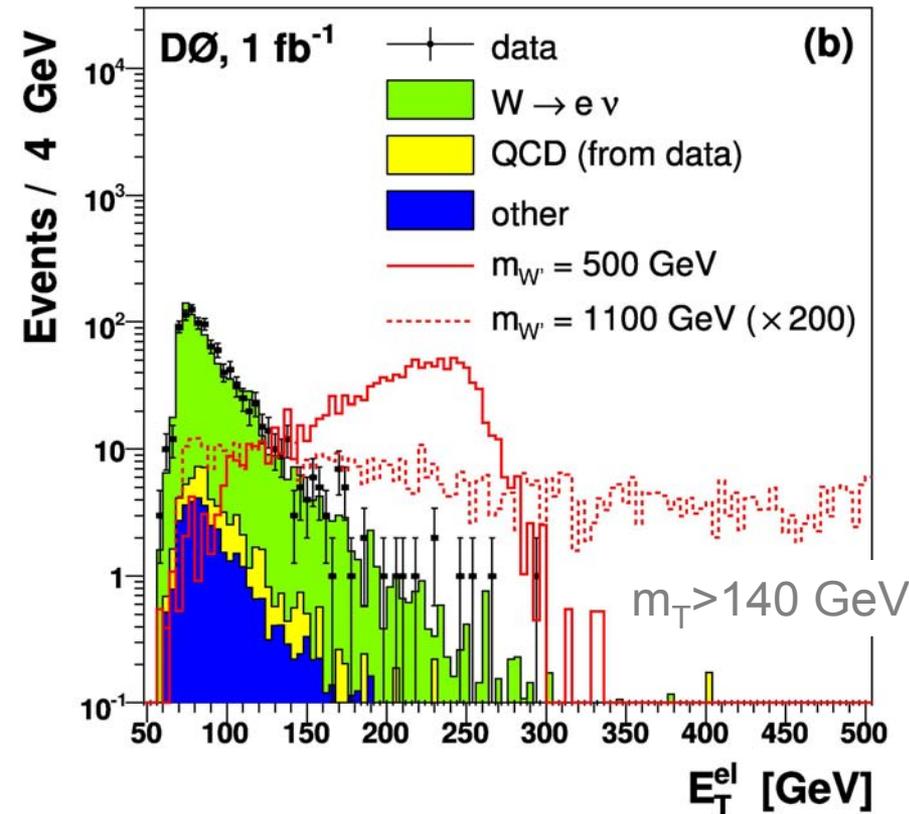
# Heavy gauge bosons

$W'$

Introduced e.g. in L-R symmetric models, SUSY-GUT's, etc.

$W'_{L,R} \rightarrow e\nu$

SM gauge coupling, light  $\nu_{L,R}$



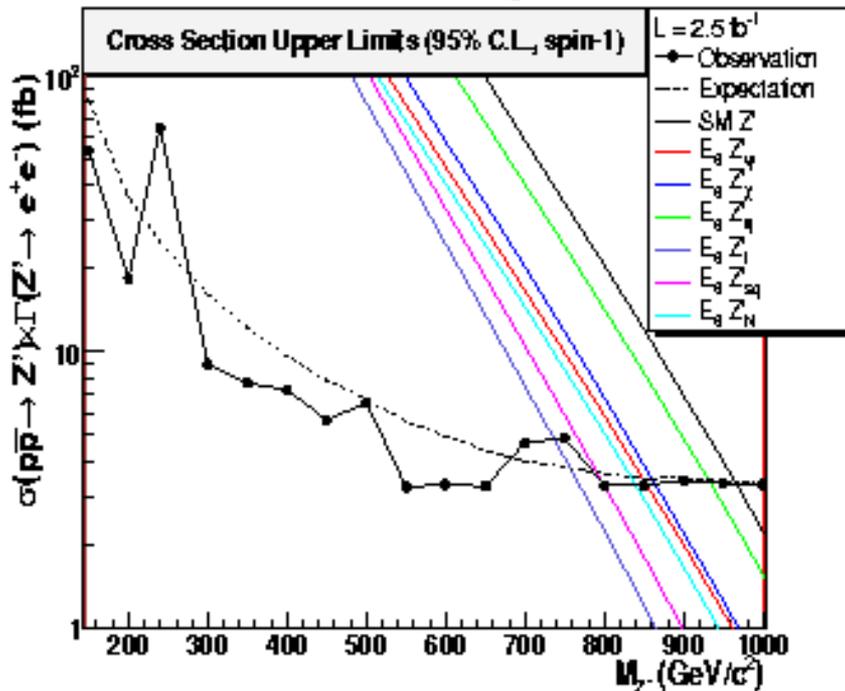
$W'_{L,R} \rightarrow tb \rightarrow l\nu jj$  studied by CDF and D0 – will be reported tomorrow in the Tevatron Top Physics talk by M. Narain

$M_{W'} < 1$  TeV excluded

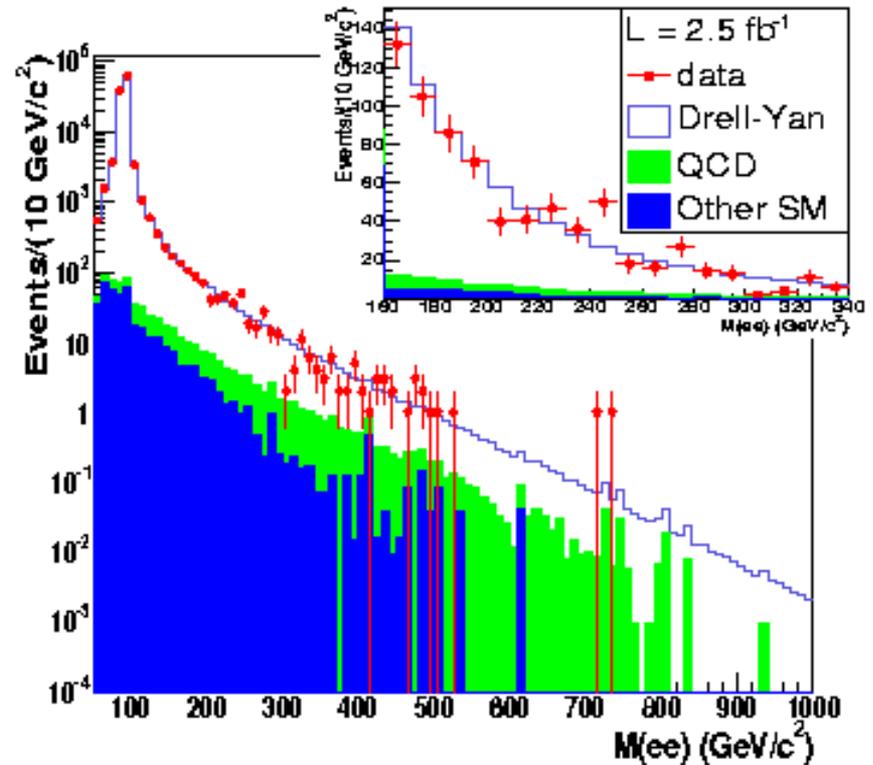
Z'

Peak in the  $M_{ee}$  spectrum is searched for in a scan of stepsize of 1 GeV.  
 The largest discrepancy found is  $3.8 \sigma$ .  
 Not considered as discovery

CDF Run II Preliminary



CDF Run II Preliminary



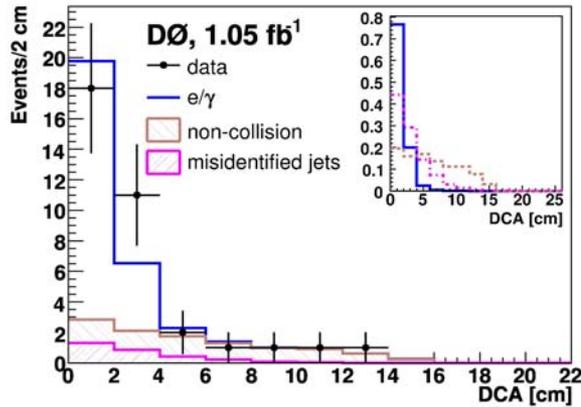
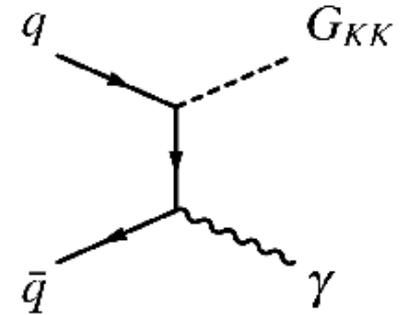
Limits for the 6 mass eigenstates of the E6 Z' are established

The result has been interpreted also as limit on the RS graviton

# Large Extra Dimensions (LED)

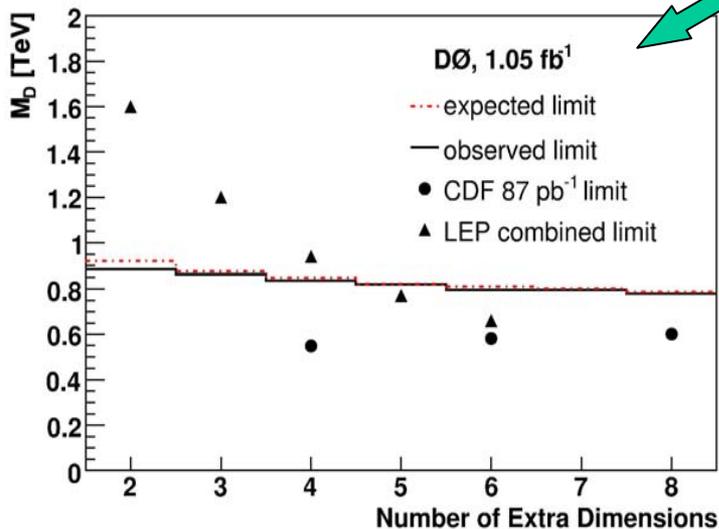
LED can explain why gravity is weak:  $1/G \sim M_{\text{Pl}}^2 \sim M_{\text{D}}^{n+2} R^n$   
 and can solve the hierarchy problem:  $M_{\text{D}} \sim M_{\text{W}}$

Searched in **monophoton** (monojet) final states: MET > 90 GeV

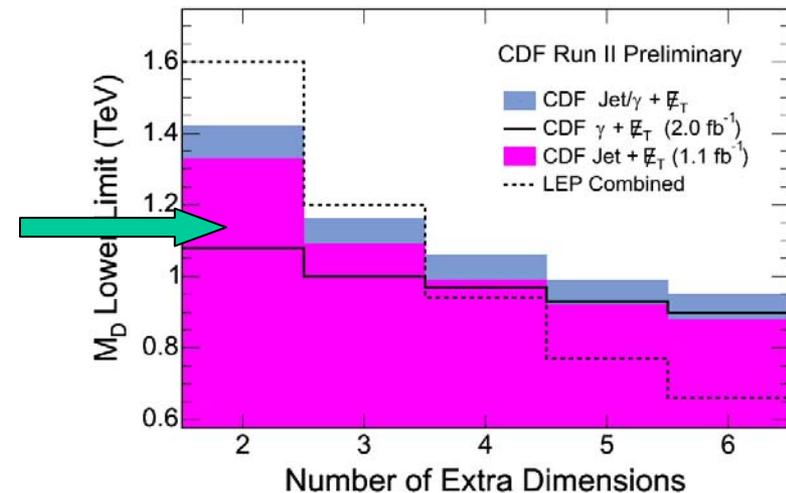


DØ uses photon pointing to determine bg and  $p_{\text{T}}^\gamma$  to look for signal

Limit upto  $N_{\text{D}}=8$  better than LEP for  $N_{\text{D}}>4$

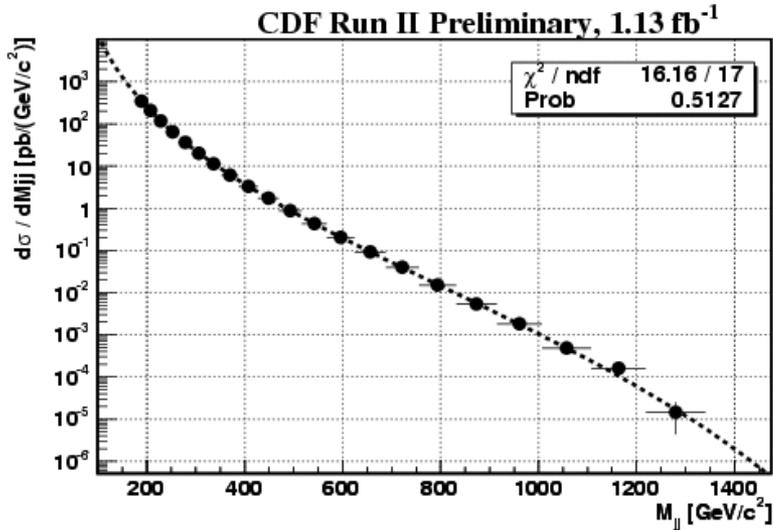


CDF combines monophoton + monojet

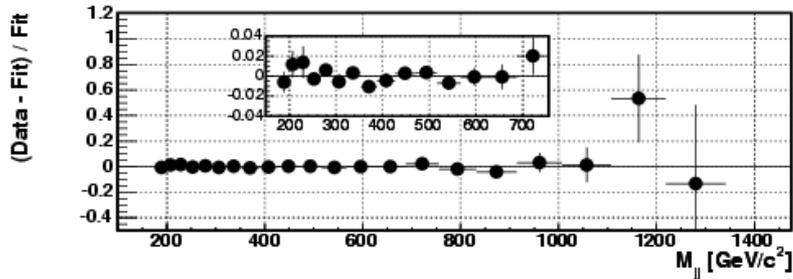


# Substructure of quarks and leptons

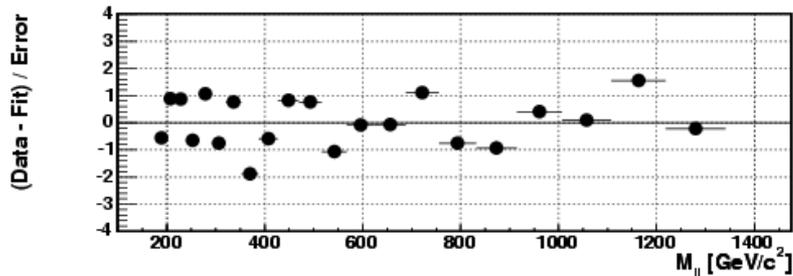
Manifests itself by excited states of quarks and leptons



A peak in the leading 2 jet mass spectrum is expected around the mass of the excited quarks

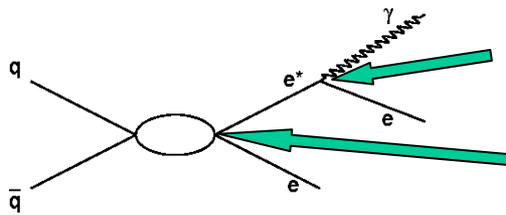


Events triggered on high  $p_T$  jets  
 $|\eta| < 1$ ;  $mE_T / \sqrt{\sum E_T} < f(p_T^{\max})$



In the absence of significant excess  
 $260 < M_{q^*} < 870$  GeV  
excluded

# Excited electrons



Decays by GMI

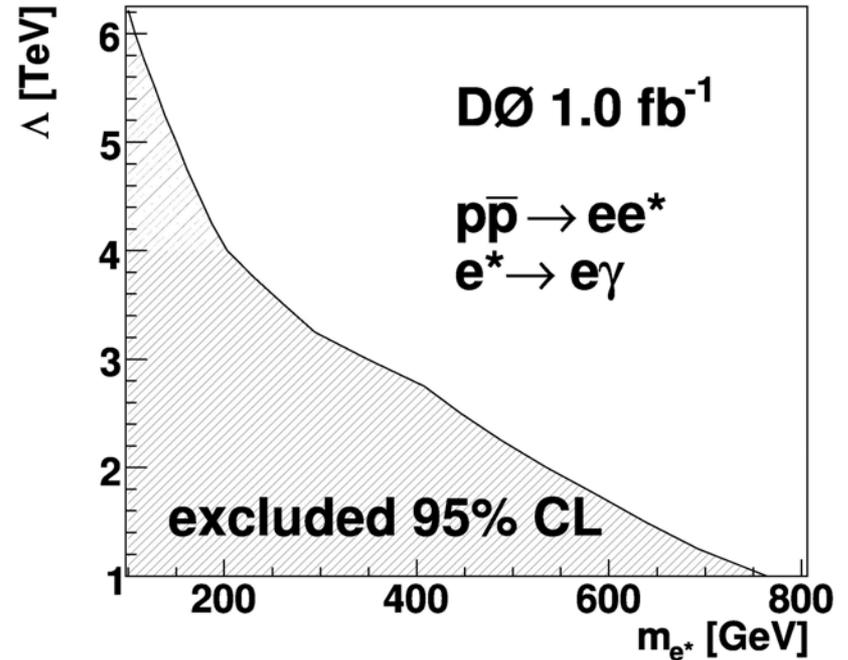
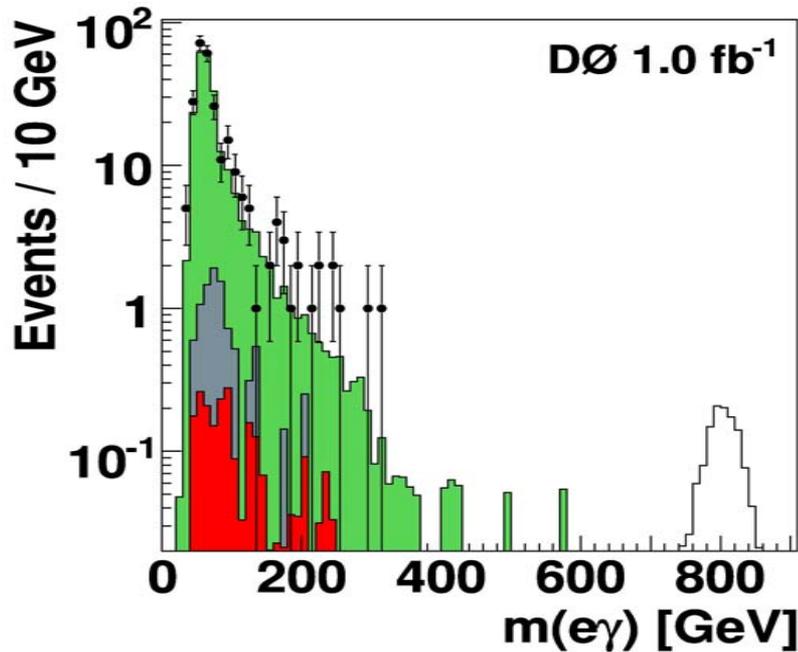
Produced by CI

$$L_{\text{GMI}} = \frac{1}{2\Lambda} j^{\mu\nu} G_{\mu\nu}$$

$$L_{\text{CI}} = \frac{g^2}{2\Lambda^2} j^\mu j_\mu$$

Compositeness  
scale:  $\Lambda$

Signal: 2 high  $p_T$  electron + 1 high ET photon  
Bg: mainly DY+j/  $\gamma$



$M_{e^*} < 756 \text{ GeV}$  excluded @  $\Lambda = 1 \text{ T eV}$

# 4<sup>th</sup> generation fermions

Search for  $t'\bar{t}'$  pairs  
 assuming:  $m_t < m_{t'} < m_W + m_b$   
 $t' \rightarrow W + j$ ;  $W \rightarrow l + \nu$

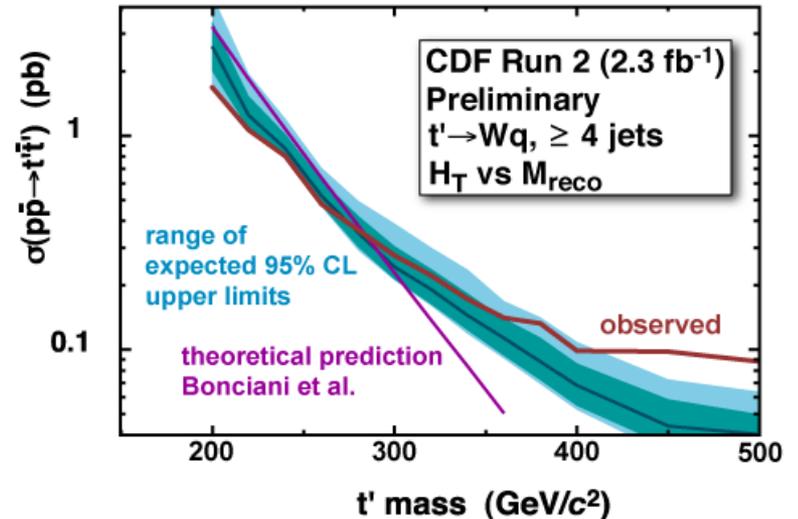
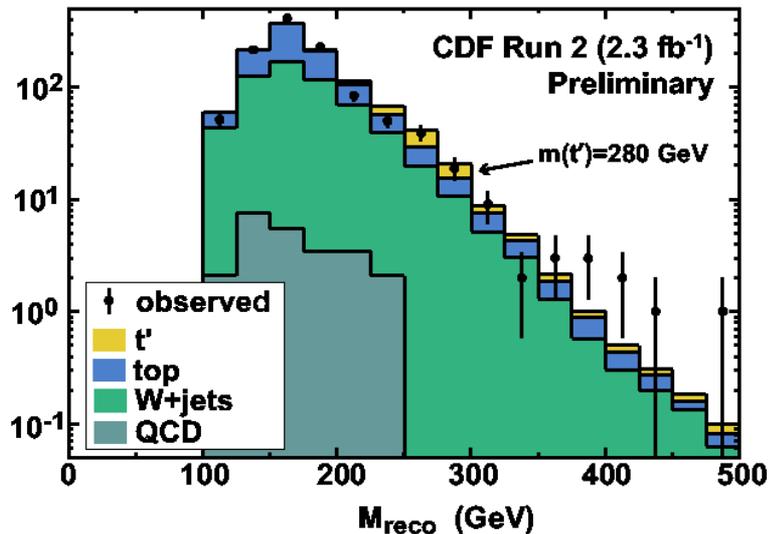
Signal: large MET  
 isolated lepton (e or  $\mu$ )  
 4 energetic jets  
 Bg: mainly  $t\bar{t}$  and  $V$ +jets

Use mass determination technique of the top in the  $l$ +jets channel:

$M_{\text{reco}} = m_{\text{jjj}} = m_{l\nu j}$  with the lowest  $\chi^2$

$$H_T = \sum_{\text{jets}} E_T + E_{T,l} + mE_T$$

For each  $m_{t'}$  calculate posterior pdf of  $\sigma_{t'}$  from the  $M_{\text{reco}}$  and  $H_T$  spectra

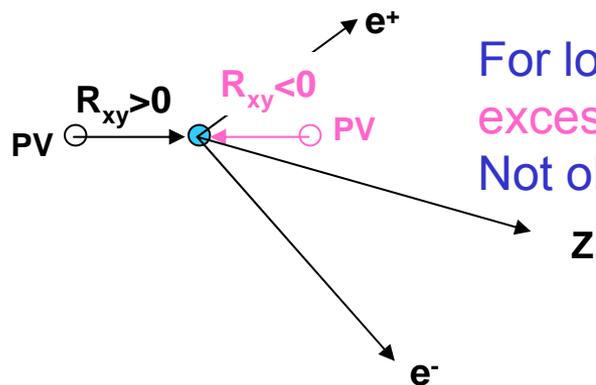
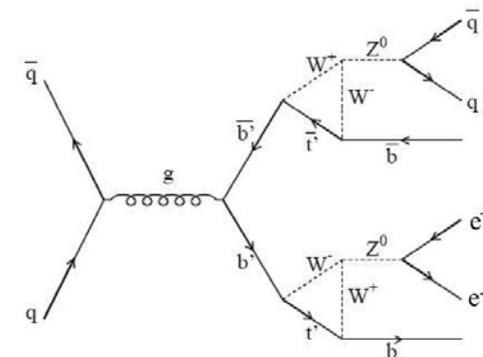


$m_{t'} < 284 \text{ GeV}$  (assuming  $m_t = 175 \text{ GeV}$ ) excluded

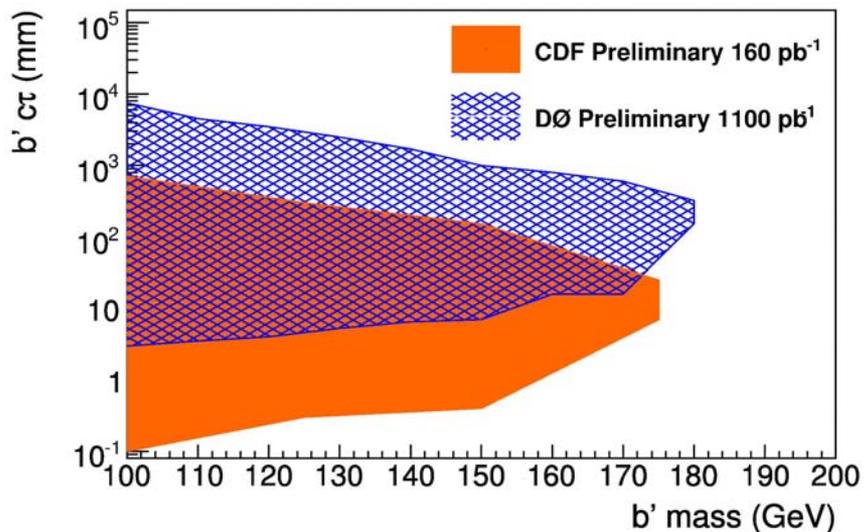
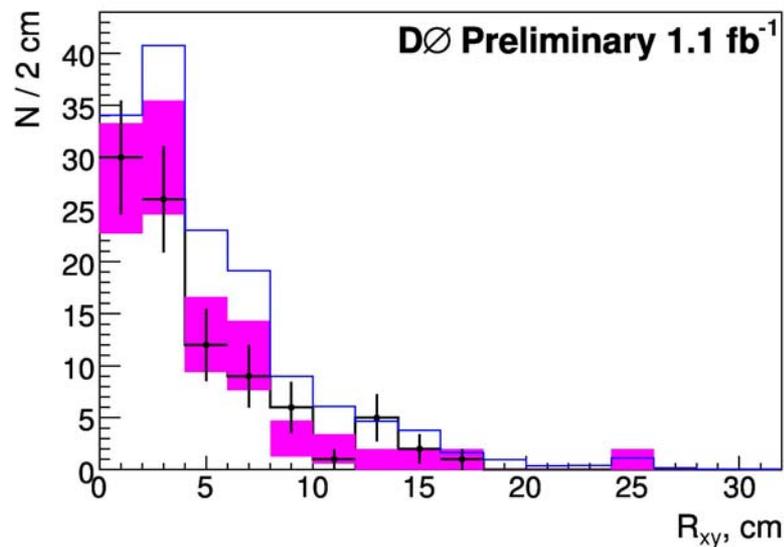
# Search for long-lived $b'$ $b' \rightarrow Z+b$

If  $m_{b'} < m_t \rightarrow b'$  can travel several meters

The displaced vertex is reconstructed by the tracker (CDF) or using the calorimeter and CPS (D0)



For long-lived particles  
excess of  $R_{xy} > 0$  expected  
Not observed in data



Several meters of lifetime has been excluded.

Same method can be applied for other long-lived particles, e.g.

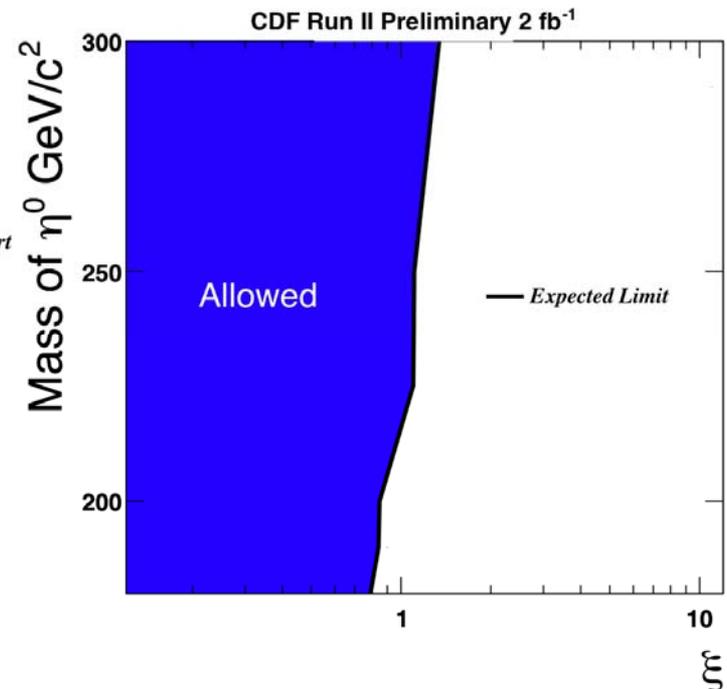
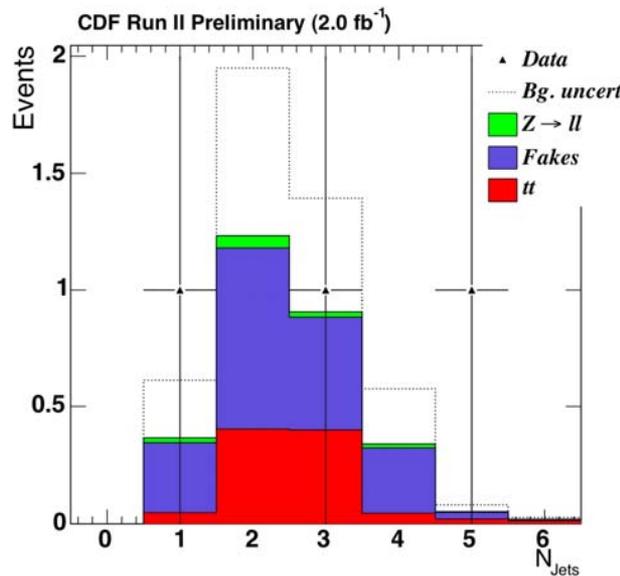
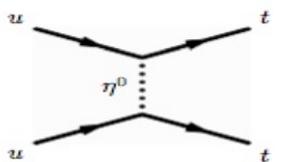
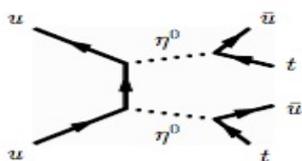
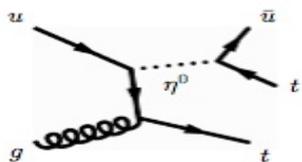
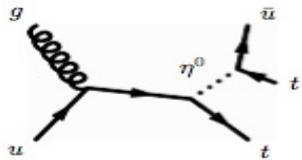
$\chi_1^0 \rightarrow G+\gamma$  in GMSB

# Maximal Flavor Violation (MxFV)

New scalar doublet  $\Phi_{FV} (\eta^0, \eta^+)$  is proposed with mass in the  $\sim 100$  GeV range and with off-diagonal coupling  $\xi$  to fermion generations ( $i=1,3$ ):  $\xi_{ii} \sim 0$   
 only  $\xi_{3i}$  and  $\xi_{i3}$  are non-zero (max FV contrarily to  $V_{CKM} \sim$  diagonal).  
 No contradiction with LE data ( $K^0, B^0, D^0$  oscillations, rare K, B decays).

Predicts new exotic final states, e.g. pair of LS top quarks

2.7-14.9 signal events  
 2.9±1.8 SM bg expected  
 2 data events observed



# Global search for New Physics

## VISTA

Search for discrepancy between observed and predicted number of events and shape of kinematical distributions of a large number of exclusive final states

## SLEUTH

Search for high  $P_T$  tails as signal for new physics

## Bump Hunter

New algorithm added to search for peaks in mass spectra

No significant excess found so far

See details in tomorrow's talk of Si Xie

# Conclusions

A very large number of ideas beyond the Standard Model has been tested at the Tevatron

No compelling evidence for new physics has been found so far

The few deviations from the SM can be understood due to the large number of tests carried out

The high performance of the collider and detectors together with innovative methods in the analyses allowed to exclude new large regions of the parameter space of BSM theories

More results are expected soon...

Apologies for subjects I haven't had time to present here

More information can be found on:

<http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm>

<http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm>

<http://www-cdf.fnal.gov/physics/W08CDFResults.html>

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

<http://www-cdf.fnal.gov/physics/new/hdq/hdq.html>

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