Constraining Little Higgs Models at the Tevatron

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hep-ph/0610156

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Outline

- Little Higgs models
  - littlest Higgs
- Little Higgs with T-parity
  - Electroweak precision and dark matter
- T-odd fermions
- Tevatron bounds on "T-quarks" from acoplanar dijet studies

Little Higgs models

- The new concept is "collective symmetry breaking"

Higgs is a pseudo-Goldstone boson (PGB) kept light by approximate global symmetries (old idea, new features)

Georgi, Kaplan – early 80's

Global symmetries are broken explicitly, but in a special way

Arkani-Hamed, Cohen, Georgi hep-ph/0105239

$$\mathcal{L} = \mathcal{L}_1 + \mathcal{L}_2$$

$\mathcal{L}_1$ breaks some of global symmetries

$\mathcal{L}_2$ breaks some others

Together, couplings break all symmetries protecting the Higgs mass, and we generate an m_H^2 at *two-loop order*

The littlest Higgs

Arkani-Hamed, Cohen, Katz, Nelson hep-ph/0206021

- Parametrize SU(5) to SO(5) breaking by nlσm
- VEV Σ_0 breaks $[SU(2)xU(1)]^2$ to $SU(2)_L xU(1)_Y$

New particles get mass ~ f

$$\Sigma = e^{2i\Pi/f}\Sigma_0 \qquad \Sigma_0 = \langle\Sigma\rangle = \Sigma_0 = \begin{pmatrix} & & & 1 & \\ & & & & 1 \\ & & 1 & & \\ 1 & & & & \\ & 1 & & & \end{pmatrix}$$

$$\Pi = \begin{pmatrix} 0 & \frac{H}{\sqrt{2}} & \Phi \\ \frac{H^\dagger}{\sqrt{2}} & 0 & \frac{H^T}{\sqrt{2}} \\ \Phi^\dagger & \frac{H^*}{\sqrt{2}} & 0 \end{pmatrix}$$

Higgs is exact Goldstone under either SU(3)

Φ is a complex triplet under $SU(2)_L$

Collective breaking

SU(5)/SO(5) symmetry breaking pattern – gauge symmetries embedded in SU(5) global symmetry

$$Q_1^a = \begin{pmatrix} \sigma^a/2 & 0 & 0 \\ 0 & \boxed{\begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix}} \\ 0 & & \end{pmatrix}, \qquad Y_1 = \mathrm{diag}(3,3,\boxed{-2,-2,-2})/10$$

$$Q_2^a = \begin{pmatrix} \boxed{\begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix}} & \begin{matrix} 0 \\ 0 \end{matrix} \\ \begin{matrix} 0 & 0 \end{matrix} & -\sigma^{a*}/2 \end{pmatrix}, \qquad Y_2 = \mathrm{diag}(\boxed{2,2,2}\,{-3},-3)/10\,,$$

$$[SU(2) \times U(1)]^2$$

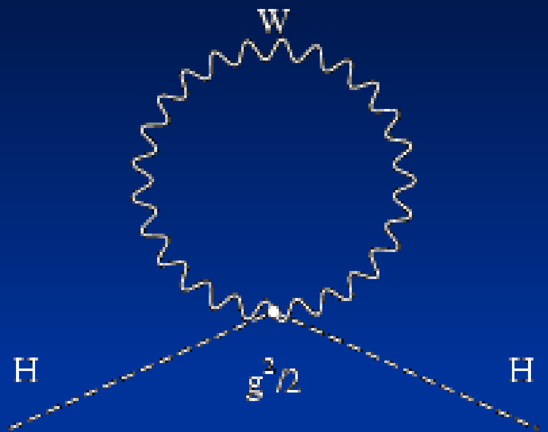
$\mathcal{L}_1$ preserves SU(3) in bottom right

$\mathcal{L}_2$ preserves SU(3) in upper left

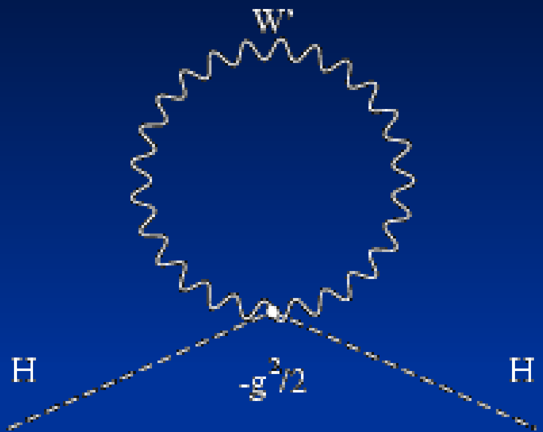
Either SU(3) is enough to keep Higgs massless

- But the sum of *all* the gauge interactions breaks all symmetries protecting the Higgs mass

New Symmetries = New Particles



$$\sim \frac{3g^2\Lambda^2}{(4\pi)^2}$$



$$\sim -\frac{3g^2\Lambda^2}{(4\pi)^2}$$

New 'partners' of standard model fields cancel one loop quadratic divergences

Global symmetry structure ensures relation between couplings

Partners have *same statistics*

T-Parity and the littlest Higgs

Cheng, Low

- Original models have stringent EWP bounds

Csaki, Hubisz, Kribs, Meade, Terning

Hewett, Petriello, Rizzo

- Other models which evade constraints exist, but involve more complicated gauge/global symmetry structures

Just as R-parity cures ills of SUSY (proton decay, lepton flavor violation), T-parity is a discrete symmetry that is added to solve the tree level EWP issues in LH

Can also provide a weak scale dark matter candidate

T-Parity and the littlest Higgs

- (Almost) all new particles introduced are odd under a discrete symmetry ($\tilde{W},\ \tilde{W}_3,\ \tilde{B},\ \Phi$)
- Dangerous diagrams are forbidden (e.g. tree level mass shifts, and 4-fermion operators)
- Parity symmetry exchanges the two gauge groups $[SU(2)xU(1)]_1$ and $[SU(2)xU(1)]_2$
- T-parity enforces relations between couplings (e.g. $g_1 = g_2$)
- To implement consistently (avoid compositeness bounds), need to enlarge fermion sector

Action of T-Parity

$$A_{SM} \to A_{SM}$$

$$A_H \to -A_H$$

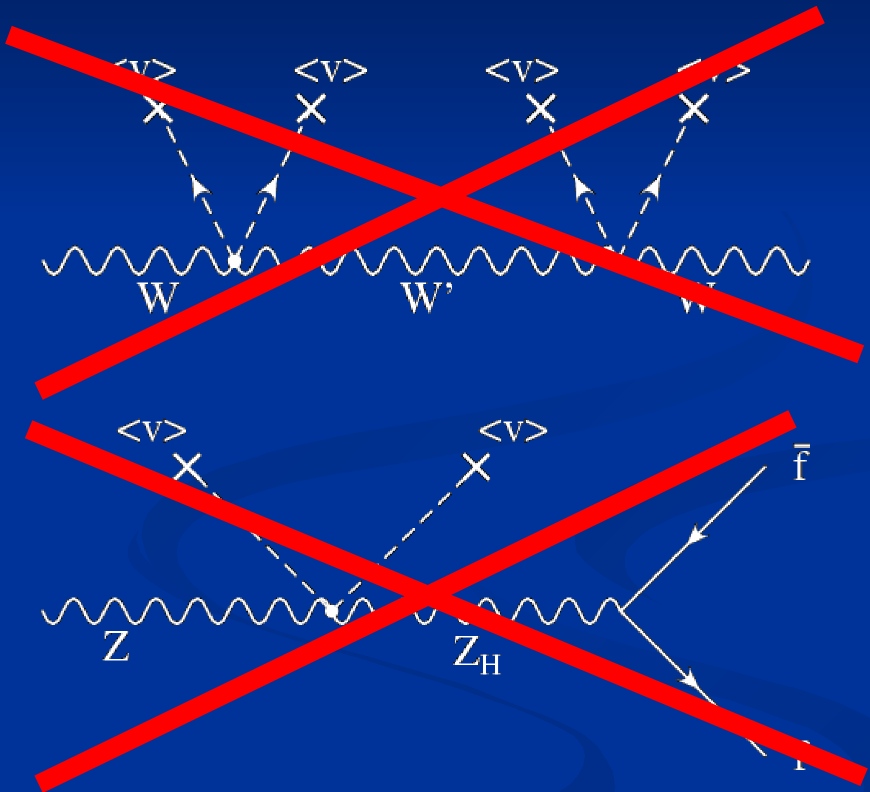
$$f_{SM} \to f_{SM}$$

$$f^{(-)} \to -f^{(-)}$$

$$H \to H$$

$$\Phi \to -\Phi$$

$$T \to T$$



New Fermions Required

$SU(2)_1$ $SU(2)_2$ T-Parity Eigenstates

$$\begin{pmatrix} \nu_{l1} \\ l_1 \end{pmatrix} + \begin{pmatrix} \nu_{l2} \\ l_2 \end{pmatrix} \longrightarrow \begin{pmatrix} \nu_l \\ l \end{pmatrix} + \begin{pmatrix} \nu_l^{(-)} \\ l^{(-)} \end{pmatrix}$$

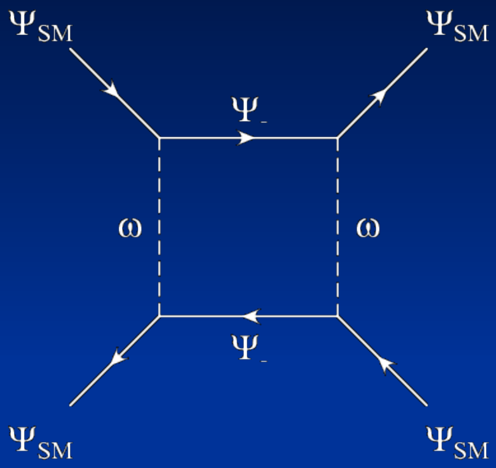
$$\begin{pmatrix} u_{i1} \\ d_{i1} \end{pmatrix} + \begin{pmatrix} u_{i2} \\ d_{i2} \end{pmatrix} \longrightarrow \begin{pmatrix} u_i \\ d_i \end{pmatrix} + \begin{pmatrix} u_i^{(-)} \\ d_i^{(-)} \end{pmatrix}$$

SM **NEW T-ODD STATES**

For each SM left handed fermion, have a vector-like (Dirac) fermion partner - odd under T-parity

"T-leptons" $\tilde{L}_i$ and "T-quarks" $\tilde{Q}_i$

'Composite' fermion constraints



$$= -i \frac{\kappa^2}{128\pi^2 f^2} \bar{\psi}_L \gamma^\mu \psi_L \bar{\psi}'_L \gamma_\mu \psi'_L$$

constraints from eedd operator require $M_{\mathrm{TeV}} \leq 4.8 f^2_{\mathrm{TeV}}$

upper bound on masses of T-odd mirror fermions

f at 1 TeV implies maximum of 5 TeV mass T-odd fermions

EWP also prefers light T-quarks and T-leptons

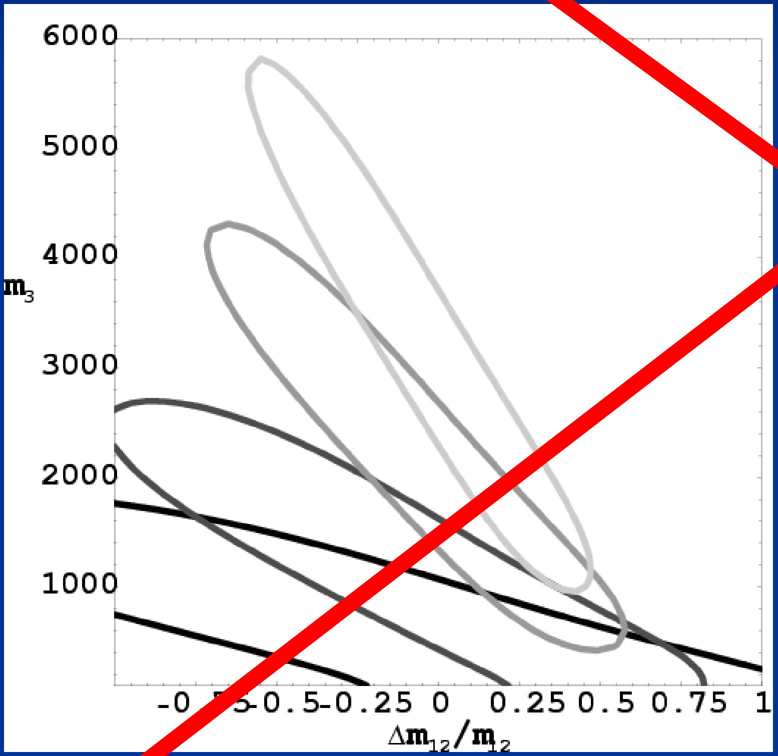
Flavor: new flavor structure – one loop contributions to FCNC's

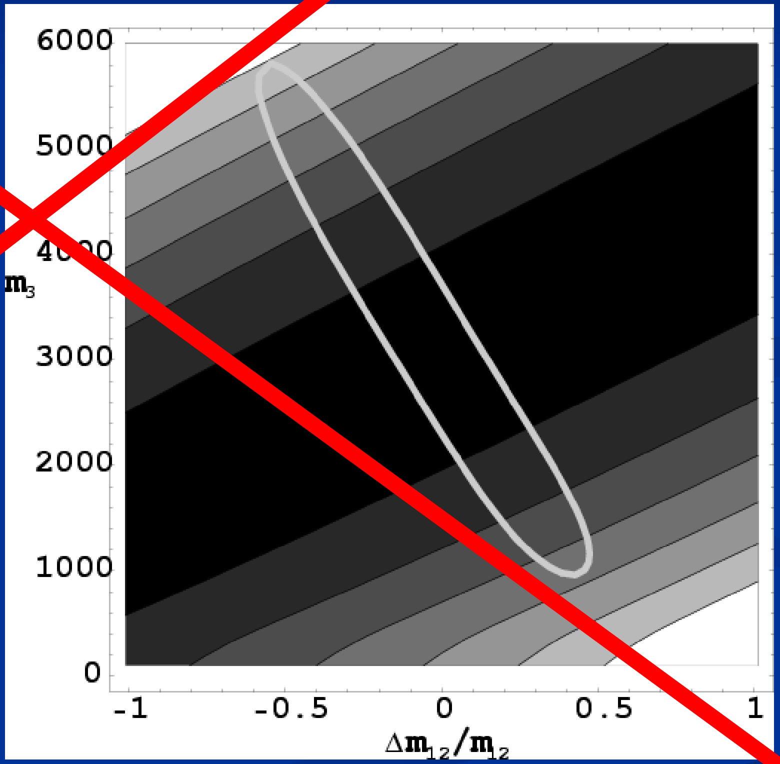
Hubisz, Lee, Paz hep-ph/**0512169**
Buras et. al. hep-ph/**0605214**

B_s mixing enhancement!

Can pick angles specifically to enhance B_s mixing,
but avoid other constraints

$$s_{23}^d = 1/\sqrt{2},\ s_{12}^d = 0,\ s_{13}^d = 0,\ \delta_{13}^d = 0$$





$m_{12} = 3000$ GeV

New physics spectrum

f ~ 1000 GeV

$M(X)$

Add. Heavy States

$M(\Phi),\ M(\tilde{W}) \approx 650\ \text{GeV}$

T-odd fermion masses – free parameter in theory

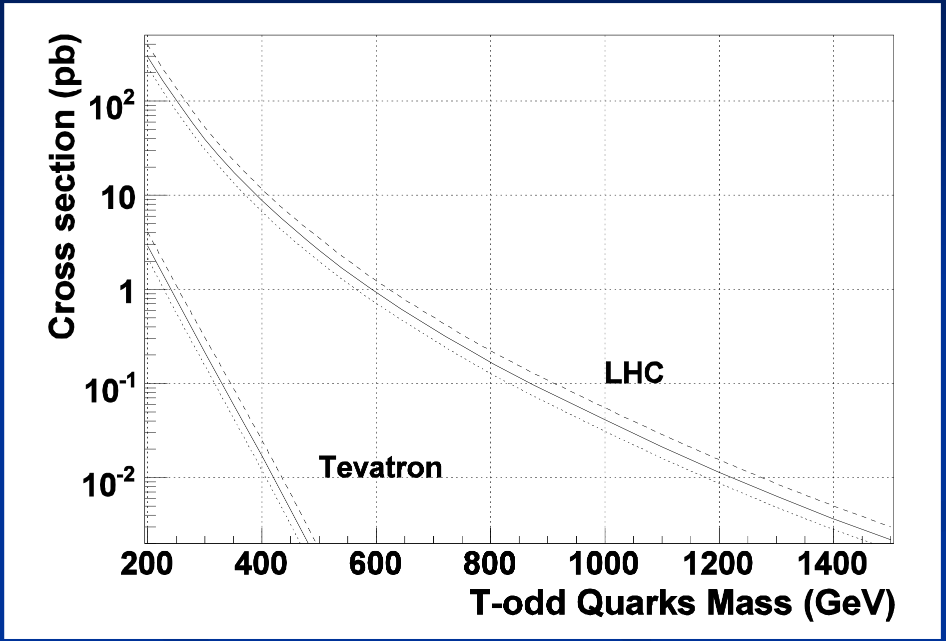
$\tilde{M} \approx \kappa f \approx 150 - 5000\ \text{GeV}$

Lightest T-odd particle – partner of hypercharge GB

$M(\tilde{B}) \approx 150\ \text{GeV}$

T-quark pair production at the Tevatron

- T-quarks are produced in hadron colliders
  - Drell-Yan and gluon fusion
    - same as squarks
- Tevatron has produced some T-quarks if $\tilde{M} < 500\ \text{GeV}$!!



Production cross section for one flavor of T-quark

- CDF and DØ have already done analyses searching for new physics
  - how can we use what has already been done to constrain this new model?

MSSM and Little Higgs w/ T-parity

- MSSM with light squarks

  $q\bar{q} \to \tilde{q}\tilde{q}^*, \;\; gg \to \tilde{q}\tilde{q}^*$ $\quad \tilde{q} \to q\bar{\chi}_0^1$

- LHT with light T-quarks

  $q\bar{q} \to \tilde{Q}\bar{\tilde{Q}}, \;\; gg \to \tilde{Q}\bar{\tilde{Q}}$ $\quad \tilde{Q} \longrightarrow q\tilde{B}$

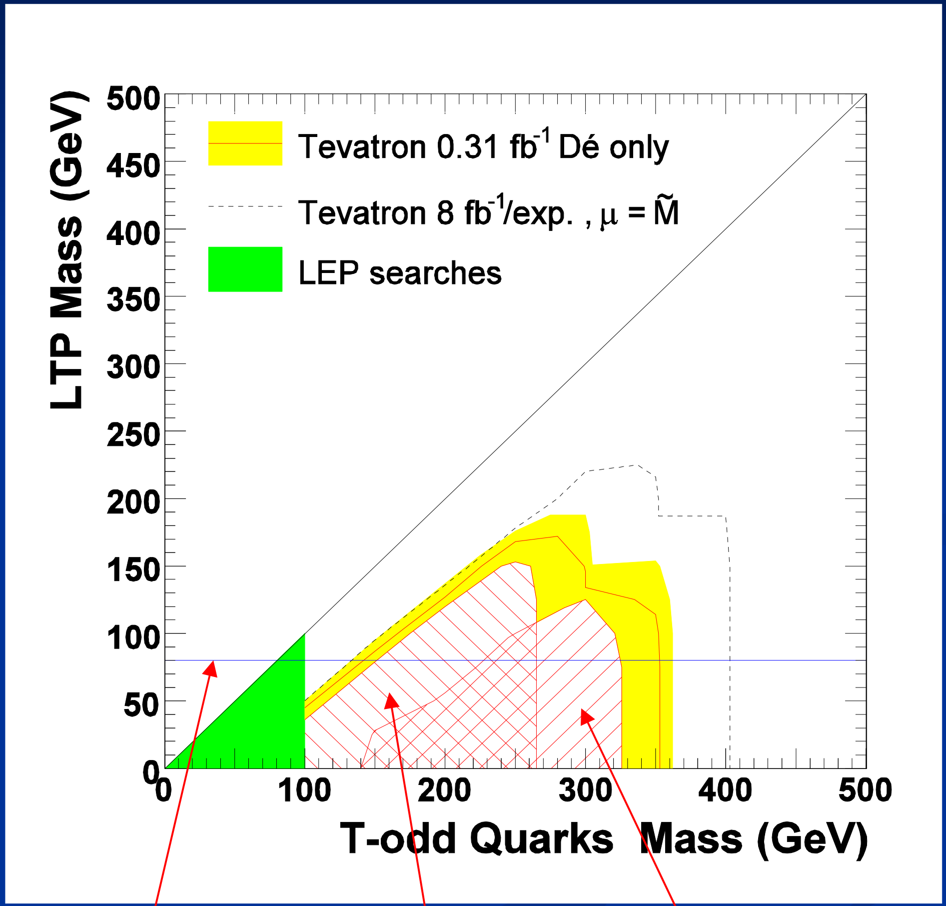
- Signal: ‘acoplanar dijets’ – 2j+MET
  - DØ squark and lepto-quark searches
  - distinction? – not at hadron collider
  - p_T and η distributions basically identical (MadGraph – parton level)
  - can use PYTHIA6.323 as MSSM generator – beyond parton level
    - scale to match cross section to LHT

T-odd fermion bounds

- Present and projected reach
- signal $p\bar{p} \rightarrow \tilde{Q}\bar{\tilde{Q}} \rightarrow 2j + 2\tilde{B}$
  - assume 100% branching fraction to jets+MET
  - Assume degenerate T-quark masses
  - NOT REAL DATA
- Re-interpret DØ bounds on squarks and scalar lepto-quarks
  - Rescale prod. cross section

yellow bands reflect uncertainty due to to choice of renormalization scale and PDF set

outer red band is for $\mu = \tilde{M}$



EWP bounds

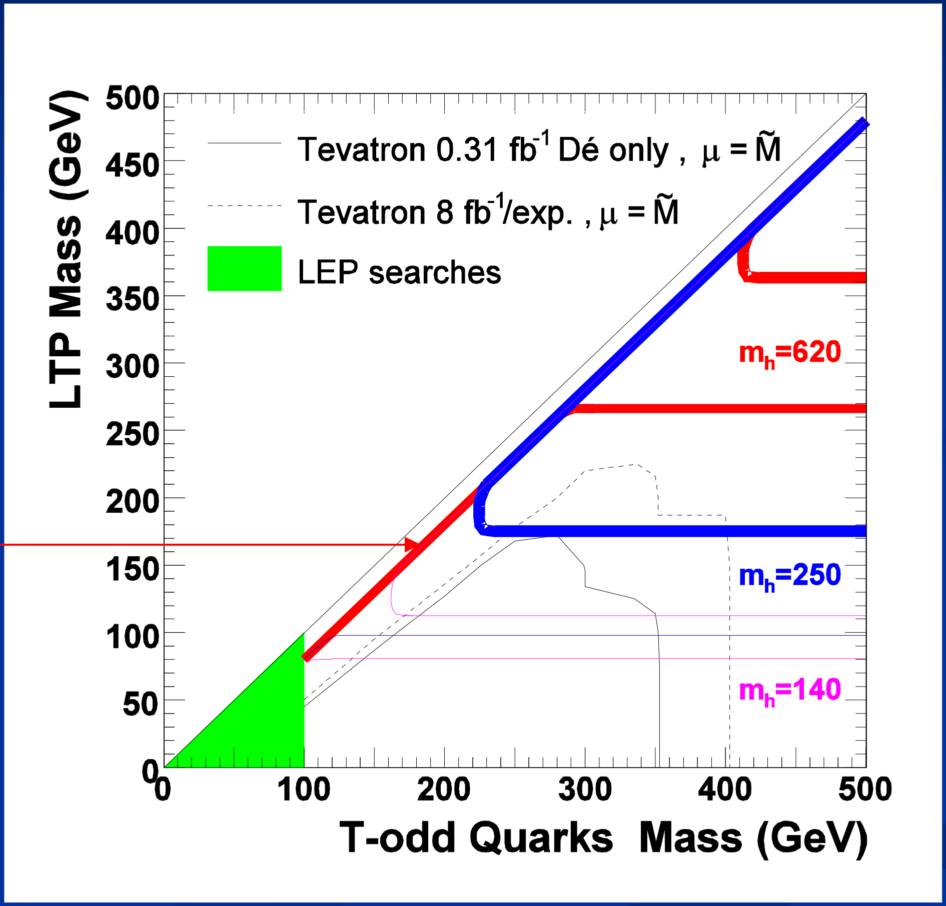
DØ Scalar lepto-quark

DØ squark

Dark Matter

Hubisz, Meade hep-ph/0411264
Birkedal, Noble, Perelstein, Spray hep-ph/0603077

- Overlay dark matter constraints
  - require $\tilde{B}$ account for DM
  - diff. values of Higgs mass



T-odd fermions can play role in providing the right amount of DM

Conclusions

- Little Higgs models offer a unique weakly coupled solution to the hierarchy problem
- T-parity found in many realistic models
  - Dark matter – new fermions
- Exciting phenomenology (astro, flavor, direct collider signals)
- Have calculated present and projected reach using DØ squark and lepto-quark analyses
- Tevatron is continuing to collect 1/femtobarns
  - Full dedicated DØ analysis (with real data)
  - Discovery of new physics could be just another 10^{12} times around the ring!