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Non supersymmetric SU(5) is alive and kicking

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NON SUPERSYMMETRIC SU(5): ALIVE AND KICKING

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B. Bajc, G. Senjanović, 06

B.Bajc, M. Nemevšek, G. Senjanović, 07

Various works in progress with A. Arhrib, D. Ghosh, M. Nemevšek, I. Puljak, G. Senjanović

Purpose of this talk:

- an example of a predictive GUT - weak triplet with TeV mass (with all threshold corrections included)

- at the same time an example of testable see-saw model (same parameters will describe the triplet decays)

Why is the minimal nonsupersymmetric SU(5) ruled out?

Minimal: $24_H + 5_H + 3(10_F + \overline{5}_F)$

1. gauge couplings do not unify
   - 2 and 3 meet at 10^{16} GeV (as in susy),
   - but 1 meets 2 too early at $\approx 10^{13}$ GeV
2. neutrinos massless (as in the SM)

Minimal SU(5) Yukawa terms

$$\mathcal{L}_Y = 10_F^i y_{10}^{ij} 10_F^j 5_H + 5_H^* 10_F^i y_5^{ij} \bar{5}_F^j + \frac{1}{\Lambda}\left[5_H^* 10_F^i 24_H g_5^{ij} \bar{5}_F^j + ...\right]$$

Nonrenormalizable terms needed to improve fermion mass relations

($y_b \neq y_\tau$ at M_{GUT}+ perturbativity need $\Lambda \approx 100 M_{GUT}$)

$$\langle 24_H \rangle = (M_{GUT}/\sqrt{30}) diag(2,2,2,-3,-3)$$

$$y_D = -y_5 - \frac{2M_{GUT}}{\sqrt{30}\Lambda} g_5 + ...$$

$$y_E = -y_5 + \frac{3M_{GUT}}{\sqrt{30}\Lambda} g_5 + ...$$

Neutrinos here massless

Add just one extra fermionic 24_F

New Yukawa terms

$$\mathcal{L}_{Y\nu} = y_0^i \bar{5}_F^i 24_F 5_H + \frac{1}{\Lambda} \bar{5}_F^i \left(y_1^i 24_F 24_H + \ldots \right) 5_H + h.c.$$

Under $SU(3)_C \times SU(2)_W \times U(1)_Y$ decomposition

$$24_F = (1,1)_0 + (1,3)_0 + (8,1)_0 + (3,2)_{5/6} + (\bar{3},2)_{-5/6}$$

singlet $S=(1,1)_0$
triplet $T=(1,3)_0$

$$\mathcal{L}_{Y\nu}=L_i\left(y_T^iT+y_S^iS\right)H+h.c.$$

Mixed Type I and Type III seesaw:

$$(m_\nu)^{ij}=v^2\left(\frac{y_T^iy_T^j}{m_T}+\frac{y_S^iy_S^j}{m_S}\right)$$

→ one massless neutrino !

Extra states $(m_3, m_8, m_{(3,2)})$ with respect to the minimal model

→ RGE change:

$$\exp\left[30\pi\left(\alpha_1^{-1}-\alpha_2^{-1}\right)(M_Z)\right]=\left(\frac{M_{GUT}}{M_Z}\right)^{84}\left(\frac{m_3}{M_Z}\right)^{25}\left(\frac{M_{GUT}}{m_{(3,2)}}\right)^{20}$$

$$\exp\left[20\pi\left(\alpha_1^{-1}-\alpha_3^{-1}\right)(M_Z)\right]=\left(\frac{M_{GUT}}{M_Z}\right)^{86}\left(\frac{m_8}{M_Z}\right)^{25}\left(\frac{M_{GUT}}{m_{(3,2)}}\right)^{20}$$

Ranges of the masses in 24_F:

$$
\begin{aligned}
\mathcal{L}_F &= m_F Tr\left(24_F^2\right) + \lambda_F Tr\left(24_F^2 24_H\right) \\
&+ \frac{1}{\Lambda}\Big[a_1 Tr\left(24_F^2\right) Tr\left(24_H^2\right) + a_2\left(Tr\left(24_F 24_H\right)\right)^2 \\
&+ a_3 Tr\left(24_F^2 24_H^2\right) + a_4 Tr\left(24_F 24_H 24_F 24_H\right)\Big]
\end{aligned}
$$

Nonrenormalizable operators needed anyway for fermion mass relations

$$
\begin{aligned}
m_3 &= m_F - \frac{3\lambda_F M_{GUT}}{\sqrt{30}} + \frac{M_{GUT}^2}{\Lambda}\left[a_1 + \frac{3}{10}\left(a_3 + a_4\right)\right] \\
m_8 &= m_F + \frac{2\lambda_F M_{GUT}}{\sqrt{30}} + \frac{M_{GUT}^2}{\Lambda}\left[a_1 + \frac{2}{15}\left(a_3 + a_4\right)\right] \\
m_{(3,2)} &= m_F - \frac{\lambda_F M_{GUT}}{2\sqrt{30}} + \frac{M_{GUT}^2}{\Lambda}\left[a_1 + \frac{(13a_3 - 12a_4)}{60}\right]
\end{aligned}
$$

If $a_i = 0$ only 2 different scales possible → NO SOLUTIONS

So one needs $a_i \neq 0$

$$\rightarrow \quad m_3, m_8, m_{(3,2)} \lesssim \frac{M_{GUT}^2}{\Lambda}$$

The only possible pattern:

$$m_3 \ll m_8 \ll m_{(3,2)} \ll M_{GUT}$$

A typical solution

$$\begin{aligned} m_3 &= 10^2 \mathrm{GeV} \\ m_8 &= 10^7 \mathrm{GeV} \\ m_{(3,2)} &= 10^{14} \mathrm{GeV} \\ M_{GUT} &= 10^{16} \mathrm{GeV} \end{aligned}$$

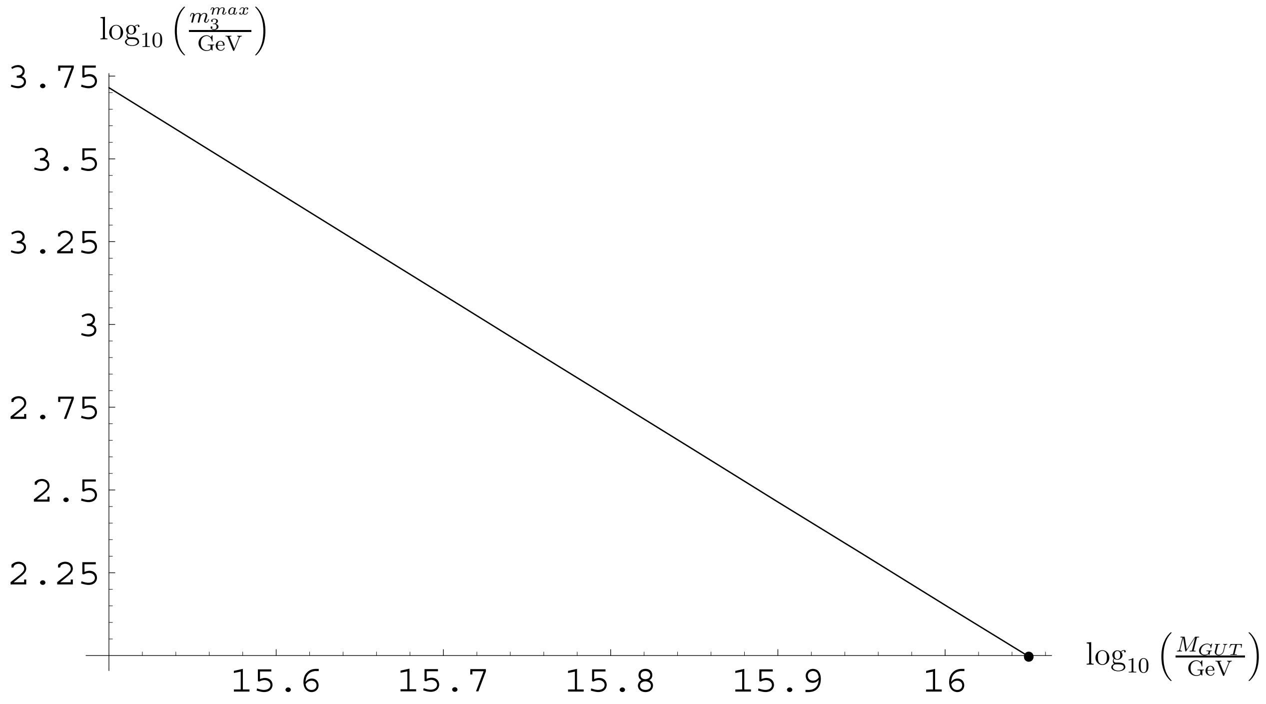
1-loop result:

For $M_{GUT} \gtrsim 10^{15.5}$ GeV (p decay)

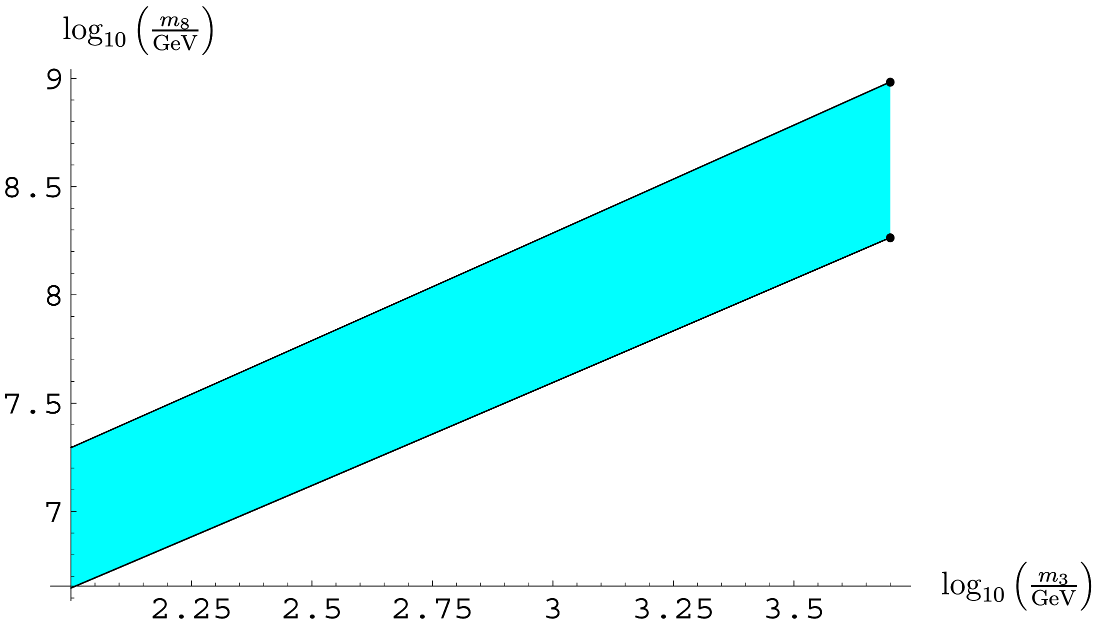
$\rightarrow m_3 \lesssim 1\mathrm{TeV}$

Prediction of the model !

$m_3^{max} - M_{GUT}$ at two loops



Allowed region $m_3 - m_8$ for $M_{GUT} = 10^{16}$ GeV



Triplet decays

$$\begin{aligned} T^{\pm} &\rightarrow Z l_k^{\pm} \qquad & T^0 &\rightarrow Z \nu_k \\ T^{\pm} &\rightarrow W^{\pm} \nu_k \qquad & T^0 &\rightarrow W^{\pm} l_k^{\mp} \end{aligned}$$

$$\Gamma_T \approx m_T |y_T|^2$$

$$\Delta m_T \equiv m_{T^+} - m_{T^-} \approx 160\text{MeV}$$

Two consequences:

1. other decay modes suppressed

$$\Gamma(T^+ \to T^0 \pi^+) \propto \frac{\Delta m_T^5}{m_T^4} \ll \Gamma(T^+ \to W^+ \nu \,\text{or}\, Z l^+)$$

2. oblique corrections small

$$\begin{aligned} \hat{S}, \hat{T}, Y &\approx 0 \qquad\qquad (\propto \Delta m_T \text{ or } \propto \text{hypercharge}) \\ W &\approx \frac{\alpha_2}{15\pi} \frac{M_W^2}{m_T^2} \end{aligned}$$

as in the light wino heavy rest MSSM

If you want to avoid missing energy (no ν)

1. only charged leptons

$$T^{\pm}\to Zl^{\pm}\to l'^{+}l'^{-}l^{\pm}$$

2. charged leptons + jets

$$\begin{aligned} T^{\pm}\to Zl^{\pm}&\to l^{\pm}+2jets\\ T^{0}\to W^{\mp}l^{\pm}&\to l^{\pm}+2jets \end{aligned}$$

The best channel is like-sign dileptons + jets

(like in LR models with low W_R mass and $m_{\nu_R} \leq m_{W_R}$)

Keung, Senjanović, 83

$$BR(T^\pm T^0 \to l_i^\pm l_j^\pm + 4 \text{ jets}) \approx \frac{1}{20} \times \frac{|y_T^i|^2 |y_T^j|^2}{(\sum_k |y_T^k|^2)^2}$$

Same couplings y_T^i contribute to

- ν mass matrix and
- T decays !

Normal hierarchy:

$$\frac{v y_T^{i*}}{\sqrt{2}} = i\sqrt{m_T}\left(U_{i2}\sqrt{m_2^\nu}\cos z \pm U_{i3}\sqrt{m_3^\nu}\sin z\right)$$

Inverse hierarchy:

$$\frac{v y_T^{i*}}{\sqrt{2}} = i\sqrt{m_T}\left(U_{i1}\sqrt{m_1^\nu}\cos z \pm U_{i2}\sqrt{m_2^\nu}\sin z\right)$$

U = PMNS matrix, z = arbitrary complex number

Ibarra, Ross, 03

Measuring T decays → constraints on z (θ_{13}, phases)

Typical Yukawa for $m_T \approx \mathcal{O}(m_W)$:

$$y_T \approx \frac{\sqrt{m_T m^\nu}}{m_W} \gtrsim 5 \times 10^{-7}$$

$$\rightarrow \quad \tau_T \lesssim 10^{-12} \mathrm{sec} \approx (0.1 - 1) \text{ mm}$$

Probably hard to measure lifetimes (borderline),

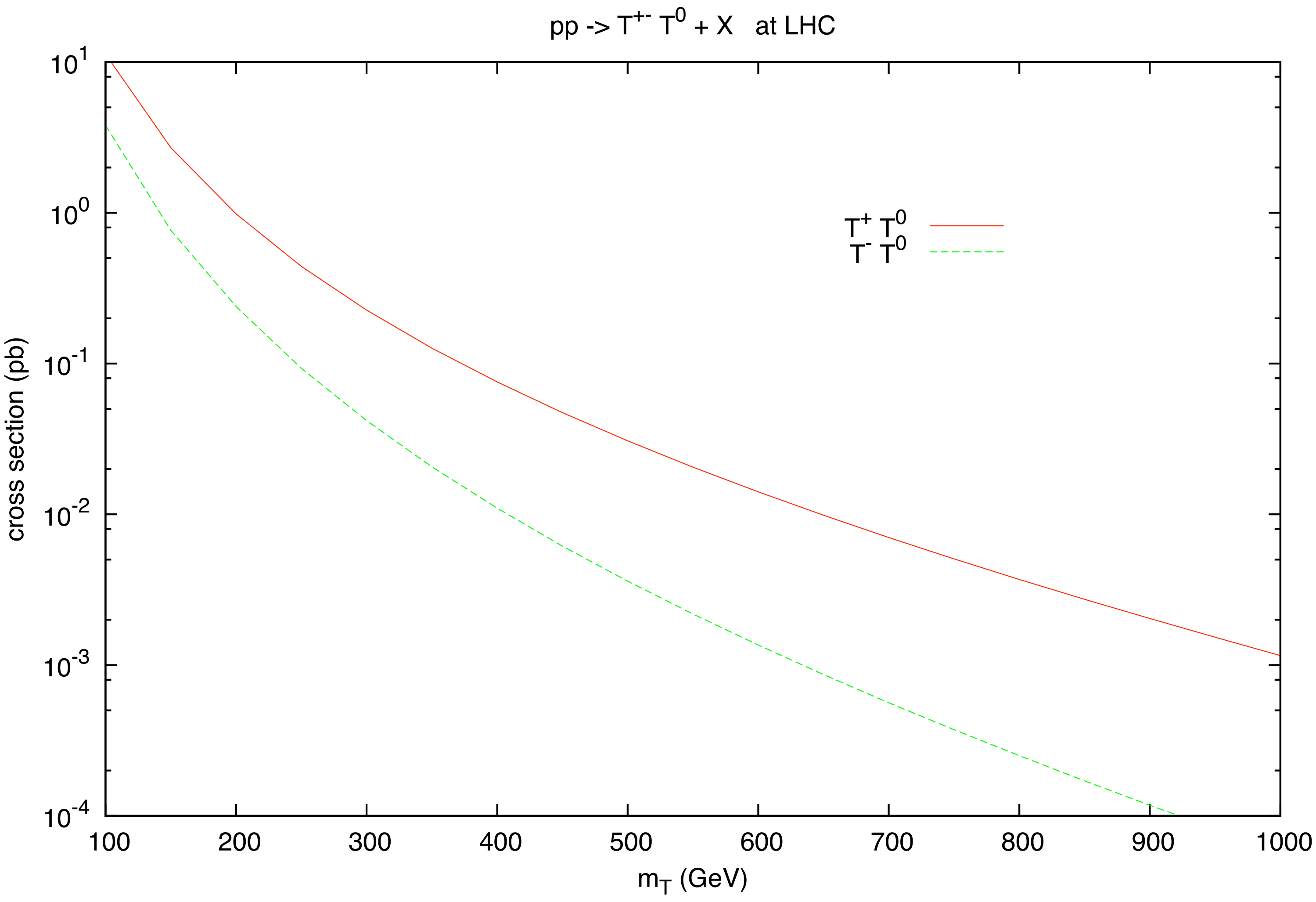
easier branching ratios

How to produce T at LHC ?

$T^{0,\pm}$ weak triplet

→ produced through gauge interactions (Drell-Yan)

$$pp \to W^{\pm} + X \to T^{\pm} T^{0} + X$$
$$pp \to (Z \,\mathrm{or}\, \gamma) + X \to T^{+} T^{-} + X$$


pp -> T+- T0 + X at LHC
cross section (pb)
10^1
10^0
10^-1
10^-2
10^-3
10^-4
100
200
300
400
500
600
700
800
900
1000
m_T (GeV)
T+ T0
T- T0

As regarding the production of triplets at LHC, the situation is equivalent to

light wino + heavy rest MSSM

$$pp \longrightarrow \tilde{w}^{\pm}\tilde{w}^{0} + X$$

Cheung, Chiang, 05

For $\int L dt = 100 \text{ fb}^{-1}$

and $m_T =$100 (500) GeV

LHC will produce

$1.5 \times 10^6 \; (4 \times 10^3) \; T^{\pm} T^0$ pairs, i.e.

$$10^5 (200) \times \left[\frac{|y_T^i|^2 |y_T^j|^2}{(\sum_k |y_T^k|^2)^2} \right] \; \left(l_i^{\pm} l_j^{\pm} + 4 \text{ jets} \right) \text{ events}$$

SM background

$$pp \to \left(W^\pm Z\,,\,W^\pm W^\pm\,,\,\bar{t}t\right)\ +\text{jets}$$

estimate: $\mathcal{O}(10^3)$ like-sign dimuon events for $\int Ldt = 100 fb^{-1}$

Del Aguila, Aguilar-Saavedra, 07

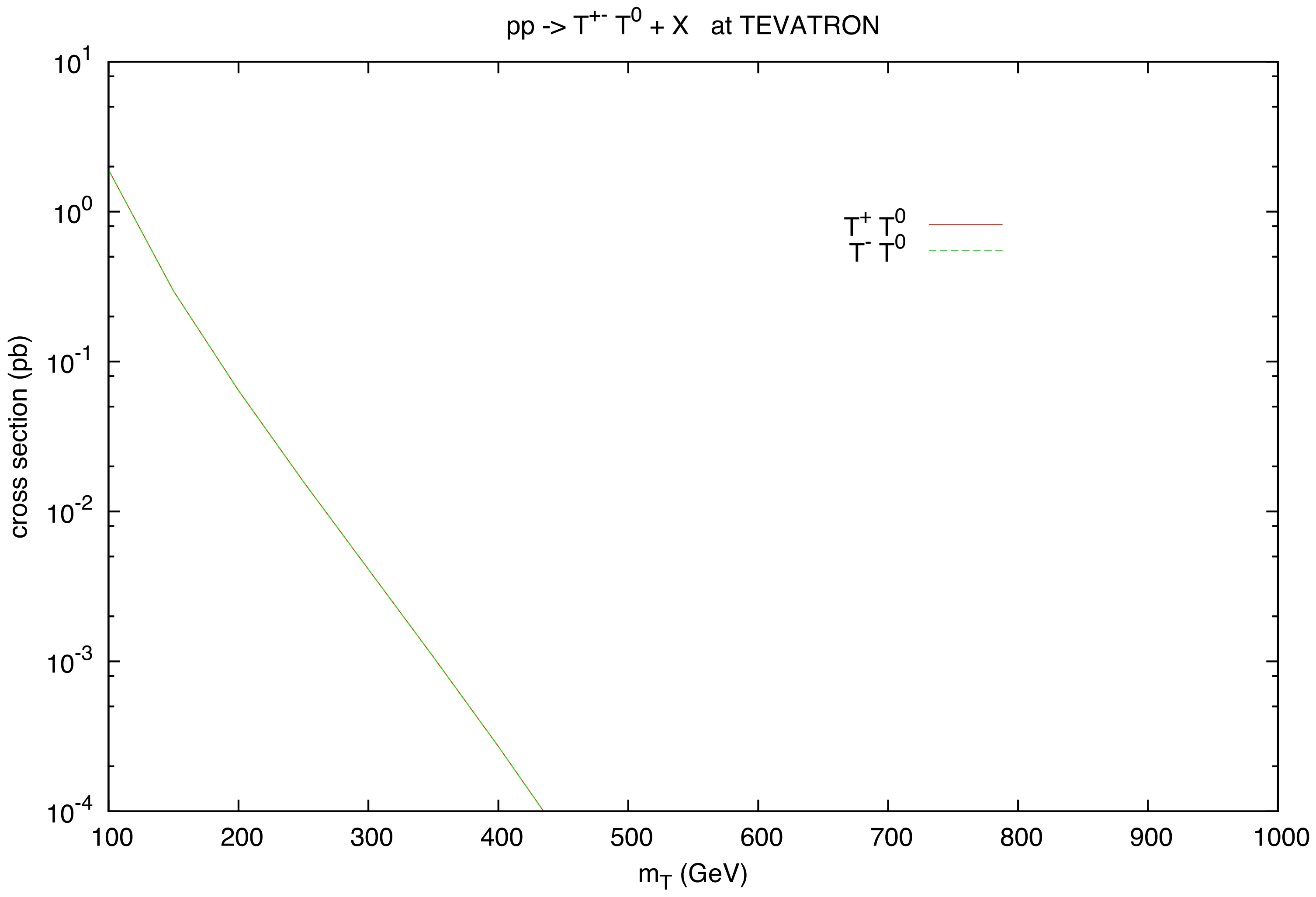
Should be possible to use proper cuts

(common belief that $m_{\tilde{w}} \lesssim 500$ GeV could be found at LHC)

Triplets at TEVATRON ?

Compared to LHC:

- smaller cross section ($\approx 10\times$)
- smaller luminosity ($\approx 100\times$)


pp -> T+- T0 + X at TEVATRON
cross section (pb)
10^1
10^0
10^-1
10^-2
10^-3
10^-4
100
200
300
400
500
600
700
800
900
1000
mT (GeV)
T+ T0
T- T0

For $\int L dt = 1 \text{ fb}^{-1}$

and $m_T =$100 (200) GeV

TEVATRON would have produced so far

4×10^3 (130) $T^\pm T^0$ pairs, i.e.

$$200(7) \times \left[\frac{|y_T^i|^2 |y_T^j|^2}{(\sum_k |y_T^k|^2)^2}\right] \left(l_i^\pm l_j^\pm + 4 \text{ jets}\right) \text{ events}$$

Further uncertainties to take into account

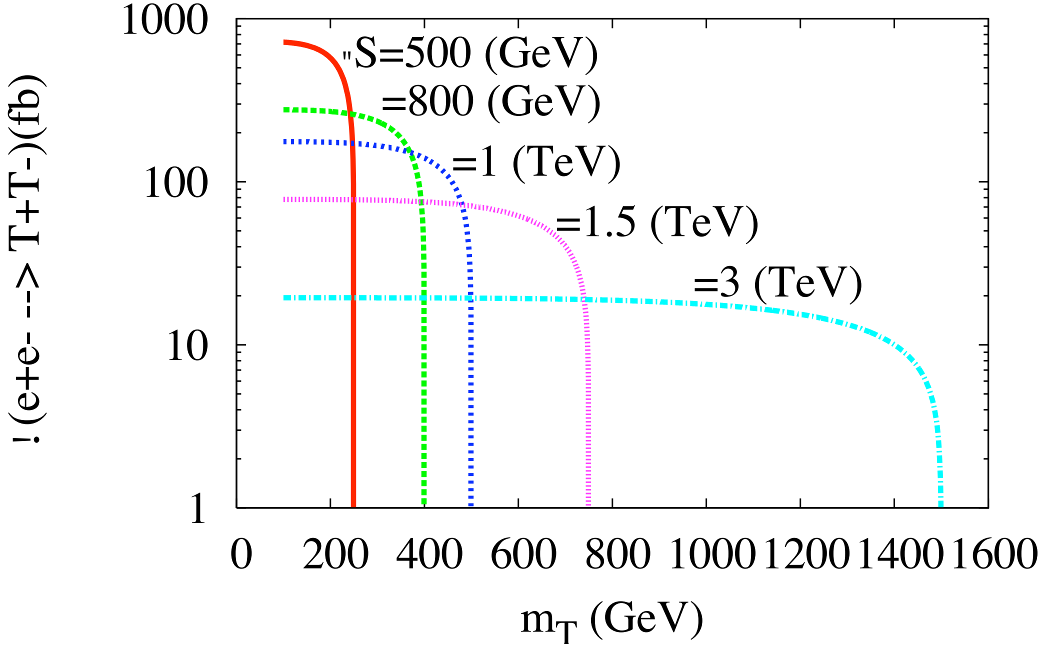
- acceptance (geometrical, jet reconstruction, etc) - 30% ?

- reduction of signal events due to cuts (cut acceptance)

- Yukawas (only some leptons can be measured, mainly muons at CMS for example)

What about linear colliders ?

- s-channel process, suppressed at high E
- Z coupling for triplets vectorial → flat angular distribution
- again similar to $\tilde{w}^+\tilde{w}^-$ production in light wino MSSM



Leptogenesis

- similar to the case of two righthanded neutrino
- Davidson-Ibarra bound real: $\epsilon \propto m_T$ too small !
- the only possibility: resonant leptogenesis

$$\epsilon_T = -\underbrace{\frac{Im\left(\vec{y_T}\vec{y_S}^*\right)^2}{|\vec{y_T}|^2\,|\vec{y_S}|^2}}_{f(z)} \times \underbrace{\frac{\left(m_S^2-m_T^2\right)m_T\Gamma_S}{\left(m_S^2-m_T^2\right)^2+m_T^2\Gamma_S^2}}_{=\mathcal{O}(1) \text{ for } m_S\approx m_T} \;.$$

Result depends on $z = a + ib$. For hierarchical light neutrino case:

$$f(z) \approx \frac{2\sinh(2b)\sin(2a)}{4 + \sinh^2(2b) + \sin^2(2a)}$$

- a and b cannot be too small
- b cannot be too big
- $f(z)$ can be even $\mathcal{O}(1)$

Important constraints on z !

Other constraints from FCNC ($\mu \to 3e$ (tree order!) or $\mu \to \gamma$)

To be tested from triplet BR's

Conclusions

- Minimal nonsupersymmetric SU(5) model is revived by adding an extra 24_F
- a light fermionic weak triplet predicted: $m_3 \lesssim 1$ TeV
- heavier the triplet, faster proton decay
- one neutrino massless
- triplet decays connected to neutrino masses and mixings
- Drell-Yan processes with like-sign leptons easily produced at LHC