Novel Collider Signatures of Little Higgs Dark Matter Models

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Outline

- Littlest Higgs Models with T-Parity and Dark Matter
  - hep-ph/0308199,0405243 Cheng and Low
  - hep-ph/0603077 Birkedal, Noble, Perelstein and Spray
- Collider Signatures
  - hep-ph/0605314 C.-S. Chen, Kingman, Cheung, and TCY
- Summary

Littlest Higgs Model

- Littlest Higgs Model (hep-ph/0206021 Arkani-Hamed, Cohen, Katz, and Nelson):

  Consider a theory with a global $G = SU(5)$ spontaneously broken down to $H = SO(5)$ at a scale $f \sim 1$ TeV. Thus, the 14 massless NGBs are described by $G/H = SU(5)/SO(5)$ non-linear σ model.

$$\Sigma(x) = \exp(i\Pi/f)\Sigma_0 \exp(i\Pi^T/f) = \exp(2i\Pi/f)\Sigma_0$$

$$\Sigma_0 = \begin{pmatrix} 0 & 0 & \mathbf{1} \\ 0 & 1 & 0 \\ \mathbf{1} & 0 & 0 \end{pmatrix} \quad , \quad \Pi(x) = \sum_{a=1}^{14} \pi^a(x) X^a \quad , \quad X^a\Sigma_0 - \Sigma_0 X^{aT} = 0$$

$$\Pi(x) = \begin{pmatrix} -\frac{\omega^0}{2} - \frac{\eta}{\sqrt{20}} & -\frac{\omega^+}{\sqrt{2}} & \frac{H^+}{\sqrt{2}} & -i\phi^{++} & -i\frac{\phi^+}{\sqrt{2}} \\ -\frac{\omega^-}{\sqrt{2}} & \frac{\omega^0}{2} - \frac{\eta}{\sqrt{20}} & \frac{H^0}{\sqrt{2}} & -i\frac{\phi^+}{\sqrt{2}} & \frac{-i\phi^0+\phi^0_P}{\sqrt{2}} \\ \frac{H^-}{\sqrt{2}} & \frac{H^{0*}}{\sqrt{2}} & \sqrt{\frac{4}{5}}\eta & \frac{H^+}{\sqrt{2}} & \frac{H^0}{\sqrt{2}} \\ -i\phi^{--} & i\frac{\phi^-}{\sqrt{2}} & \frac{H^-}{\sqrt{2}} & -\frac{\omega^0}{2} - \frac{\eta}{\sqrt{20}} & -\frac{\omega^-}{\sqrt{2}} \\ i\frac{\phi^-}{\sqrt{2}} & \frac{i\phi^0+\phi^0_P}{\sqrt{2}} & \frac{H^{0*}}{\sqrt{2}} & -\frac{\omega^+}{\sqrt{2}} & \frac{\omega^0}{2} - \frac{\eta}{\sqrt{20}} \end{pmatrix}$$

- H is SM Higgs; ϕ is triplet scalar.

Littlest Higgs Model – (Continued)

- The global symmetry is broken by gauging an $[SU(2)\times U(1)]^2$ subgroup of $SU(5)$.

- Gauge symmetry breaking

  – η and $\omega^{\pm,0}$ are absorbed by B_H and W_H^a. H and ϕ remain physical.

$$[SU(2) \times U(1)]^2 \xrightarrow{\Sigma_0} SU_L(2) \times U_Y(1)$$

  – At a scale $v \sim 246$ GeV, EWSB is triggered by a radiatively induced Higgs potential. Similar mechanism used by Alvarez-Gaume, Polchinski, and Wise in SUSY.

$$SU_L(2) \times U_Y(1) \overset{\text{Coleman}-\text{Weinberg}}{\longrightarrow} U_{em}(1)$$

- Collective symmetry breaking mechanism is a design to ensure quadratic divergences are cancelled at 1-loop level.

- Solve the little hierarchy problem up to one-loop between the two scales M_W and $\Lambda = 4\pi f$.

- f is severely constrained by electroweak precision measurement.

T-Parity and Dark Matter

- (Cheng-Low) T-Parity acts an automorphism which exchanges the two gauge factors:

$$[SU(2) \times U(1)]_1 \overset{T-\text{Parity}}{\longleftrightarrow} [SU(2) \times U(1)]_2$$

  This implies

$$g_1 = g_2 \ \ , \ \ g_1' = g_2'$$

  and

$$\Pi(x) \overset{T-\text{Parity}}{\longrightarrow} -\Omega\Pi(x)\Omega, \quad \Omega = \text{diag}(1, 1, -1, 1, 1)$$

- Before EWSB, the gauge boson mass eigenstates have the simple form

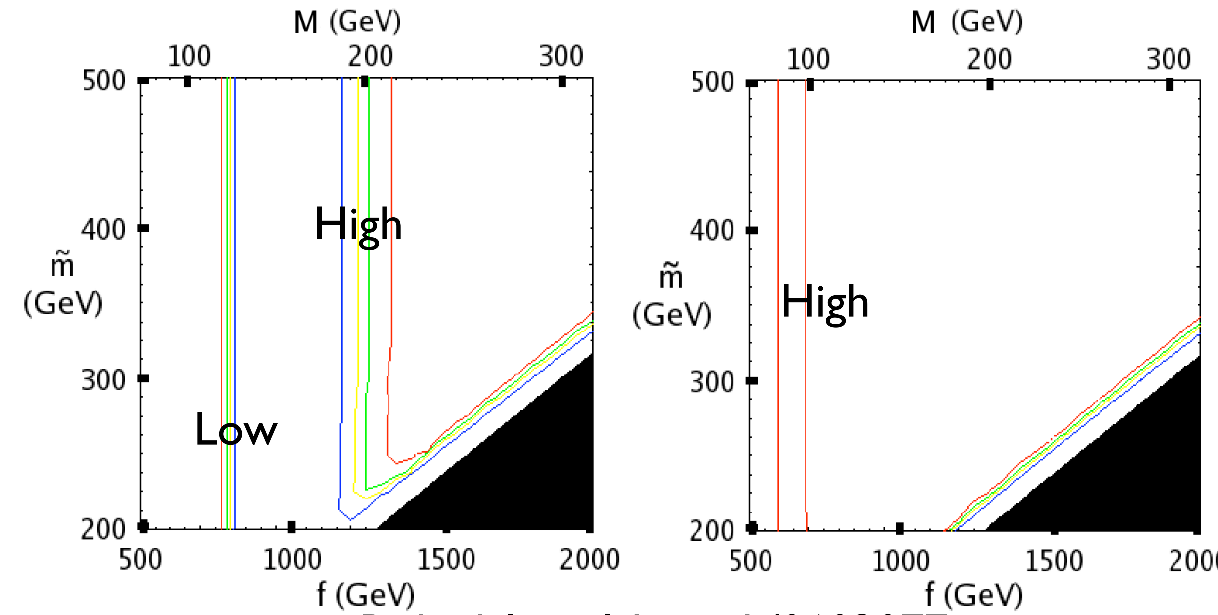
$$W_\pm = \frac{W_1 \pm W_2}{\sqrt{2}} \ , \quad B_\pm = \frac{B_1 \pm B_2}{\sqrt{2}}$$

  where W_+ and B_+ are SM T-even gauge bosons, whereas, W_- and B_- are additional T-odd states. After EWSB by Coleman-Weinberg mechanism, W_+^3 and B_+ mix to produce the SM Z and γ.

- Typically, B_- is the lightest T-odd state (LTP) and plays the role of dark matter. In the literature, B_- is sometimes denoted as A_H, the heavy photon. Interesting mass range of A_H :

$$M_{A_H} \approx \frac{g' f}{\sqrt{5}} \approx 0.16 f$$

$$600 \text{ GeV} \leq f \leq 2 \text{ TeV} \longleftrightarrow 100 \text{ GeV} \leq M_{A_H} \leq 300 \text{ GeV}$$



Birkedal et al, hep-ph/0603077

Figure 2: The contours of constant present abundance of the heavy photon LTP, $\Omega_{\rm LTP}h^2$, in the $M - \tilde{M}$ plane. The Higgs mass is taken to be 300 GeV (left panel) and 120 GeV (right panel). The red and green contours correspond to the upper and lower bounds from WMAP, Eq. (10), assuming that the LTP makes up all of dark matter. The yellow and blue lines correspond to the LTP contributing 50% and 70%, respectively, of the measured dark matter density. The shaded region corresponds to a charged and/or colored LTP.

- WMAP data: $\Omega_{\rm CDM}h^2 = 0.105 \pm 0.009$

- $\Omega_\chi h^2 \sim \langle \sigma v \rangle^{-1}$

- Pair annihilation of LTP $(A_H + A_H)$: For a given Higgs mass m_h, there are two solutions for the A_H mass to satisfy the WMAP data

$$M_{A_H} \approx \frac{m_h - 24 \text{ GeV}}{2.38} \quad \text{(Low)}$$

$$M_{A_H} \approx \frac{m_h + 83 \text{ GeV}}{1.89} \quad \text{(High)}$$

- Coannihilation region $(A_H + Q_H)$:

$$M_{Q_H} \approx M_{A_H} + 20 \text{ GeV}$$

roughly independent of the Higgs mass.

Collider Signatures

- We are primarily interested in the coannihilation region deduced from the above relic density calculation in our work.

- Search for

  - Monojet events $pp(\bar{p}) \longrightarrow A_H Q_H (\overline{Q}_H)$ followed by $Q_H \longrightarrow q A_H$ and $\overline{Q_H} \longrightarrow \bar{q} A_H$ plus missing energies

  - Dijet events $pp(\bar{p}) \longrightarrow Q_H \overline{Q_H}$ followed by $Q_H \longrightarrow q A_H$ and $\overline{Q_H} \longrightarrow \bar{q} A_H$ plus missing energies

- Signatures are similar with SUSY with R-parity. But the p_T spectrum of the jet is expected to be harder in SUSY.

- Parton processes are

  - $qg \longrightarrow A_H Q_H$ and $\bar{q}g \longrightarrow A_H \overline{Q_H}$

  - $gg \longrightarrow Q_H \overline{Q_H}$ and $q\bar{q} \longrightarrow Q_H \overline{Q_H}$

- $A_H - Q_H - q$ vertex

$$\mathcal{L} = g_H \overline{Q_H} \gamma_\mu P_L q A_H^\mu + \text{H.c.} \quad \text{with} \quad g_H = g' \tilde{Y}$$

  In the coannihilation scenario, g_H constraints to be rather small by the WMAP data.

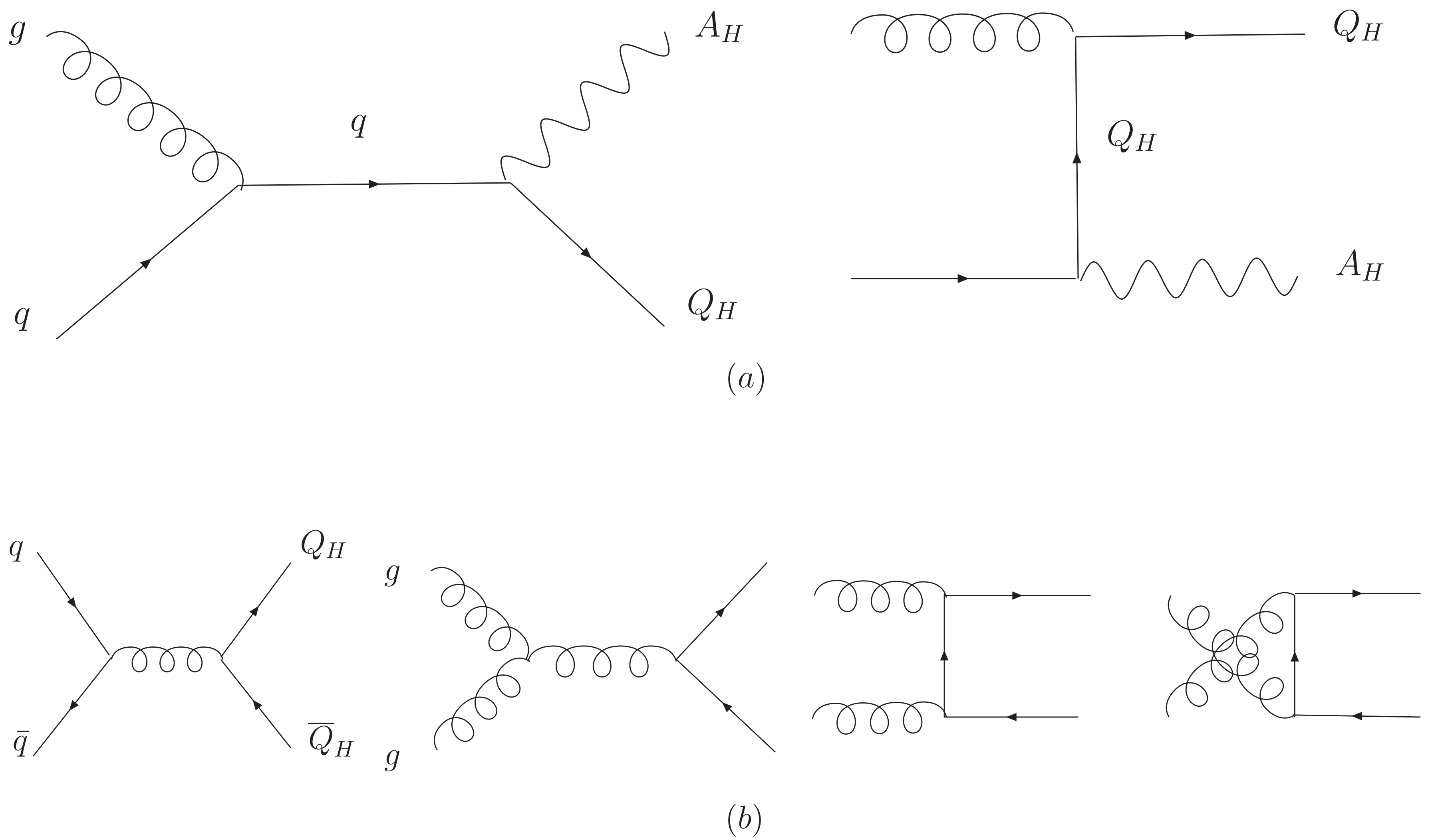


FIG. 1: Feynman diagrams for (a) production and coannihilation of $A_H Q_H$ and (b) production and coannihilation of $Q_H \overline{Q}_H$. Production reads from left to right, whereas coannihilation reads from right to left.

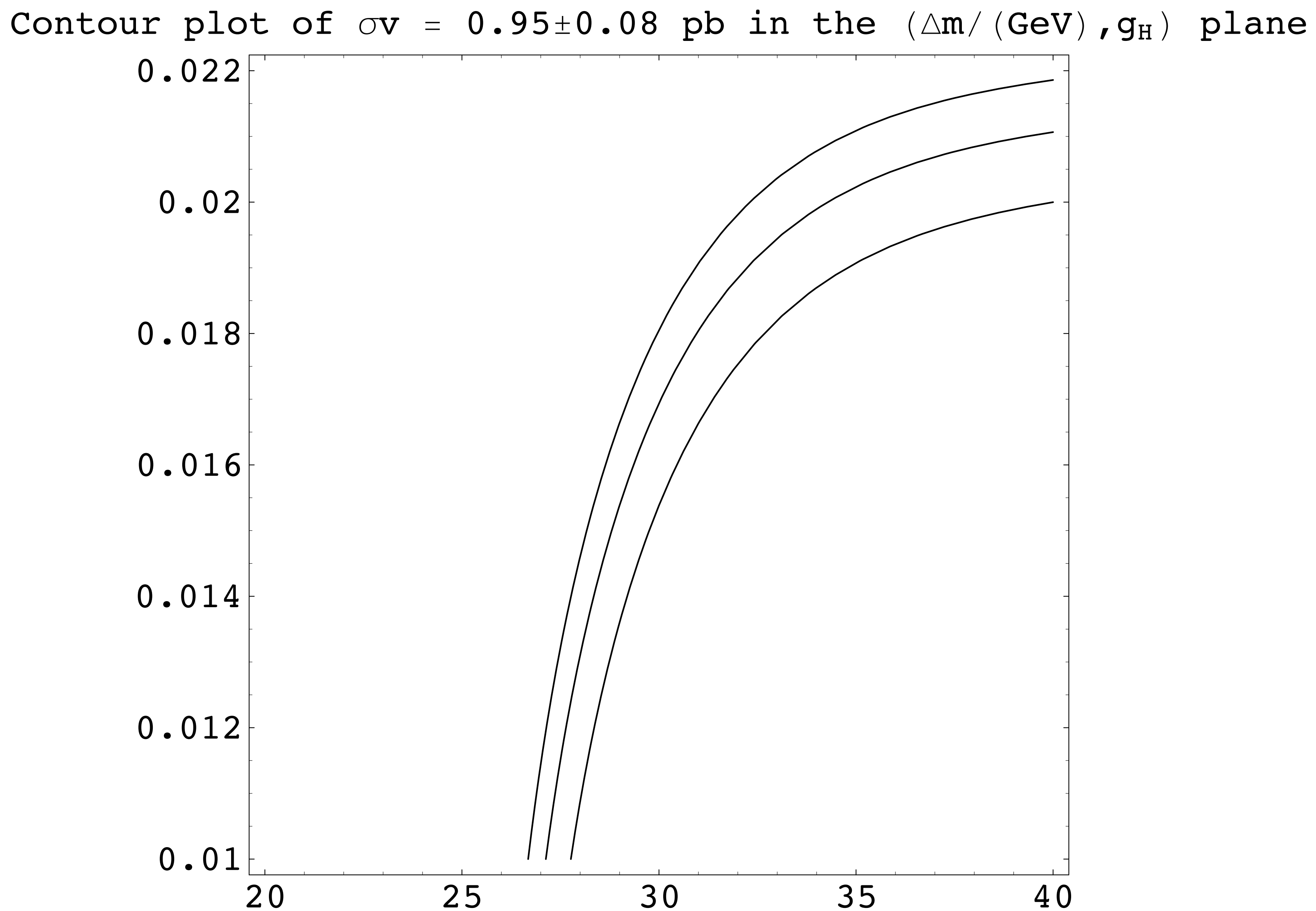
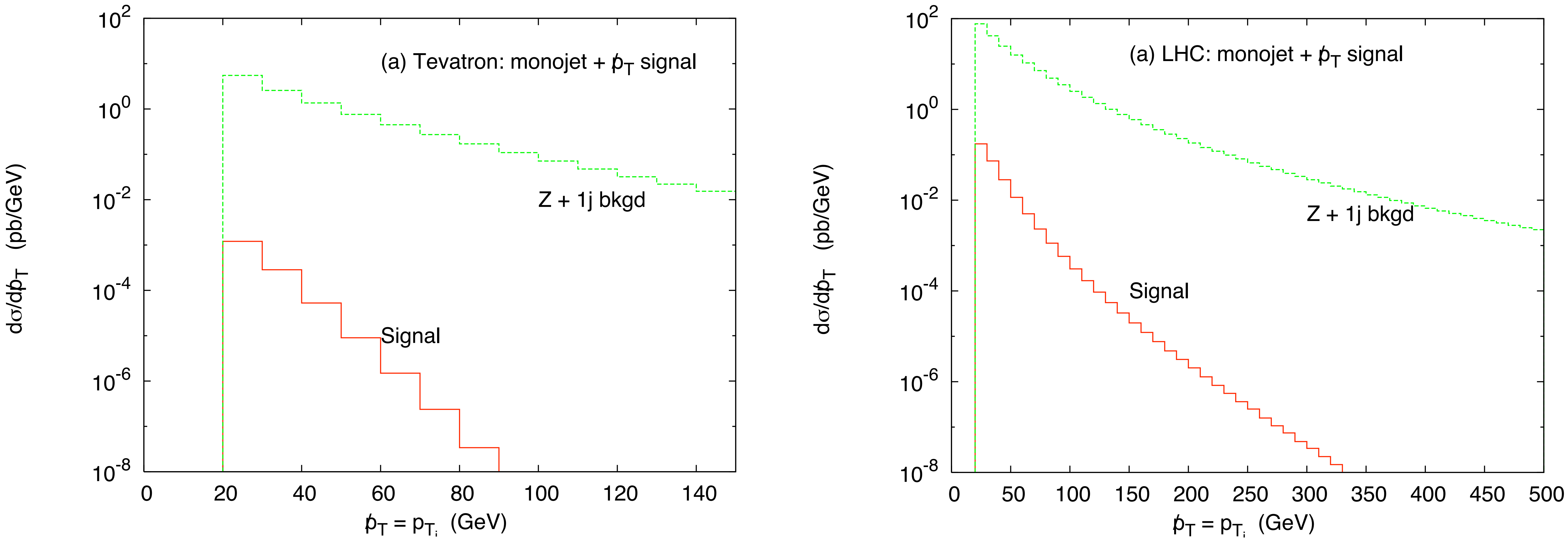


FIG. 2: The contour plot of coannihilation cross section $\sigma_{\rm eff} v$ in the plane of $(\Delta m, g_H)$. We take $M_{A_H} = 200$ GeV. The WMAP implied result of 0.95 ± 0.08 pb for this quantity is shown.

Collider Signatures (Continued)

- Major SM monojet backgrounds:
  - $pp(\bar{p}) \longrightarrow Z + 1j$ production followed by invisible decay of Z. This is irreducible in hadronic environment.
  - $pp(\bar{p}) \longrightarrow W + 1j \longrightarrow l\nu + 1j$ with unidentified charged lepton.
- Major SM dijet backgrounds:
  - $pp(\bar{p}) \longrightarrow Z + 2j \longrightarrow \nu\bar{\nu} + 2j$.



(a) Tevatron: monojet + $\not{p}_T$ signal
Z + 1j bkgd
Signal
$d\sigma/d\not{p}_T$ (pb/GeV)
$\not{p}_T = p_{T_i}$ (GeV)
(a) LHC: monojet + $\not{p}_T$ signal
Z + 1j bkgd
Signal
$d\sigma/d\not{p}_T$ (pb/GeV)
$\not{p}_T = p_{T_i}$ (GeV)

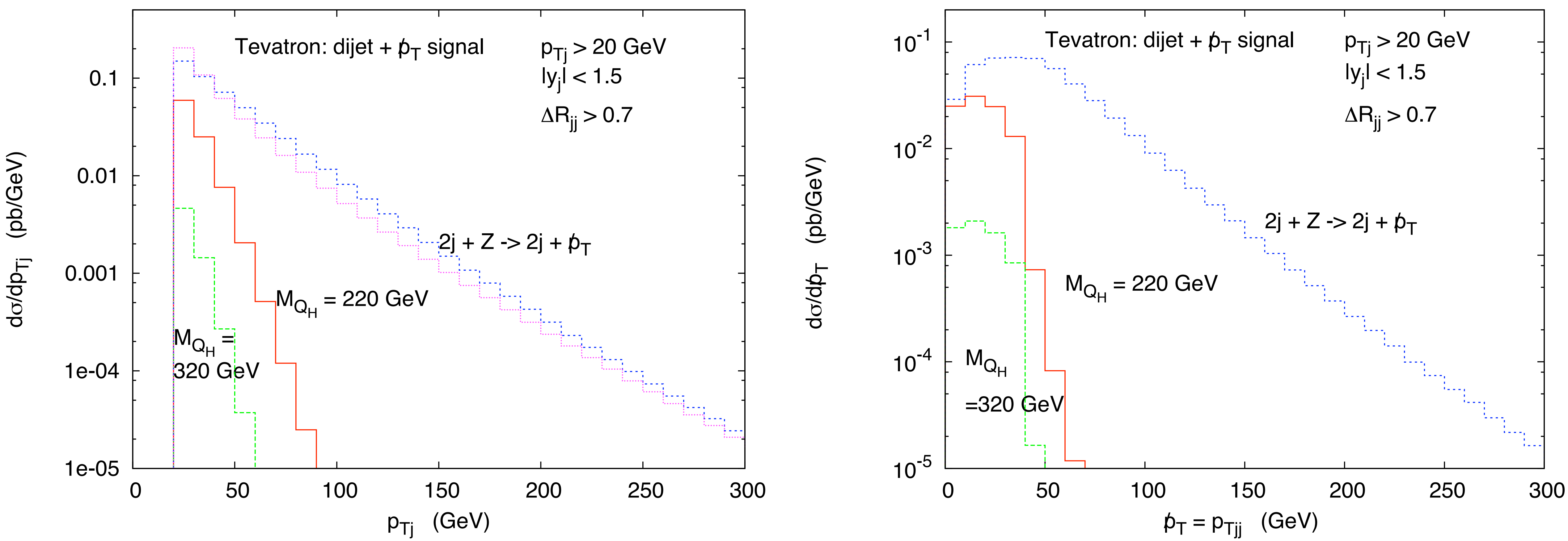


FIG. 4: The differential cross section versus (a) the transverse momentum of the jets and (b) the missing transverse momentum for the dijet + $\not{p}_T$ signal and the $Z + 2j \to 2j + \not{p}_T$ background at the Tevatron. We have used 2 sets of $(M_{Q_H}, M_{A_H}) = (220, 200)$ and $(320, 300)$ GeV.

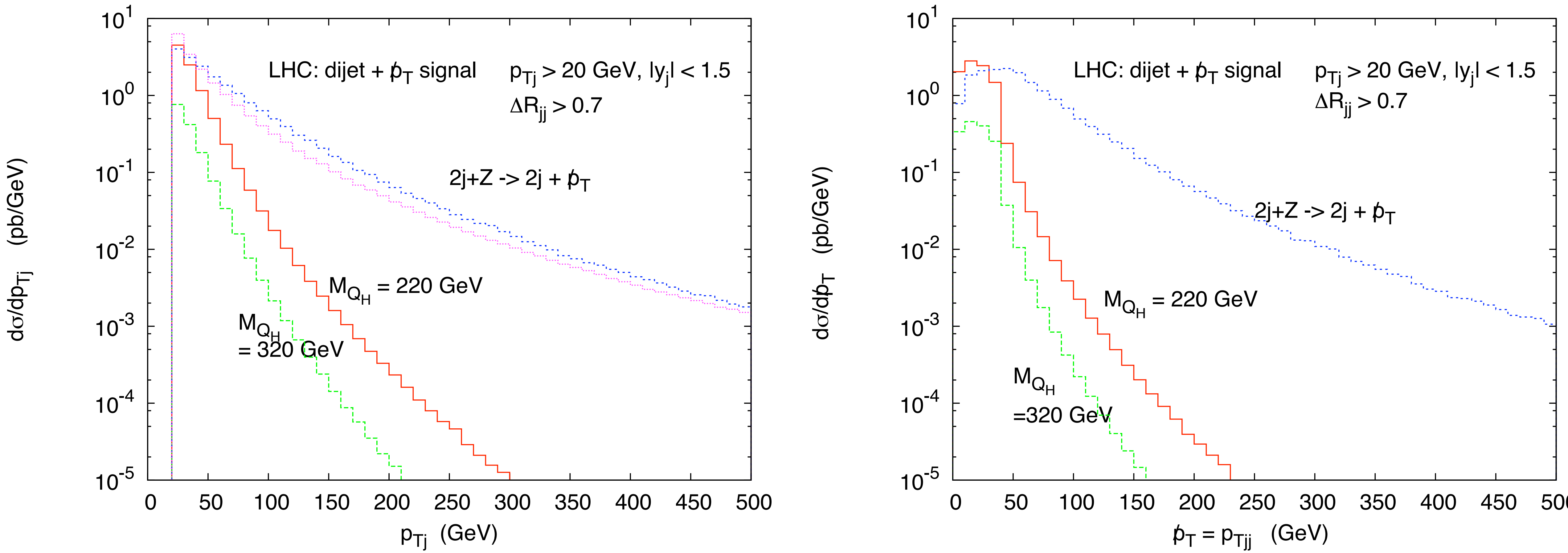


FIG. 5: The differential cross section versus (a) the transverse momentum of the jets and (b) the missing transverse momentum for the dijet + $\not{p}_T$ signal and the $Z + 2j \to 2j + \not{p}_T$ background at the LHC. We have used 2 sets of $(M_{Q_H}, M_{A_H}) = (220, 200)$ and $(320, 300)$ GeV.

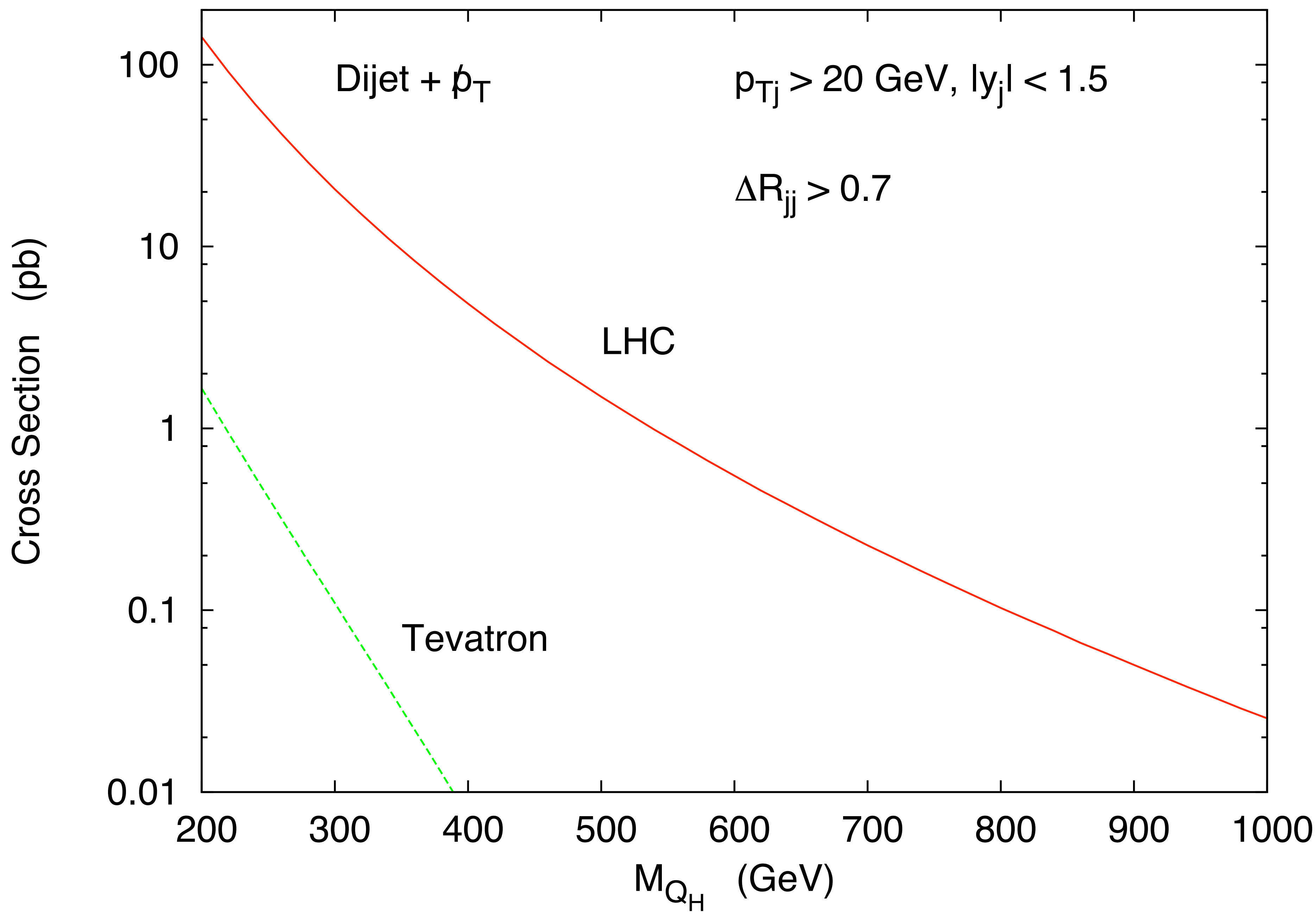


FIG. 3: Production rate for the dijet plus missing energy signal with the acceptance cuts defined in Eq. (18) at the Tevatron and at the LHC.

Summary

- The heavy photon A_H in the Little Higgs models with T-Parity is an interesting alternative dark matter candidate.

- We have studied the production rates for $A_H Q_H$ and $Q_H \overline{Q_H}$ at hadronic colliders that can lead to monojet and dijet events plus missing energies.

- Although the monojet plus missing energy events are very clean, the SM background is several order of magnitudes larger than the signals.

- However, dijet plus missing energy events in the littlest Higgs model with T-parity have a softer p_T spectrum compared with minimal SUSY and are potential measurable at the LHC.