Direct and indirect detections of dark matter in the Littlest Higgs model with T-parity

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Dark matter in the Littlest Higgs model with T-parity
Possibility to detect the DM in direct and indirect measurements
(based on M.Asano, S.M., N.Okada and Y.Okada, hep-ph/0602157)

This model is well motivated scenario to solve the “**little hierarchy problem**”.

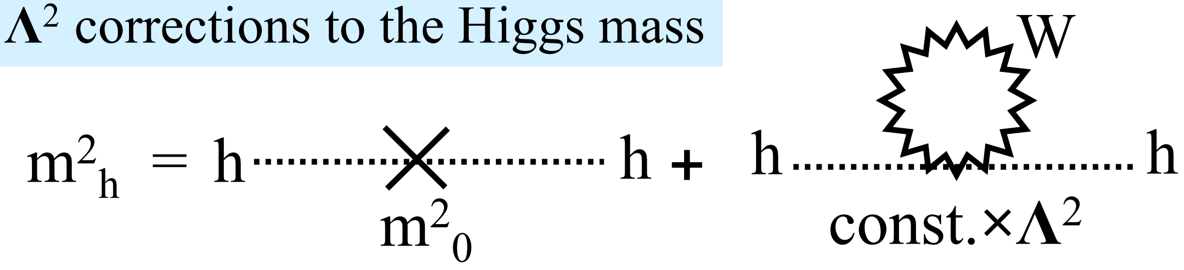
1. Littlest Higgs Model with T-parity
2. Relic abundance of LTP dark matter
3. Detections of LTP dark matter

Little hierarchy problem and Little Higgs mechanism

SM should be extended at the new physics scale **Λ.**
Electroweak precision measurements require **Λ>** O(10) TeV

This fact leads to the fine-tuning problem (little hierarchy)

Λ^2 corrections to the Higgs mass



About 0.1 % fine-tuning is needed for $m_h \sim 100$ GeV

Little Higgs mechanism has been proposed to solve this problem

Basic idea is

1. Higgs boson = pseudo NG boson of a symmetry breaking
2. The pattern of the breaking is arranged to cancel the Λ^2 at 1-loop

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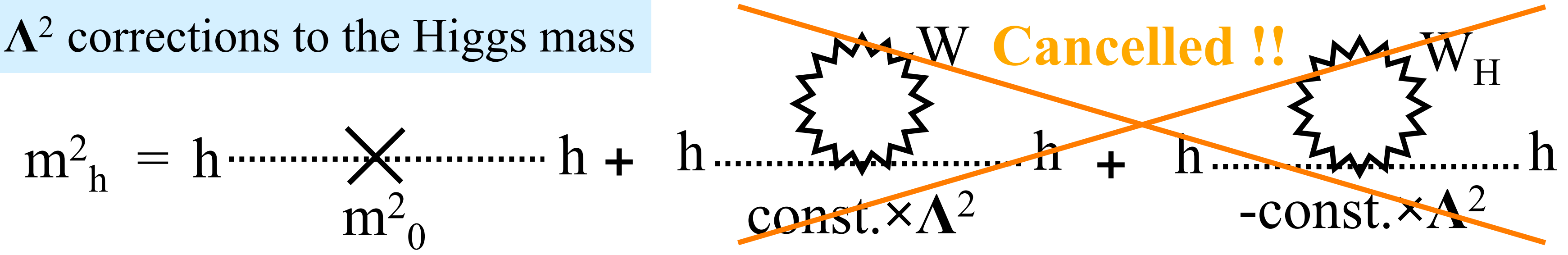

About 0.1 % fine-tuning is needed for m_h ~ 100 GeV

Λ can be taken to be 10 TeV without little higgs problem!!

Basic idea is

1. Higgs boson = pseudo NG boson of a symmetry breaking
2. The pattern of the breaking is arranged to cancel the Λ^2 at 1-loop

New particles are necessarily introduced and the Λ^2 correction is cancelled at 1-loop level due to these particles' contributions.

Using LH, many models have been proposed so far

Littlest Higgs Model

Arkani-Hamed, Cohen, Katz and Nelson (2002)

Described based on **non-linear σ-model** under SU(5)/SO(5) breaking.

$SU(5) \supset [SU(2)\times U(1)]^2$ (gauged)

(VEV = f ~ O(1) TeV)

$SO(5) \supset SU(2)\times U(1)$ (diagonal)

Lagrangian (Kinetic term)

$$\mathcal{L}_{\rm kin} = \frac{f^2}{8} {\rm Tr} D_\mu \Sigma (D^\mu \Sigma)^\dagger$$

$\Sigma = e^{2i\Pi/f}\Sigma_0$

Due to the gauge int., SU(5) in not exact, and Higgs acquires a mass

Particles in the gauge-Higgs sector of this model

After SU(5)/SO(5) breaking, and EW symmetry breaking,

4 gauge bosons : B_1, W_1 , B_2, W_2

Σ= (24 – 10) pions : $\mathbf{1}_0 \oplus \mathbf{3}_0 \oplus \mathbf{2}_{1/2} \oplus \mathbf{3}_{\pm 1}$

SM gauges : A, $W^\pm$, Z

Heavy gauges : A_H, $W_H^\pm$, Z_H

SM Higgs : h

Triplet Higgs : Φ

Littlest Higgs model with T-parity

Original LHM is suffered from severe constraints by EWPM. (Tree-level corrections due to the exchange of additional heavy gauge bosons and non-vanishing VEV of triplet higgs.)

Λ must be much larger than 10 TeV !!

→ fine-tuning again

impose **T - parity**

$B_1(W_1) \Leftrightarrow B_2(W_2)$

$\mathbf{\Pi \Leftrightarrow -\Omega\Pi\Omega}$

$\mathbf{\Omega}$= diag.(1,1,–1,1,1)

(no heavy gauge boson exchange, no triplet VEV.)

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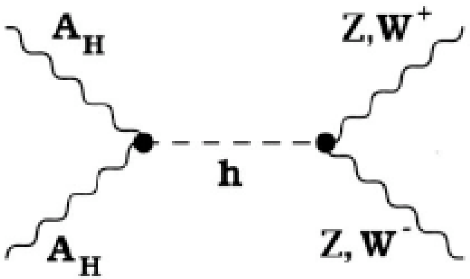
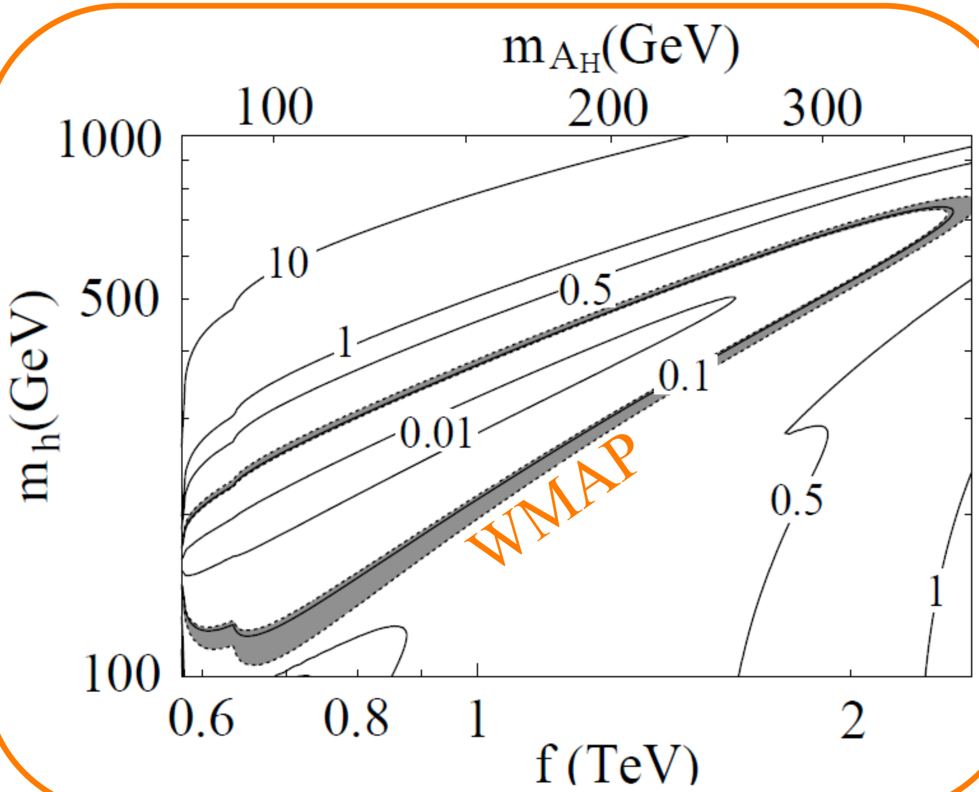
SM gauges	: A, $W^\pm$, Z	**(T-even)**
Heavy gauges	: A_H, $W_H^\pm$, Z_H	**(T-odd)**
SM Higgs	: h	**(T-even)**
Triplet Higgs	: Φ	**(T-odd)**

Lightest T-odd Particle = LTP (in this model, $\mathbf{A_H}$!!) is stable, and good candidate of cold dark matter !!

Relic abundance of the DM

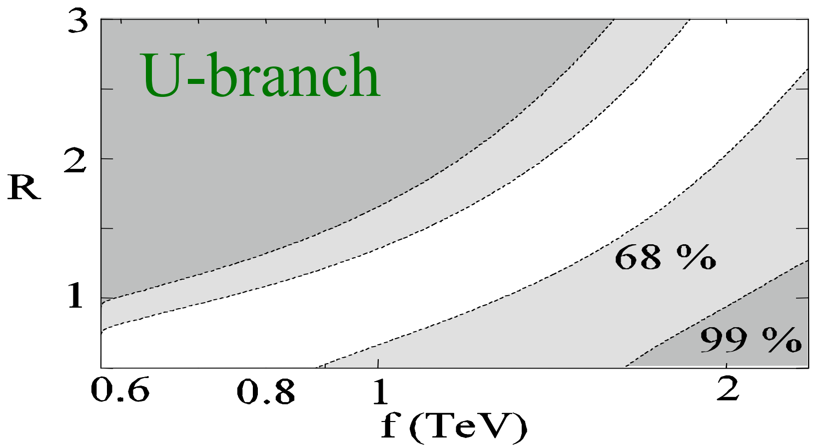
Annihilation mode

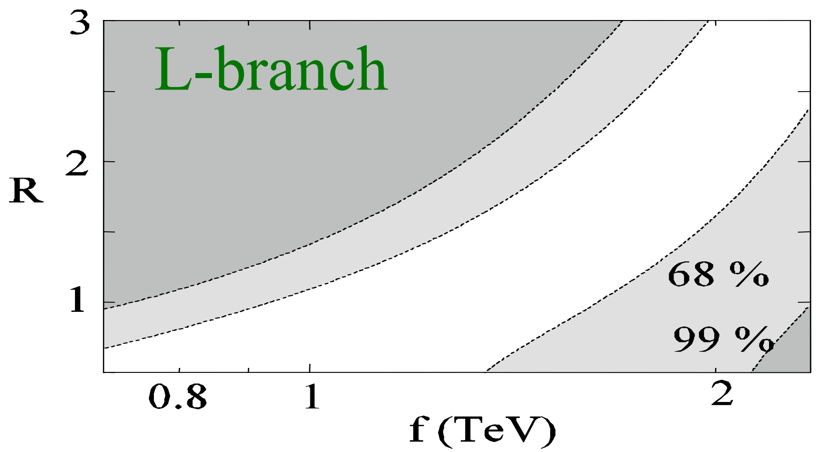




Undetermined parameter:
m_h and f (m ∝ f)

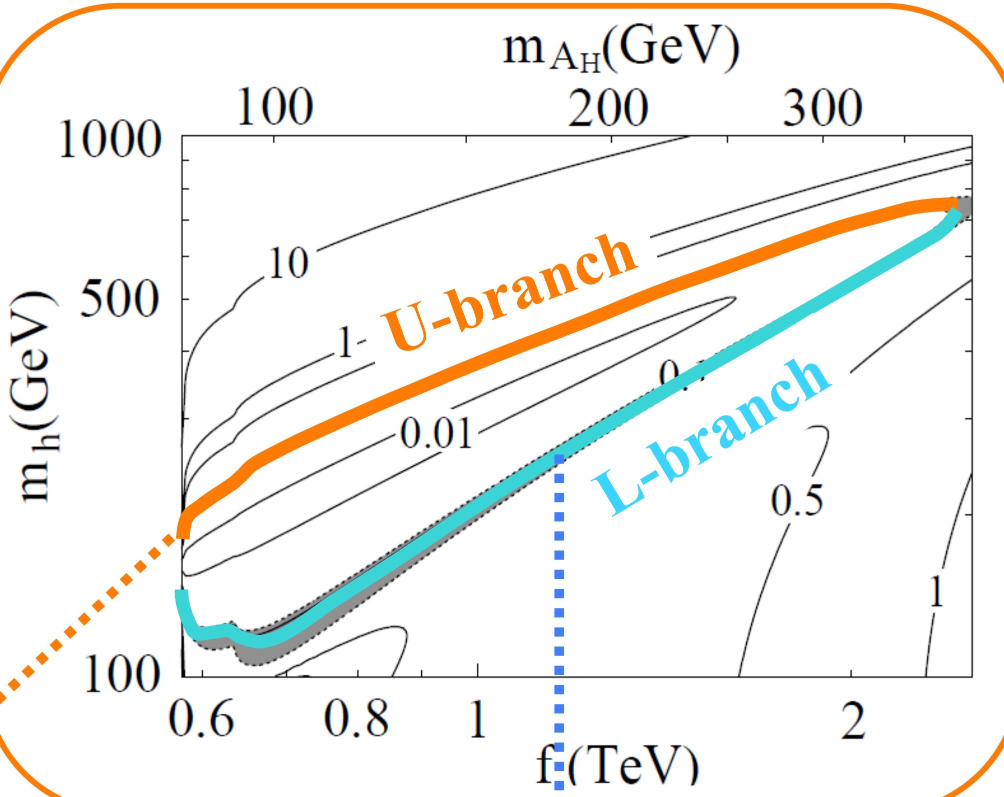
WMAP region is consistent with electroweak precision measurements ?





Relic abundance of the DM

By choosing an appropriate value of R, the entire region restricted by WMAP consistent with electroweak precision measurements.



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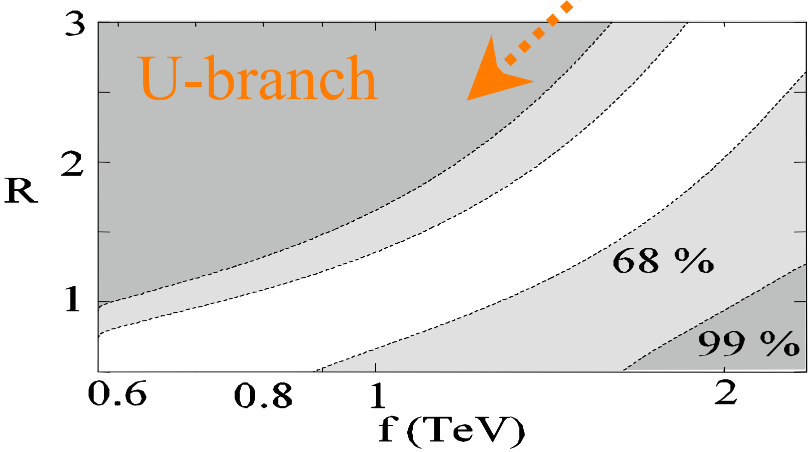
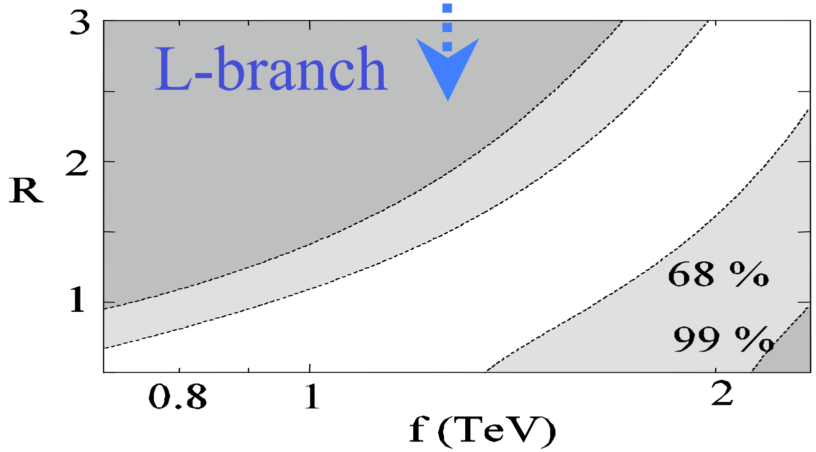
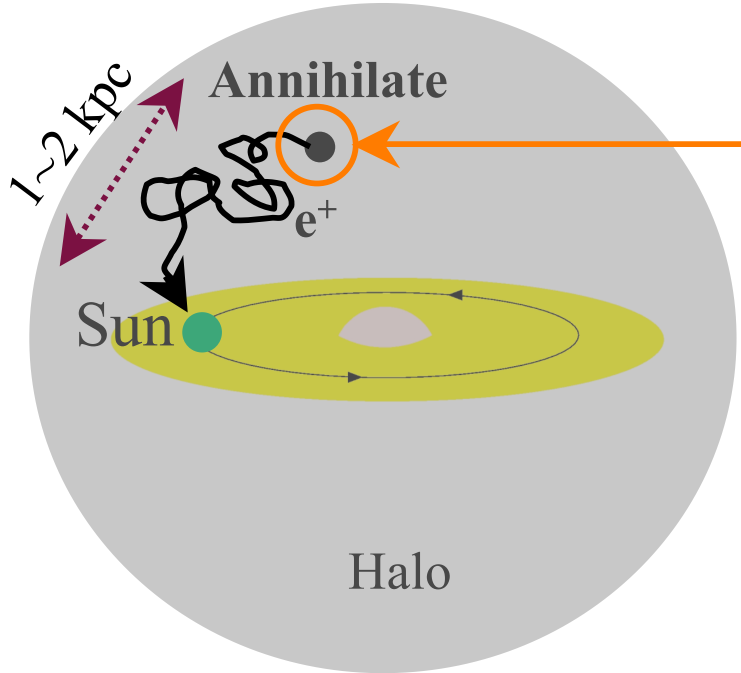
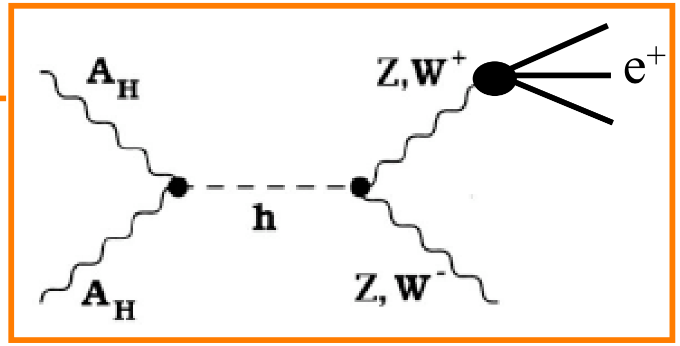




LTP DM detections

We focus on the indirect detection using e^+ (most promising method for the LTP DM)





The process is not helicity suppressed.
W decay can produce high energy e^+.

1. BG e^+ comes from the secondary prod. during the propagation of CR.
2. e^+ do not travel in straight line due to the tangled magnetic field in galaxy.

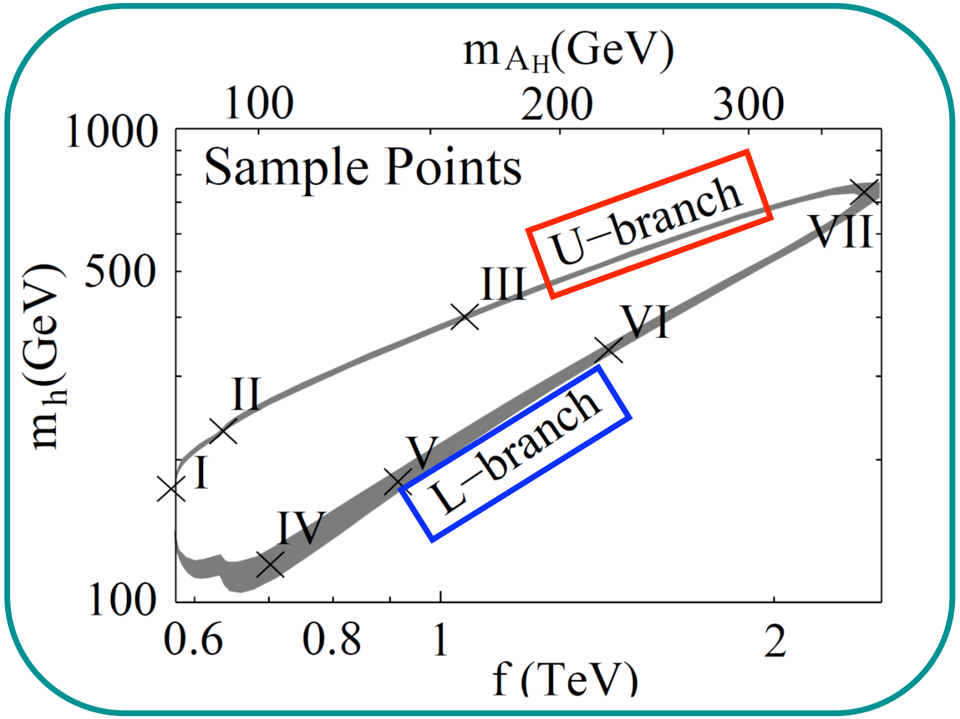
→ the signal from DM annihilation is observed as the e^+ excess in CR.

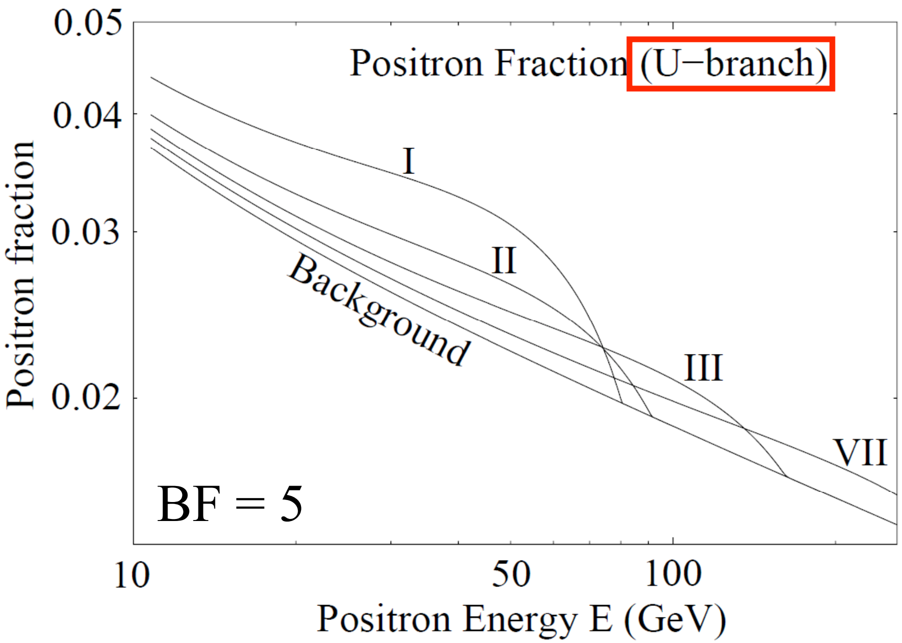
e+ is absorbed and loses its energy by the propagation in ISM. The flux at earth mostly originates within a few kpc.

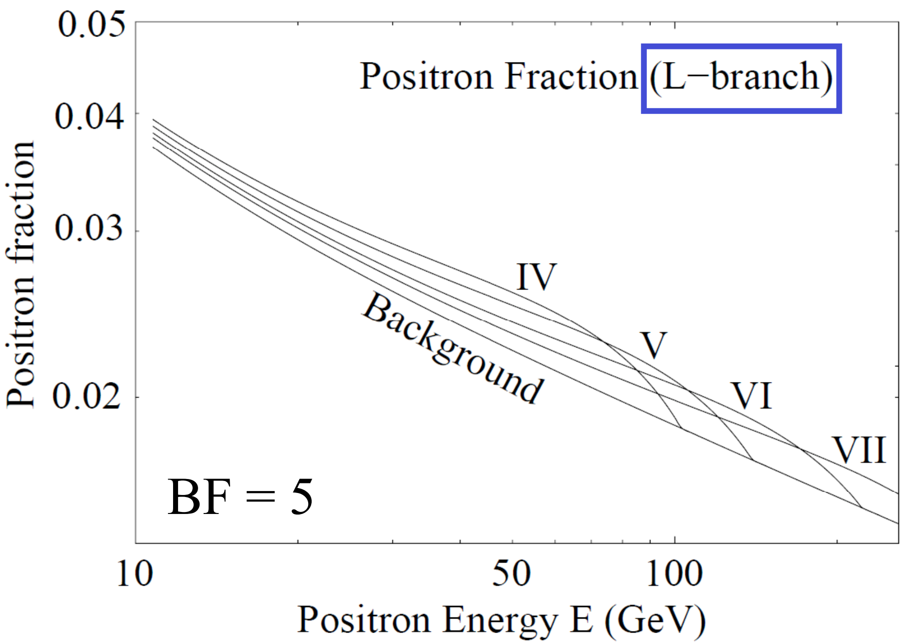
Large uncertainty comes from the local DM distribution. Due to the clamping effect of DM, the signal is expected to be enhanced. This effect is encoded in the enhancement factor of the signal as BF factor. From N-body simulations, BF is expected to be 2 ~ 5.

Positron fraction: $e^+/(e^+ + e^-)$

Positron fraction at 7 sample points on WMAP allowed region







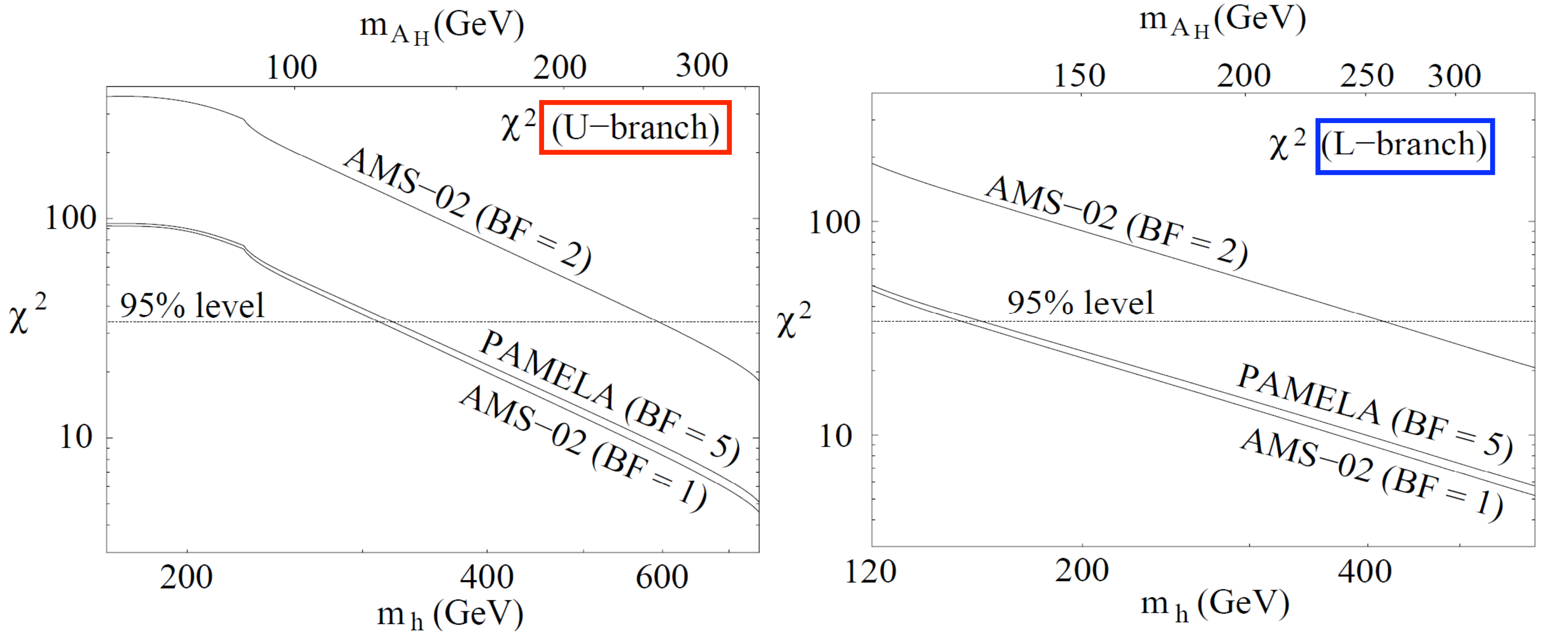
Possibility to detect the signal in PAMELA and AMS-02

In order to investigate the possibility quantitatively Hooper & Silk (2004)

$$\chi^2 = \sum_{\text{bins}} \frac{(N_{\text{Obs}} - N_{\text{BG}})^2}{N_{\text{Obs}}}$$

Energy bins of width
Δ(log E) = 0.60 (E < 40 GeV)
Δ(log E) = 0.64 (E > 40 GeV)

χ^2 representing the discrimination of the signal from B.G. statistically

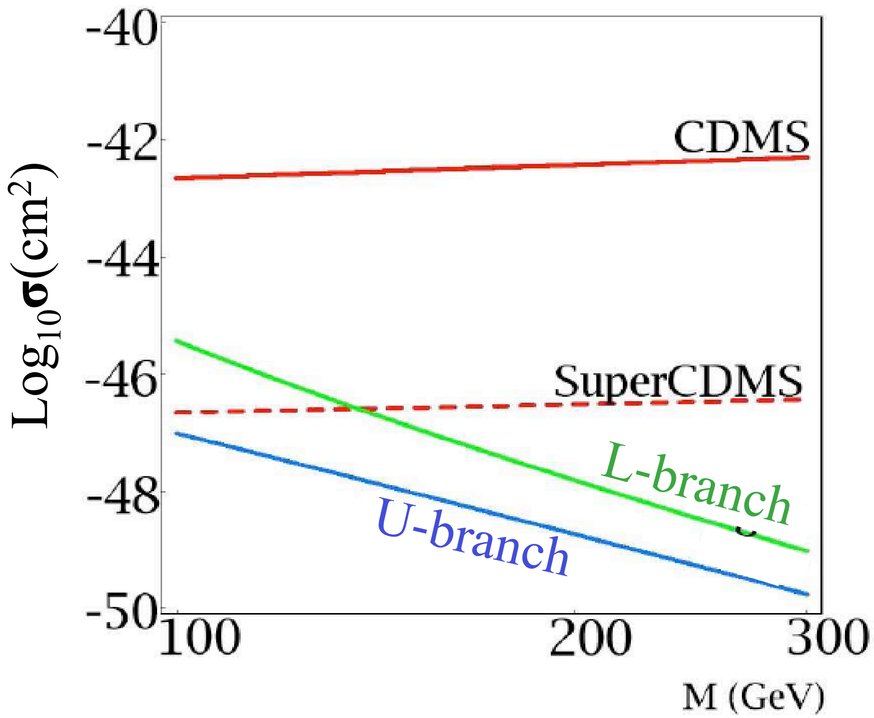


PAMELA may be capable of observing the signal for m~100 GeV & BF =5.
(AMS-02, the sensitivity is improved, can detect the signature even if BF = 1)

Signatures in other detection measurements

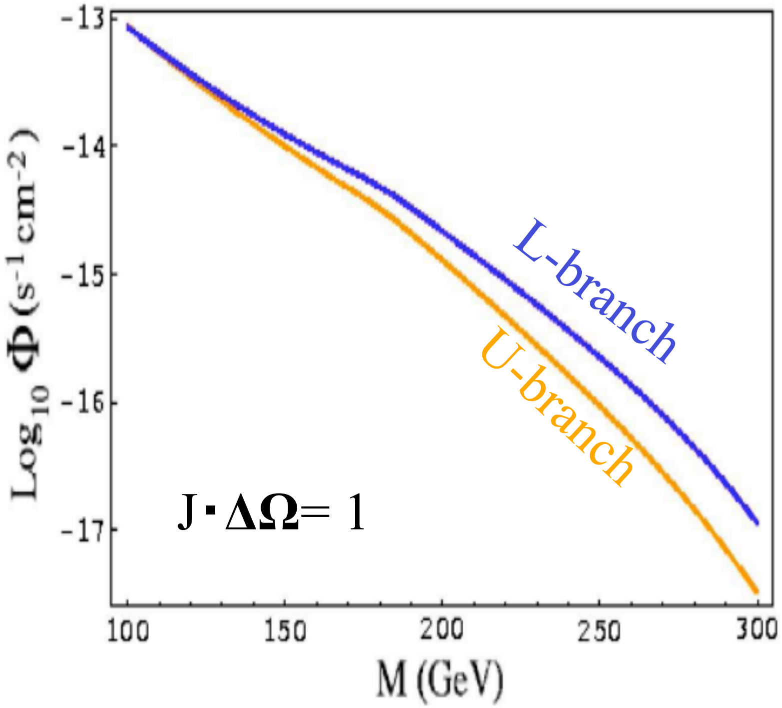
A.Birkedal, A. Noble, M. Perelstein, and A. Spray: hep-ph/0603077

Direct detection of DM
→ Scattering **σ** between DM & p(n)



Challenging to detect the signal in near future experiments

indirect detection of DM using **γ**
→ Line **γ**-ray observation from G.C.



The signal can be observed if the large Enhancement due to the cuspy structure Exsist at the G.C. ($J \sim 10^5$ is needed)

Summary

- Littlest Higgs model with T-parity provides a dark matter candidate.
- The dark matter is a WIMP (m ~ 100 GeV), and it can explain the abundance observed by WMAP.
- The dark matter can be detected in the indirect detection measurements using comic
- In PAMELA, the signal can be distinguished from B.G. if m < 120 GeV and BF = 5.
- In AMS-02, the sensitivity is considerably improved, and the signal can be detected even if BF = 1.

Future directions

- Investigating signatures of this model in LHC, and compare signals with those from the dark matter phenomenology.
- Once parameters of the model is fixed by the LHC experiments, then we can predict the relic abundance and compare the prediction with the observation.

④ LHM with T-parity

Original LHM is suffered from severe constraints from EWPM. (Tree-level corrections due to the exchange of additional heavy gauge bosons and non-vanishing VEV of triplet higgs.)
f must be larger than 5 TeV !! → fine-tuning again

impose **T - parity**

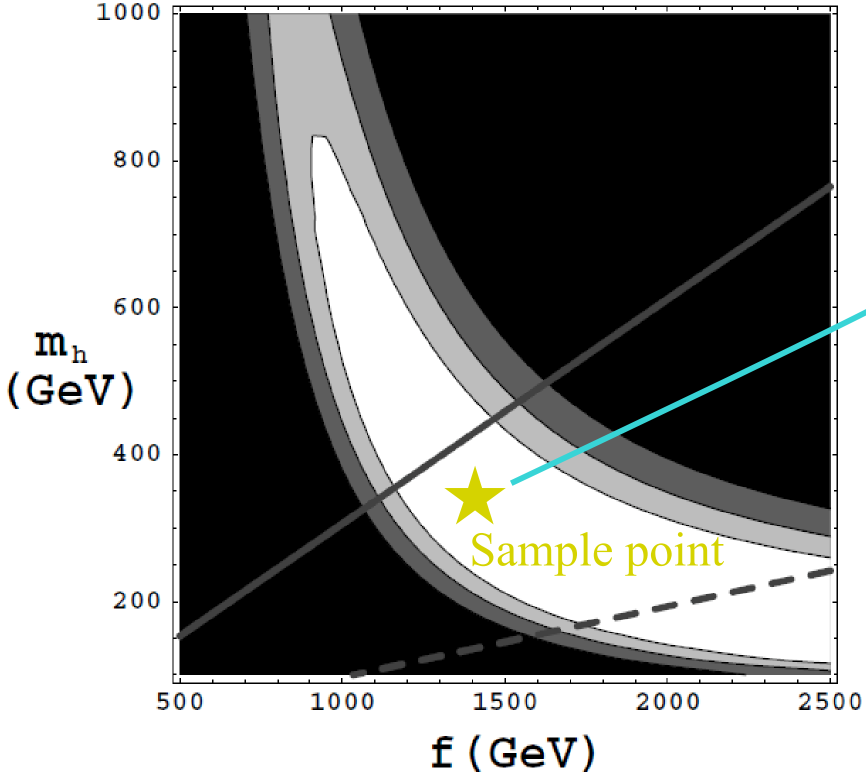
$B_1(W_1) \Leftrightarrow B_2(W_2)$

$\boldsymbol{\Pi \Leftrightarrow -\Omega\Pi\Omega}$

$\boldsymbol{\Omega}$= diag.(1,1,–1,1,1)

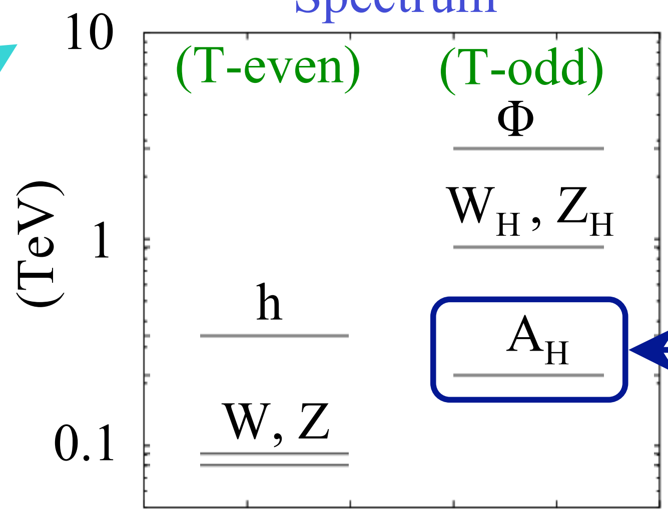
(no heavy gauge boson exchange, no triplet VEV.)

Constraint from EWPO (S,T,U)



Hubisz, Meade, Noble, Perelstein (2005)

Spectrum



Lightest T-odd Particle (LTP) is stable
→ Good Candidate of Cold Dark Matter !!

Possibility to detect the signal in PAMELA

PAMELA

(satellite-borne exp.)

e^+ : 50 (MeV) ~ 270 (GeV)

acceptance : 20.5cm^{2}sr

energy res. : 12%/E$^{1/2}$ + 2%

contamination : 10^{-4} level

PAMELA covers the interesting range of LTP dark matter.
To detect the signal, the B.G. estimation is important.

B.G. will be measure accurately at PAMELA (at 1 ~ 5 GeV) and astrophysical ambiguity will be very small !!

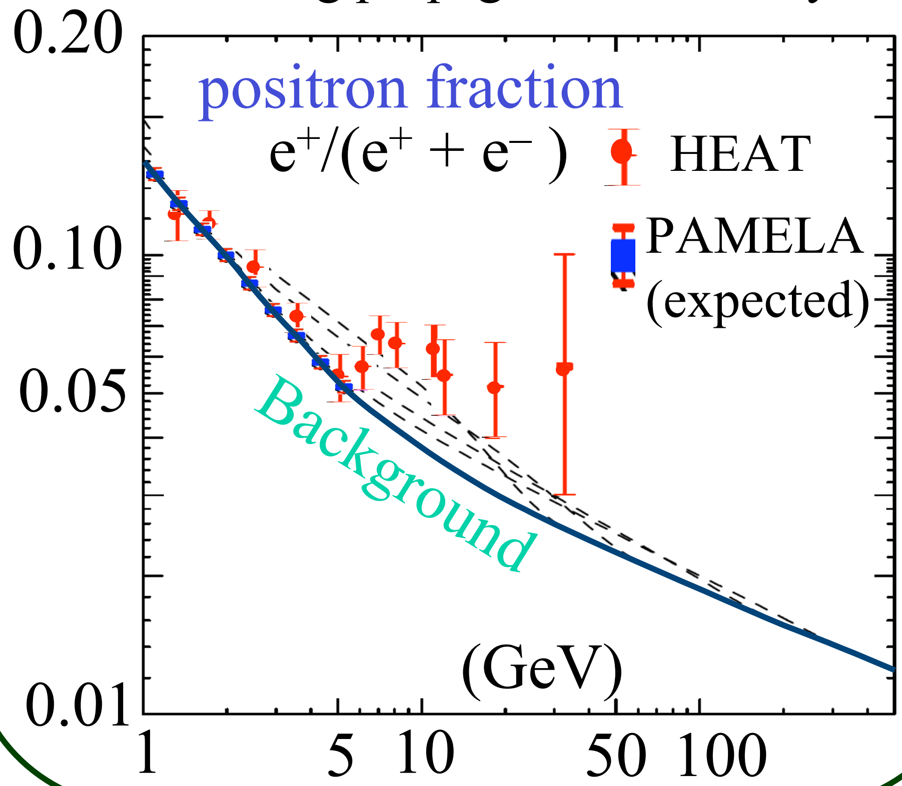
The LTP dark matter signal can be detected at the range ~ 100 GeV.

Not only DM ann. but also C.R. produces high-energy e^+

Background positrons

C.R. (primary e^-) → secondary e^+

during propagation in Galaxy



(gauged)

$SU(5) \supset [SU(2)\times U(1)]^2$

$\downarrow$

$SO(5) \supset SU(2)\times U(1)$

(SM)