How accurately is the property of the Little Higgs dark matter determined at the ILC?

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Determination of the property of the Little Higgs dark matter (mass, its abundance of thermal relics) at the LHC, 500GeV and 1 TeV linear collides.

Little Higgs scenario

Little Hierarchy Problem

Standard model is the very successful model describing physics below 100 GeV.

How large the new physics scale Λ is?

1. Fine tuning problem requires $\Lambda < 1$ TeV
2. Electroweak precision measurements $\Lambda > 10$ TeV.

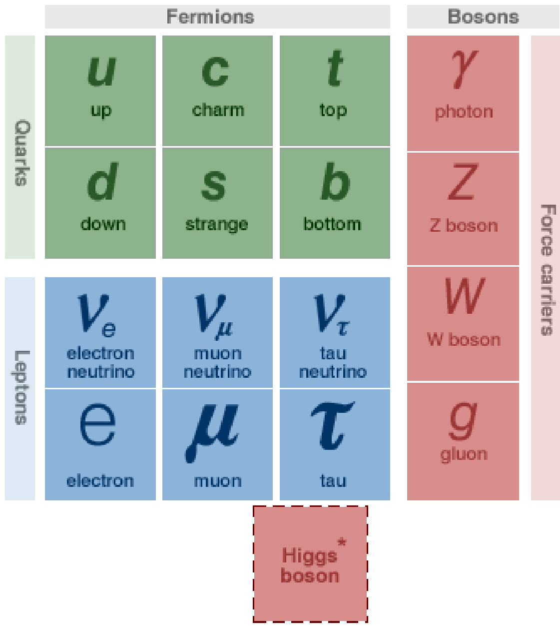
Little Higgs Scenario

1. Higgs boson is regarded as a Pseudo NG boson of a global symmetry at some higher scale.
2. Explicit breaking of the global symmetry is specially arranged to cancel quadratic divergent corrections to m_h at 1-loop level (Collective symmetry breaking)

→ Λ can be 10 TeV without fine turnings!

Littlest Higgs model with T-parity (LHT)

[N. A-Hamed, A. G. Cohen, E. Katz, A. E. Nelson, J. High Energy. Phys. (2002)]
[H. C. Cheng, I. Los, J. High Energy Phys. (2003, 2003)]



$SU(5) \rightarrow SO(5)$
$[SU(2)xU(1)]^2 \rightarrow SU(2)xU(1)$

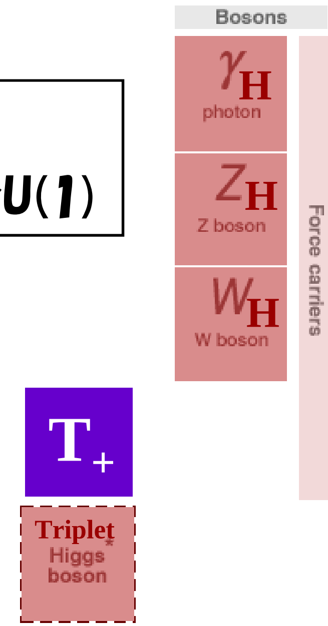
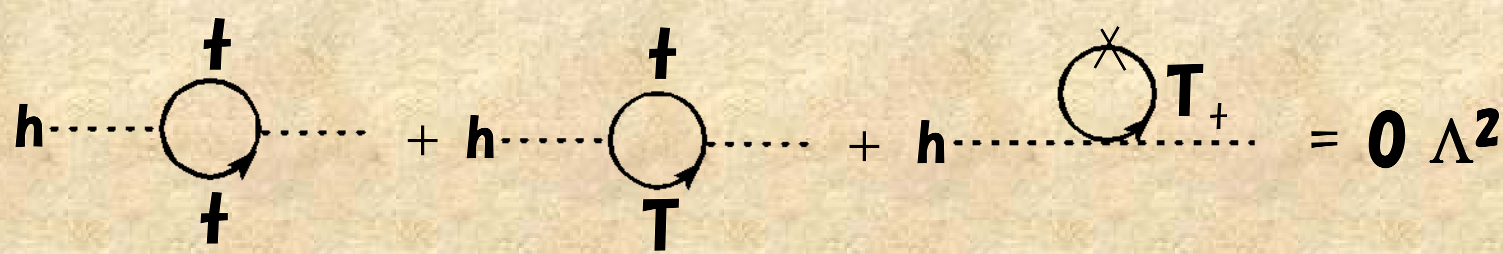


Diagram Cancellations



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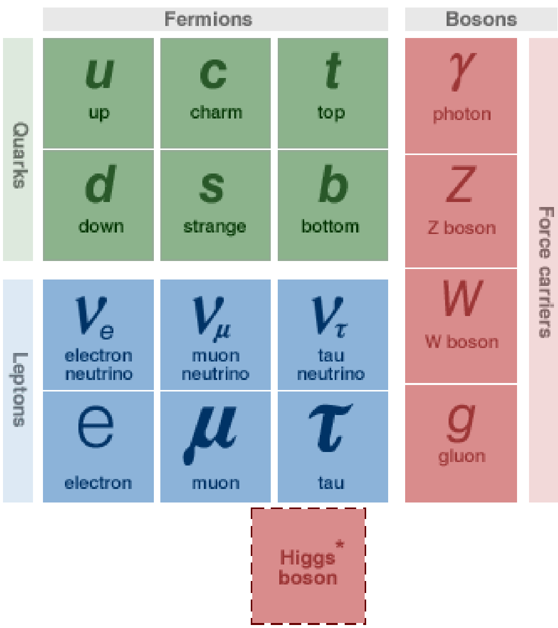

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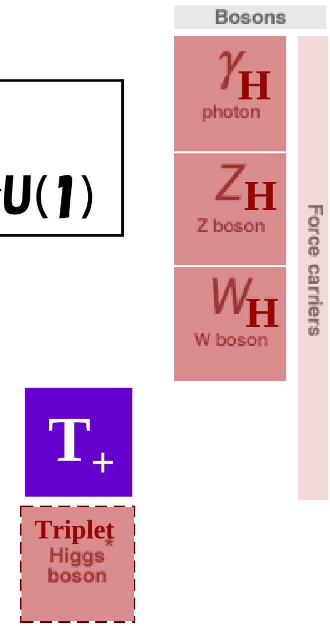

Little Higgs models suffers from EWP constraints.
→ Imposition of the Z_2-symmetry (T-parity).

In LHT,
1. SM particles & Top partner T_+ are T-even
2. Heavy Gauge bosons are T-odd.
3. T-odd partners of matter fields are introduced.

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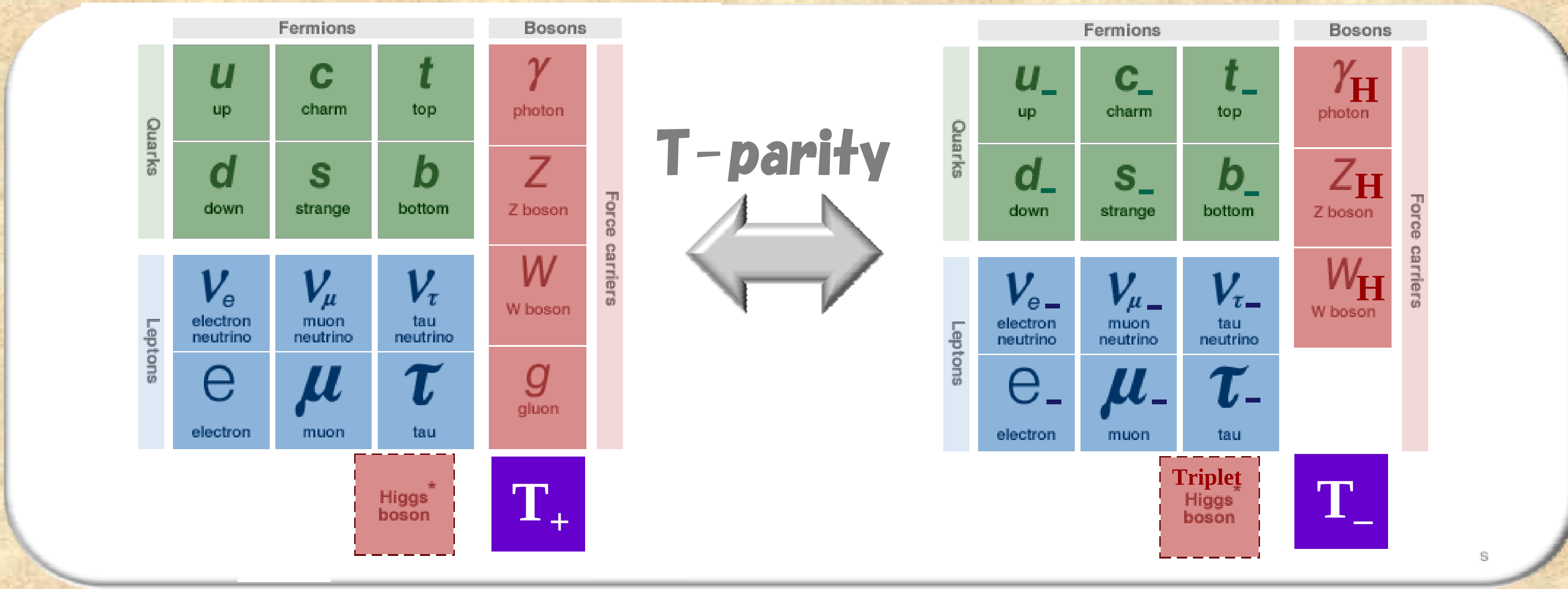

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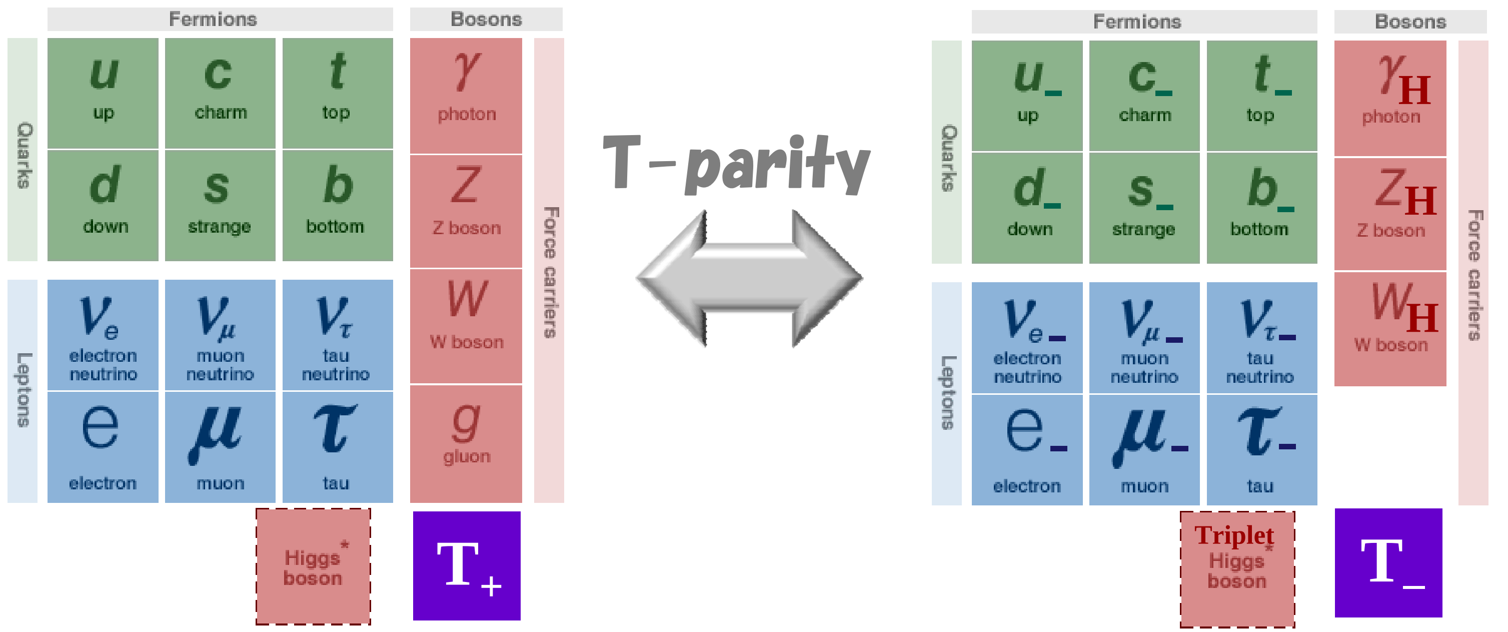

Model Parameters of the LHT

f : VEV of the SU(5) → SO(5) breaking

λ_2 : Mass of the top-partners (in units of f)

κ_x : Mass of the T-odd partner of "x" (in units of f)

+ SM parameters (m_h, ···)

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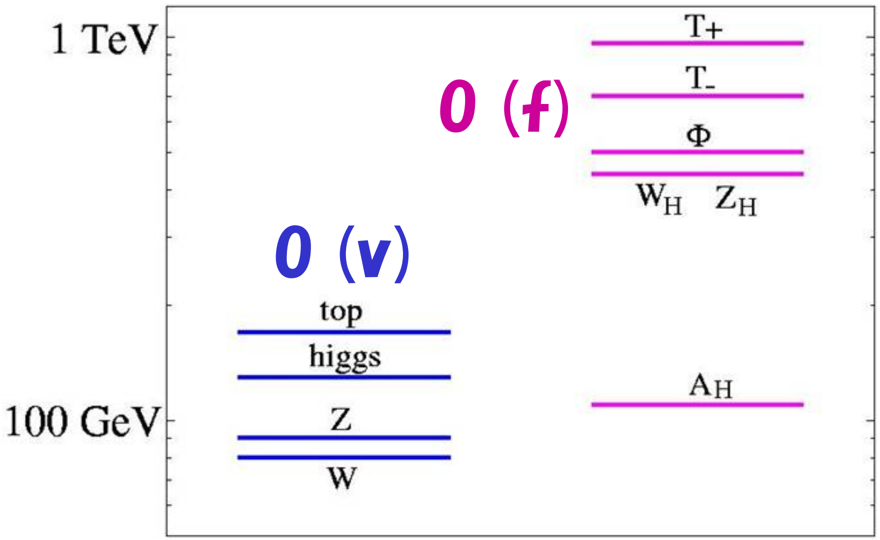


Masses of new particles are proportional to f.

Masses of SM particles are proportional to v.

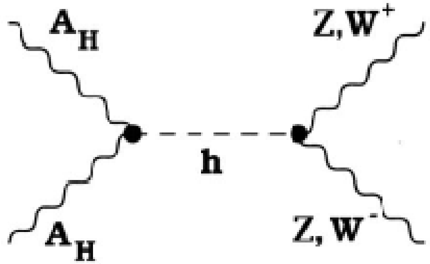
Model Parameters of the LHT

- f : VEV of the SU(5) → SO(5) breaking
- m_h : Higgs mass
- λ_2 : Mass of the top-partners (in units of f)
- κ_x : Mass of the T-odd partner of "x" (in units of f)

Little Higgs Dark Matter

Lightest T-odd Particle is stable due to the T-parity conservation.
→ Little Higgs Dark Matter! (Heavy photon in the LHT)

[J. Hubisz, P. Meade, Phys. Rev. D71, 035016 (2005)]

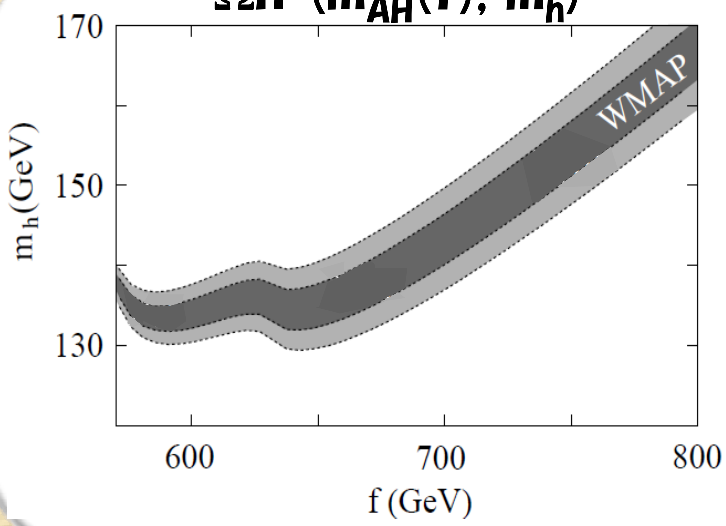


Main annihilation mode: $A_H A_H \to h \to WW$ or ZZ.

1. $A_H A_H h$ vertex is given by the SM gauge coupling.
2. Annihilation cross section depends on m_{AH} & m_h.

→ Relic abundance of A_H: $\Omega h^2(m_{AH}(f), m_h)$

$\Omega h^2(m_{AH}(f), m_h)$



[Asano, S.M, N.Okada, Y.Okada (2006)]

When $m_h < 150$ GeV,
then $550 < f < 750$ GeV.

Masses of heavy gauge bosons are several hundred GeV.
→ can be produced at ILC.

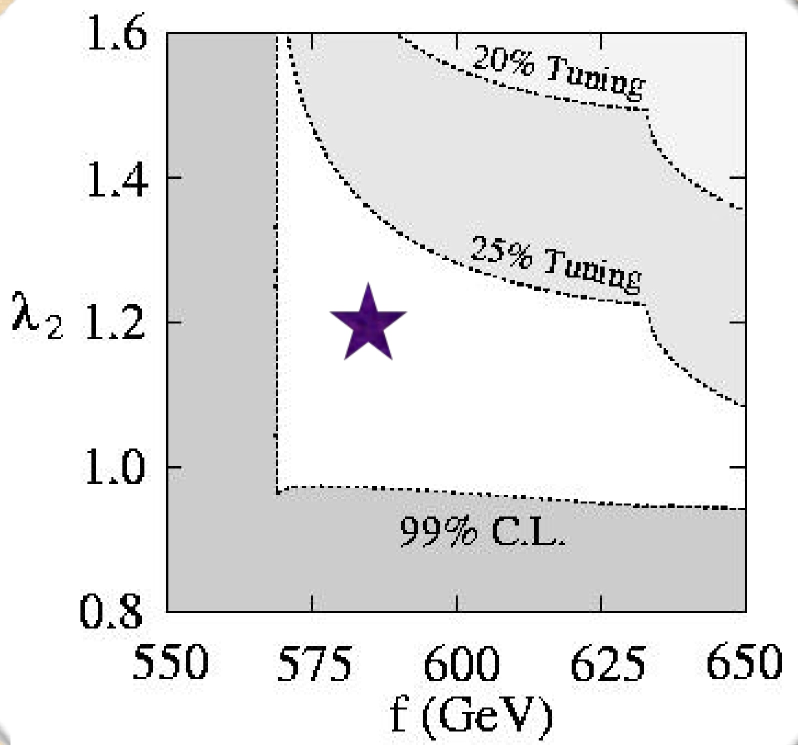
Masses of top partners are about (or less than) 1 TeV
→ copiously produced at LHC.

Representative point for simulation study

Considering EW precision & WMAP constraints

[J. Hubisz, P. Meade, A. Noble, M. Perelstein, JHEP0601 (2006)]

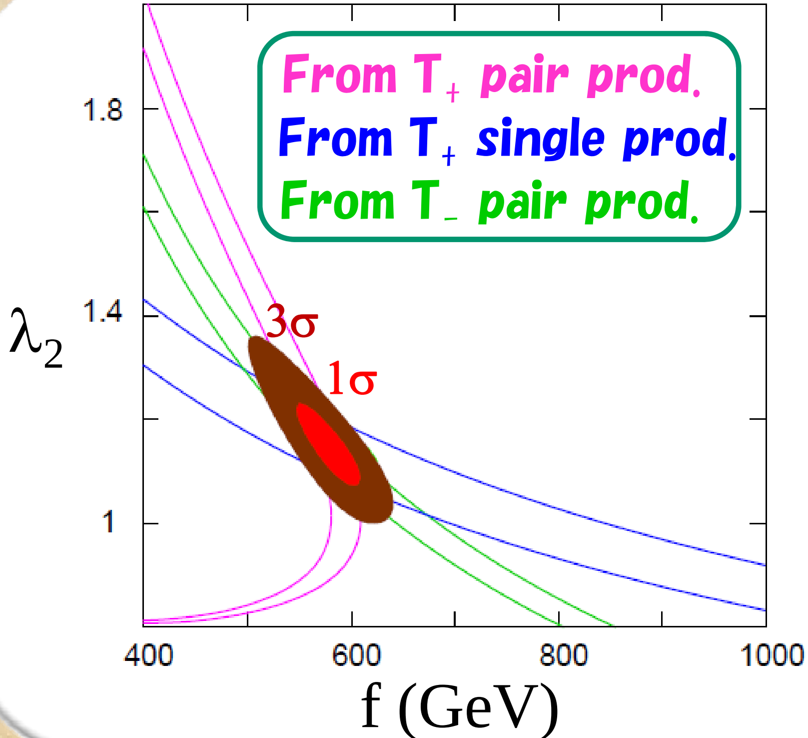
(1) Observables (m_W, $\sin\theta_W$, Γ_l, $\Omega_{DM}h^2$) vs. Model parameters (f, λ_2, m_h)
(2) $2m_h^2/\mu_t > O(0.1-1)$, where μ_t is the top-loop contribution to m_h.

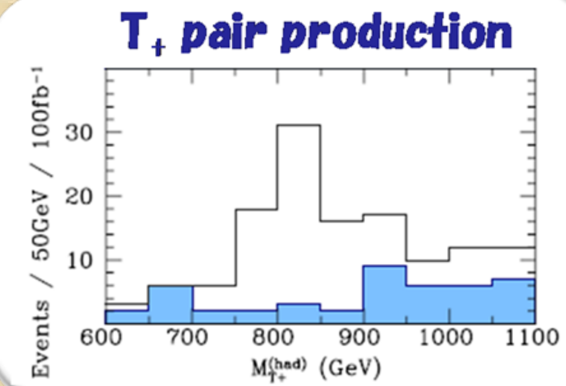


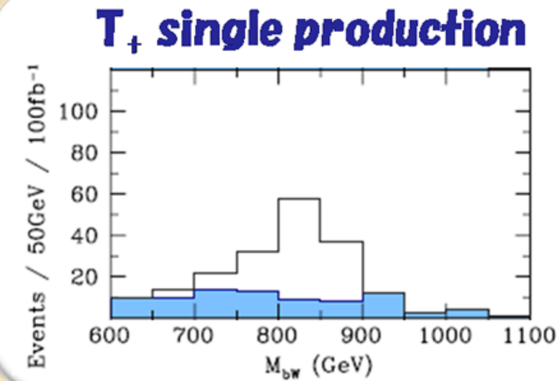
f = 580 GeV
λ_2 = 1.15
m_h = 134 GeV
m_{AH} = 81.9 GeV
m_{WH} = 368 GeV
m_{ZH} = 369 GeV
m_{T+} = 834 GeV
m_{T-} = 664 GeV
m_Φ = 440 GeV
(m_{LH} = 410 GeV)

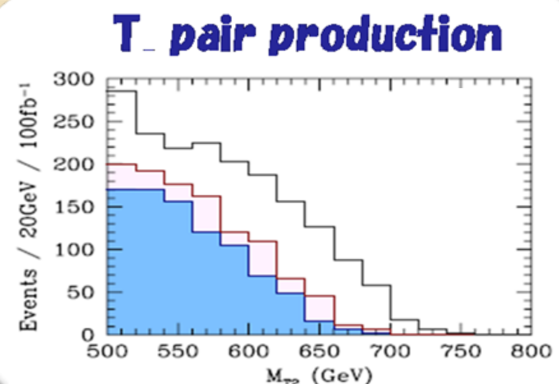
Little Higgs signals at LHC

[S.M., T. Moroi, K. Tobe, Phys.Rev.D78 (2008)]







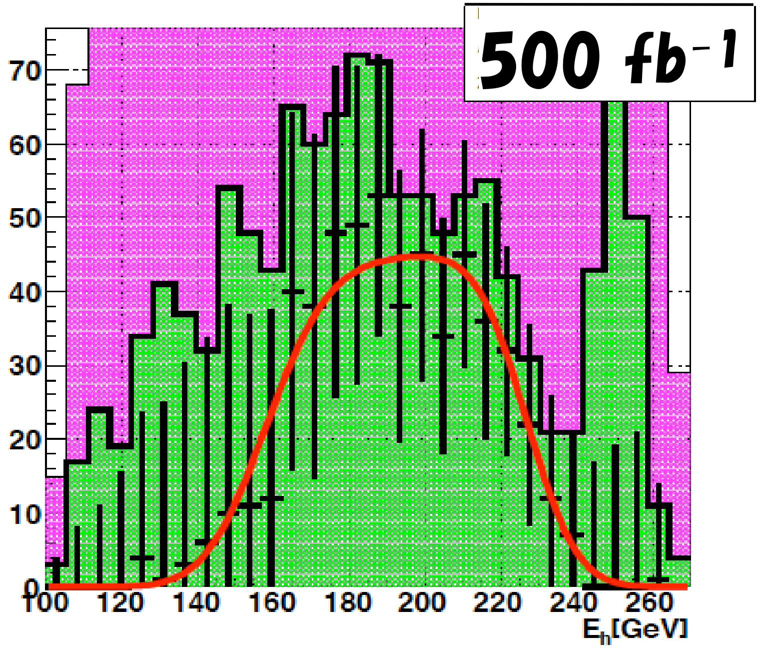


The parameter f is determined as

$$f = 580 +/- 33 \text{ GeV}$$

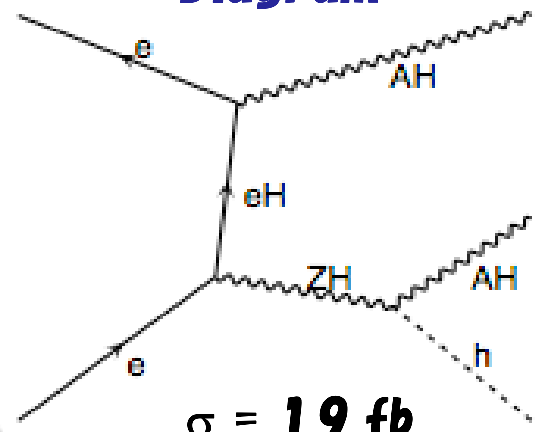
Little higgs signal at ILC (0.5 TeV)

Signal + BG(ZZ, Zh, $\nu\nu$Z, $\nu\nu$h)

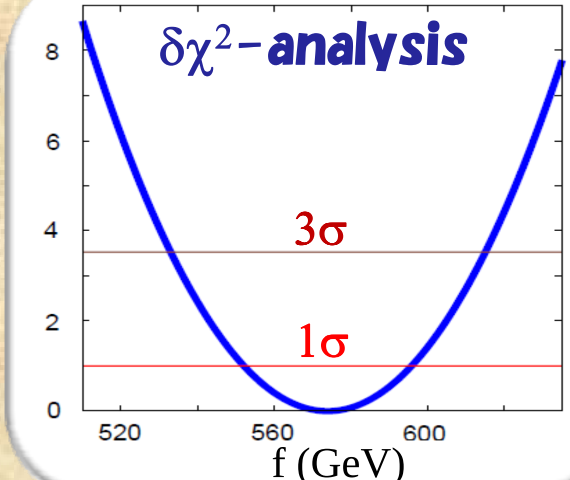


m_{AH} = 80.1 ±7.3 GeV
m_{ZH} = 366±17GeV

Diagram



σ = 1.9 fb

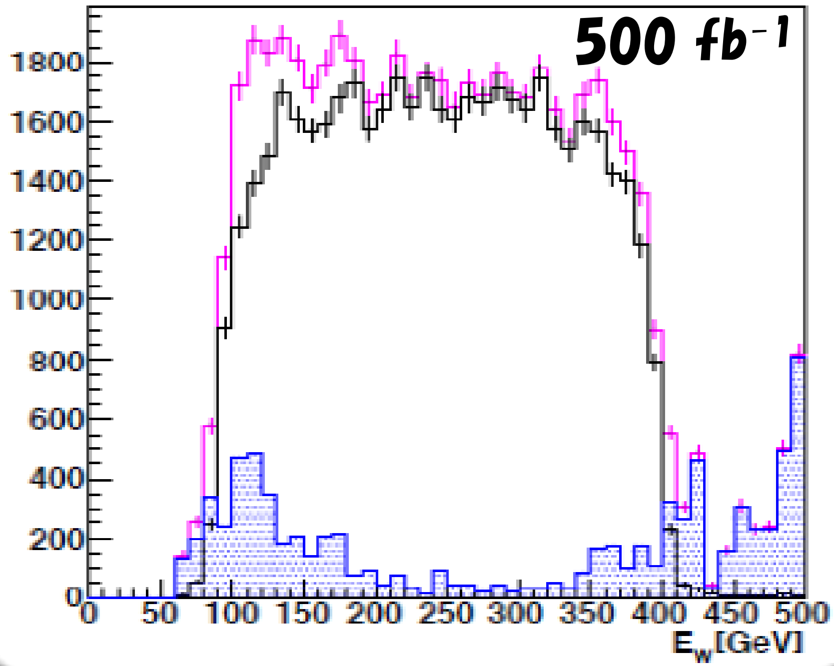


f is determined as

f = 580 +/- 22 GeV

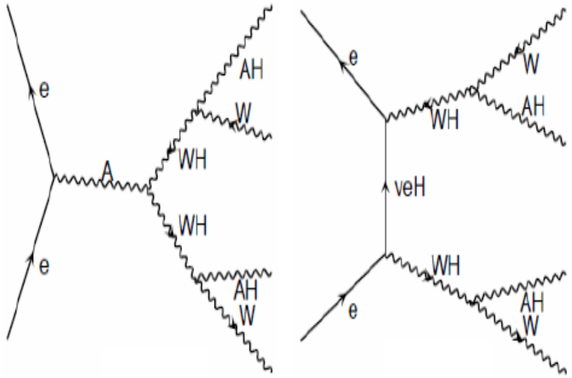
Little Higgs signal at ILC (1 TeV)

Signal + BG(WW, eeWW)

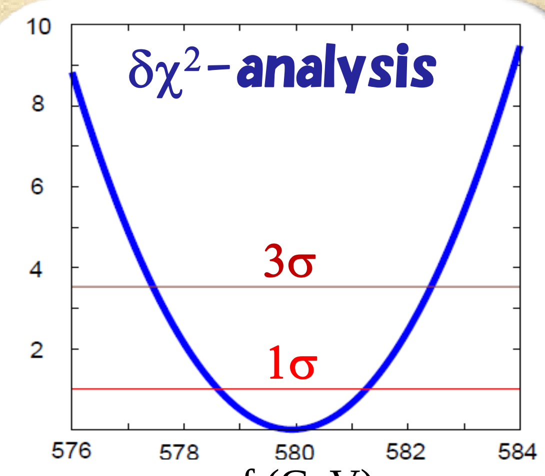


$$m_{AH} = 82.42 \pm 1.09$$
$$m_{WH} = 368.0 \pm 0.9$$

Diagram



σ = 121 fb



f is determined as

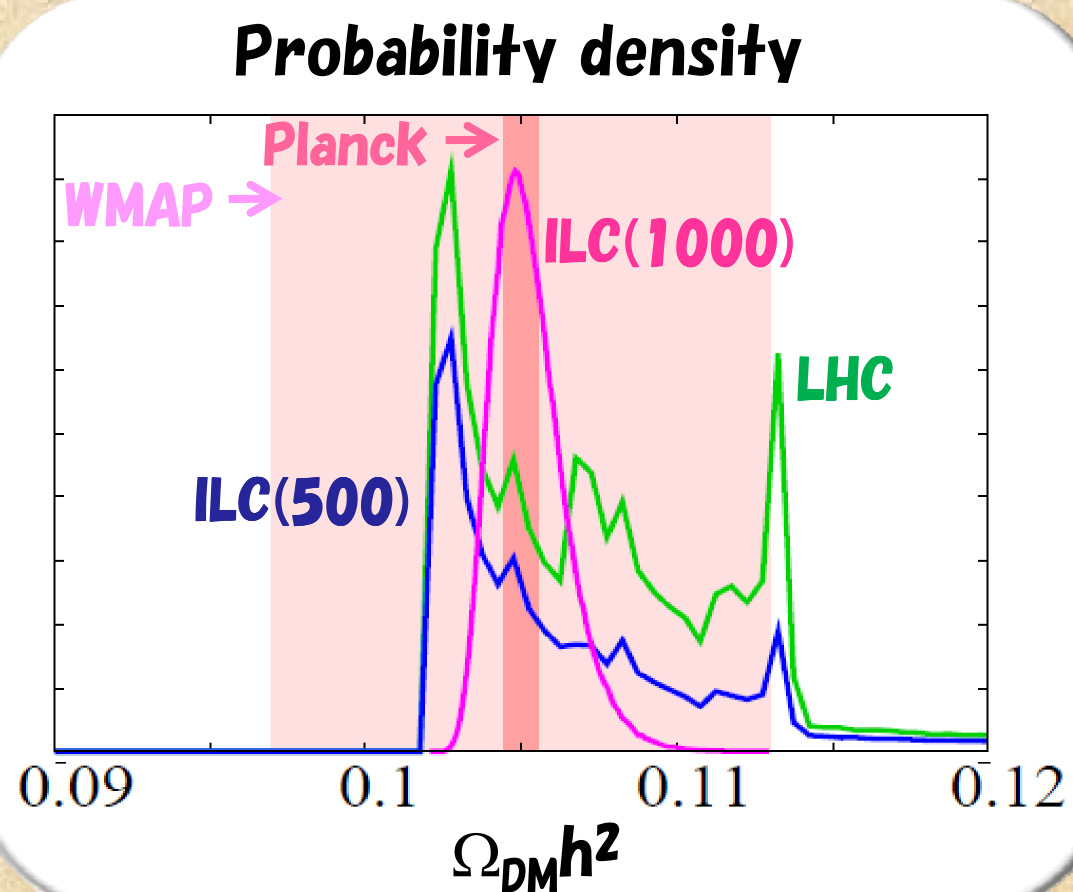
f = 580 +/- 1.3 GeV

Relic abundance of the little higgs dark matter

Simulation results
+ Higgs mass

Annihilation X-section
$\langle \sigma v \rangle (m_{AH}, m_h) \rightarrow \Omega_{DM}h^2$

Probability density of the dark matter relics



LHC: Abut 10% accuracy (Model-dependent analysis)

ILC(500): Better than 10% accuracy (Model-independent analysis)

ILC(1000): 2% accuracy!! (Model-independent analysis)

Summary

- Little Higgs model with T-parity is one of attractive scenario describing New Physics at TeraScale.
- It contains a candidate for cold dark matter whose stability is guaranteed by the T-parity (Little Higgs dark matter).
- The property of the dark matter can be investigated at collider experiments such as LHC & ILC with $s^{1/2}$ = 0.5 and 1 TeV.
- At LHC, top partners can be detected. From their data, the property of the dark matter can be estimated with the model dependent way.
- At ILC with $s^{1/2}$ = 500 GeV, the property of the dark matter can be determined with model-independent way. Also, the relic abundance can be determined with the accuracy comparable to the WMAP.
- AT ILC with $s^{1/2}$ = 1 TeV, the property of the dark matter can be determined very accurately. For instance, the relic abundance will be determined with the accuracy comparable to PLANCK experiment.