

19th International Summer Institute on Phenomenology of Elementary Particles and Cosmology
SI2013



The Higgs boson phenomenon in the Little Higgs model with T-parity via the heavy Z_h pair production

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22 Aug 2013



Reference:

- J. Reuter and M. Tonini, arXiv:1212.5930 [hep-ph]
- J. Reuter, M. Tonini and M. de Vries, arXiv:1307.5010[hep-ph]
- J. Hubisz, P. Meade, Phys. Rev. D71, 035016 (2005)
- K. Cheung, K-Y. Lee, S-Y. Shim, J. Song, N. Yoo, arXiv: 1302.0594[hep-ph]
- J. Reuter (DESY), Snowmass Meeting, 2013 presentation.

Work In Progress With

Prof. Jeonghyeon Song (Konkuk U.)

Prof. Kingman Cheung (Taiwan, Natl. Tsing Hua U. & Konkuk U.)

Introduction

The 125 GeV boson characteristic fit perfectly with the SM Higgs boson.

The Little Higgs Mechanism --
One Solution to The Hierarchy Problem.
Suffers strong constraint from the EWPT.

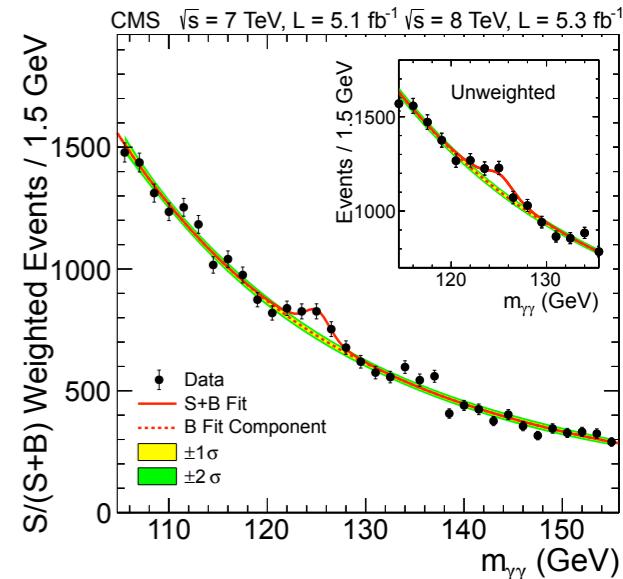
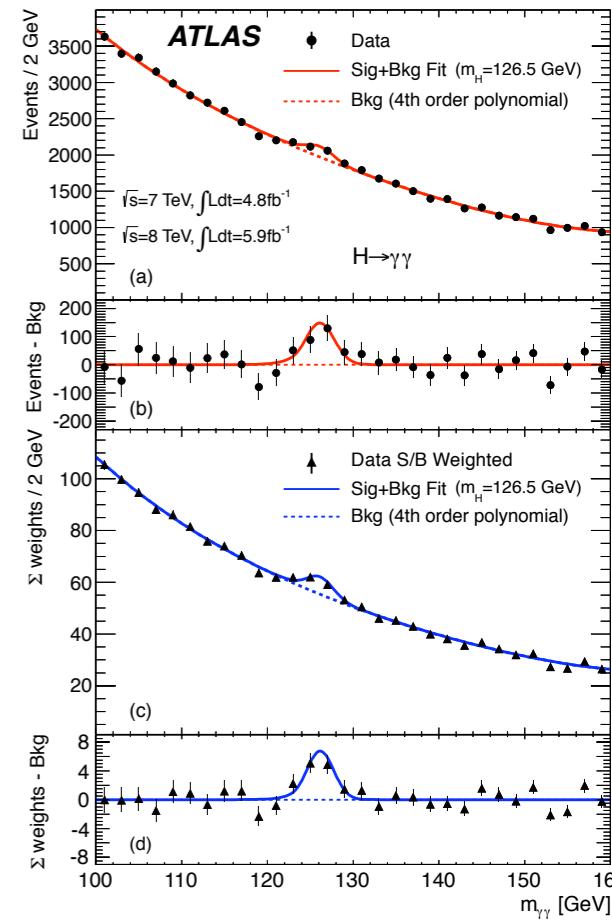
(In the SM, there are Quadratically divergent diagrams which contribute to the Higgs mass)

WELL-MOTIVATED NEW PHYSICS MODEL CAN ENHANCE HIGGS PAIR PRODUCTION:

The Little Higgs model with T-parity

The Higgs-boson pair production cross section in the SM is about 1 fb at the LHC-14.

If we observed large Higgs-pair production, it would indicate some new physics.



The Little Higgs Model

Nambu-Goldstone theorem: Spontaneous Breaking of a global symmetry:
massless (Goldstone) bosons in the spectrum

Georgi/Pais, 1974; Georgi/Dimopoulos/Kaplan, 1984

Light Higgs as (Pseudo)-Goldstone boson of a
spontaneously broken global symmetry
 $\Lambda \text{ O}(10\text{TeV}) \rightarrow v \text{ O}(250\text{GeV})$

Arkani-Hamed/Cohen/Georgi/Nelson/. . . , 2001

Collective Symmetry Breaking
 $\Lambda \text{ O}(10\text{TeV}) \rightarrow f \text{ O}(1\text{TeV}) \rightarrow v \text{ O}(250\text{GeV})$

scale Λ : Global Symmetry Breaking,
New particles,... scale v : Higgs, W/Z,...

the Original Idea

unsuccessful, due to re-introduced a fine-tuning to separate the symmetry breaking scale (Goldstone) and the EW scale.

scale Λ : Global Symmetry Breaking,...
scale f : Pseudo-Goldstone bosons, new
particles,... scale v : Higgs, W/Z,...

the New Idea

2 different global symmetries; one of them
unbroken Higgs exact Goldstone boson.

at scale $\Lambda=4\pi f$: $SU(5) \rightarrow SO(5)$, $[SU(2) \times U(1)]^2$ embedded in $SU(5)$



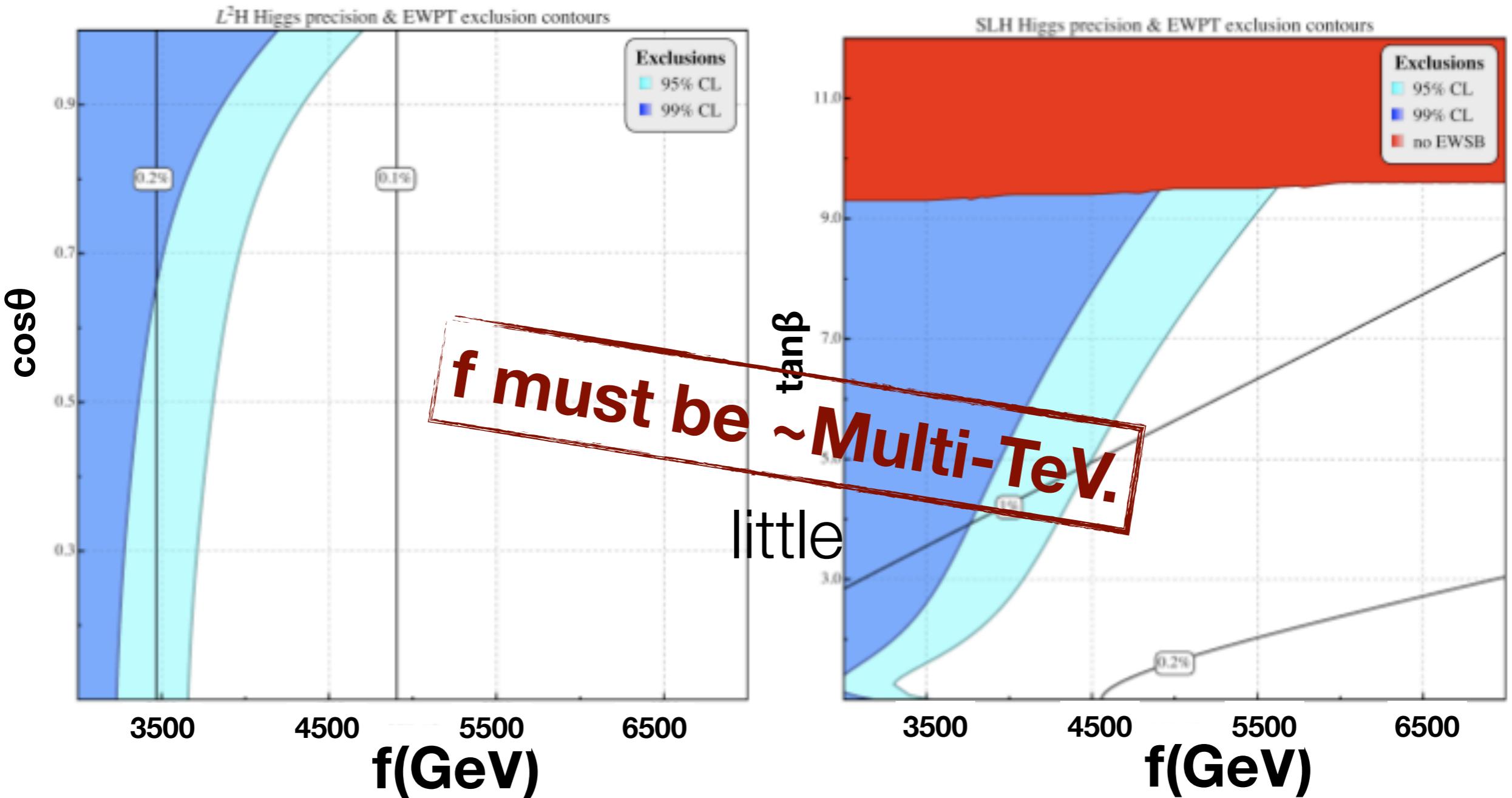
at scale f : $[SU(2) \times U(1)]^2 \rightarrow SU(2)_L \times U(1)_Y$



at scale $v=g^2f/(4\pi)$ (EWSB) : $SU(2)_L \times U(1)_Y \rightarrow U(1)_{EM}$

Constraints from Higgs data & EWPT

J. Reuter, M. Tonini and M. de Vries, arXiv:1307.5010[hep-ph]



Many new particles at the scale f to cancel the 1-loop quadratic divergence for the Higgs mass.

But faced the **constraints from the EWPT** (come from the tree level mixing of heavy and light mass eigenstate).

The Little Higgs Model with T Parity

Cheng / Low 2003; 2004

Introducing a discrete symmetry called

⇒ “ **T-Parity** ”, Exchange $[\text{SU}(2) \times \text{U}(1)]_1 \Leftrightarrow [\text{SU}(2) \times \text{U}(1)]_2$

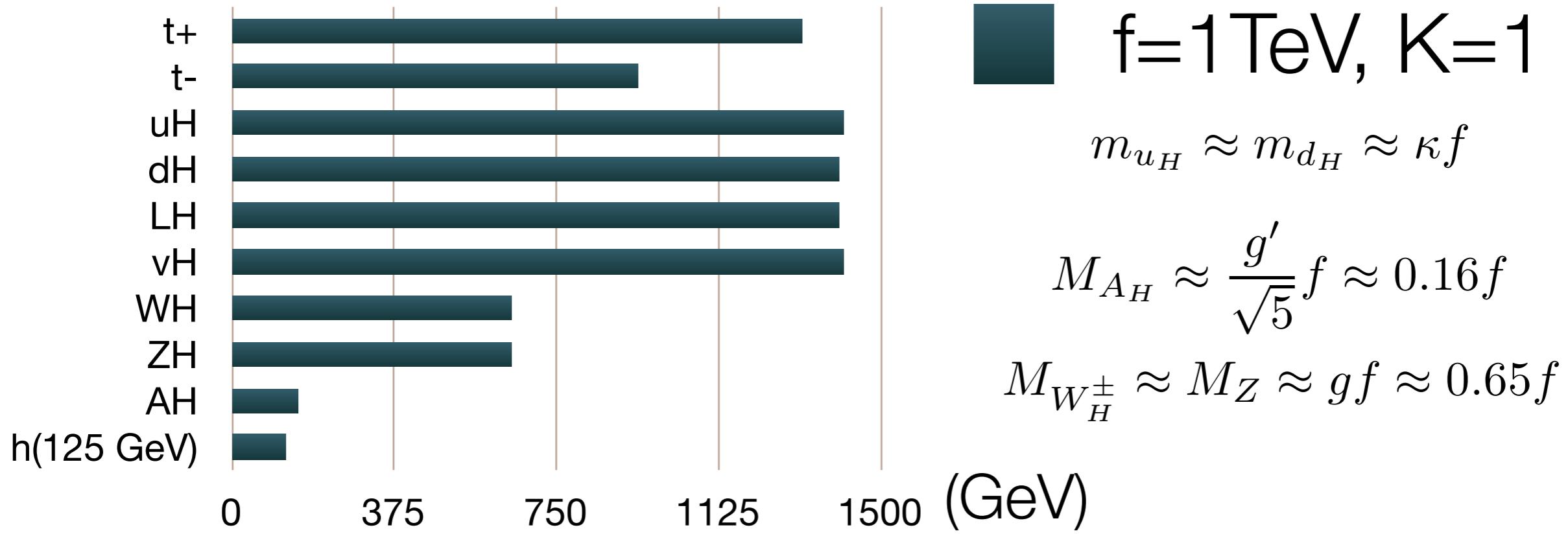
SM particles T-even \Leftrightarrow heavy new gauge boson W_H, Z_H, A_H T-odd

⇒ No tree-level corrections to EW precision observables

⇒ No triplet and doublet Higgs ($H^\dagger \Phi H$) terms: no triplet vev, $\rho=1$

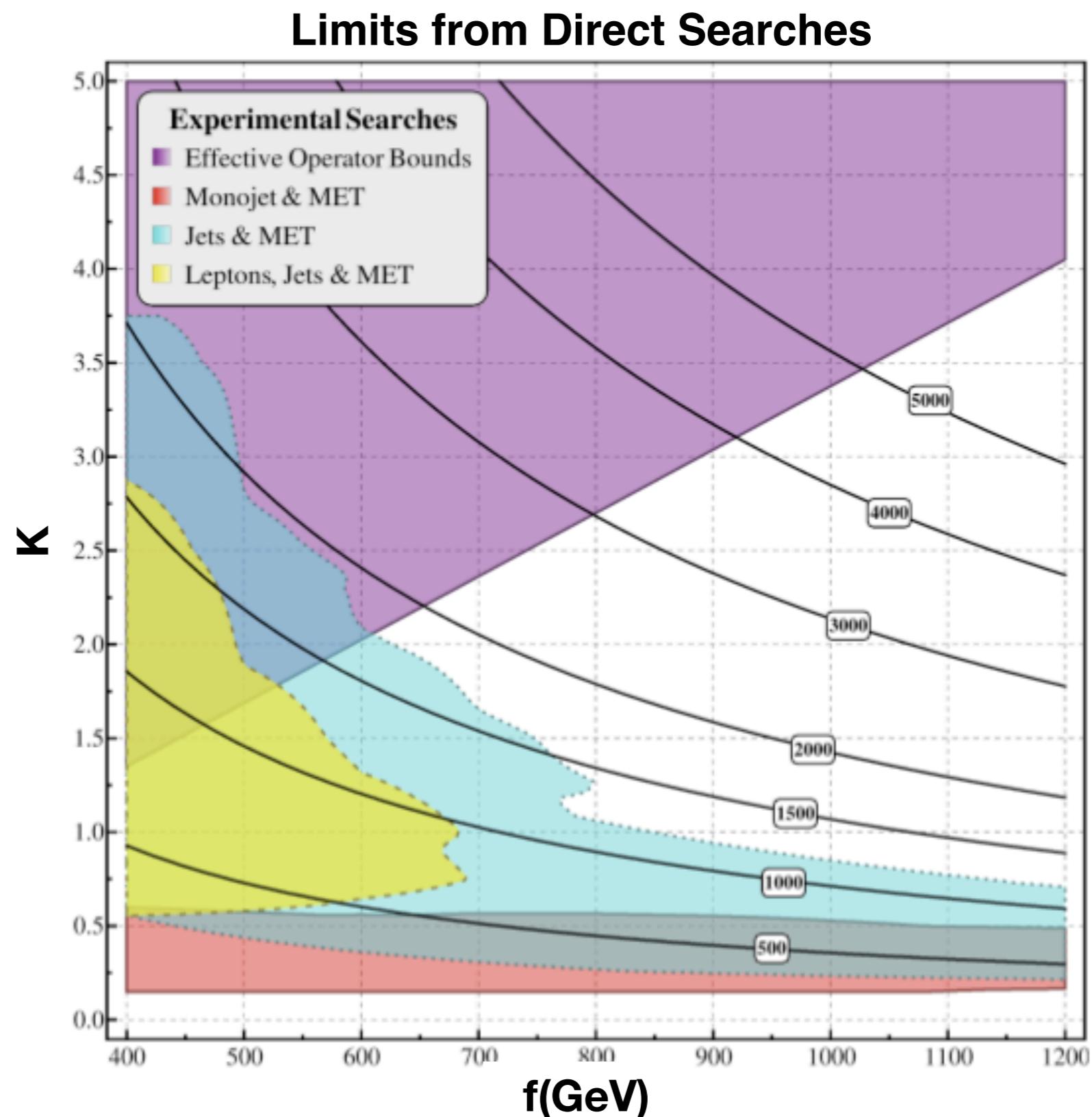
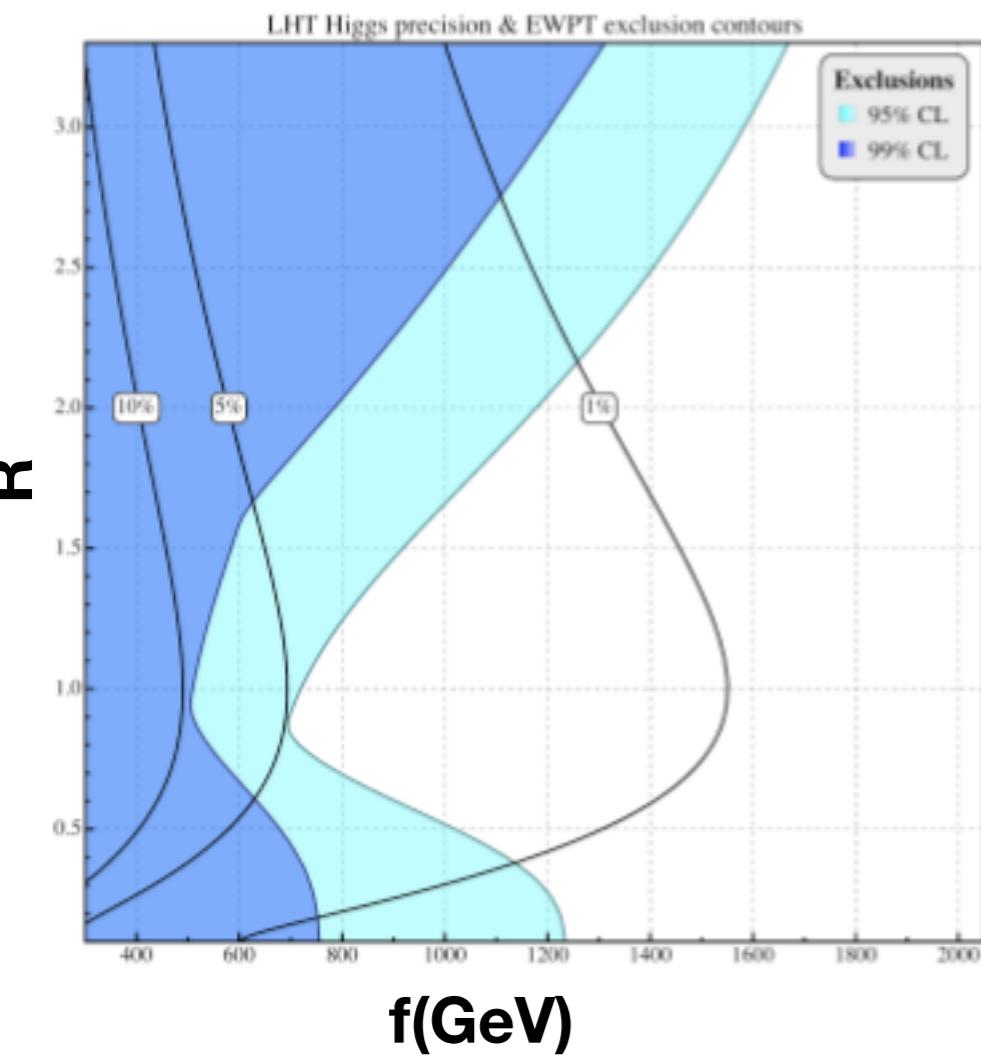
(custodial symmetry preserved)

⇒ Lightest T-odd particle A_H : which is stable and neutral, DM candidate



Constraint from the current data for LHT model.

Constraints from Higgs data &EWPT



The Higgs pair production

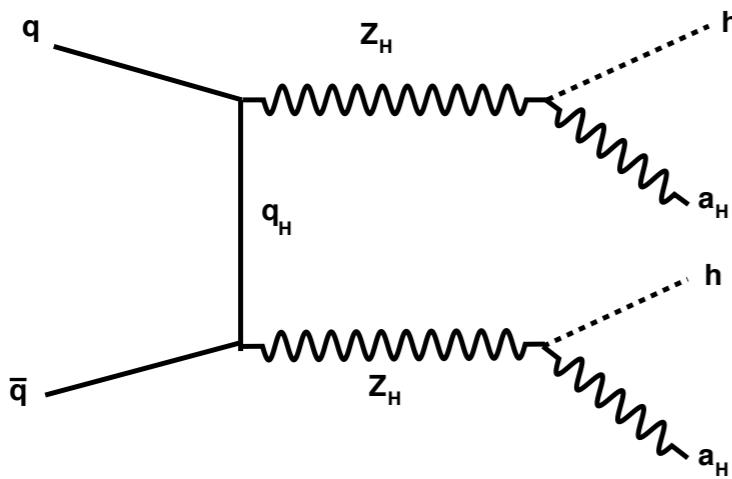
$$pp \rightarrow Z_H Z_H$$

$$Z_H \rightarrow h A_H$$

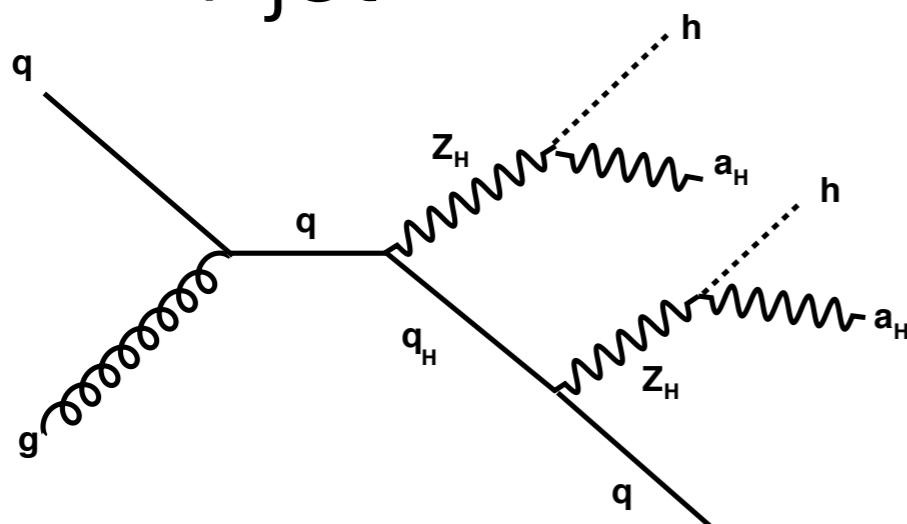
$$h \rightarrow b\bar{b}$$

$$h \rightarrow \tau^+ \tau^-$$

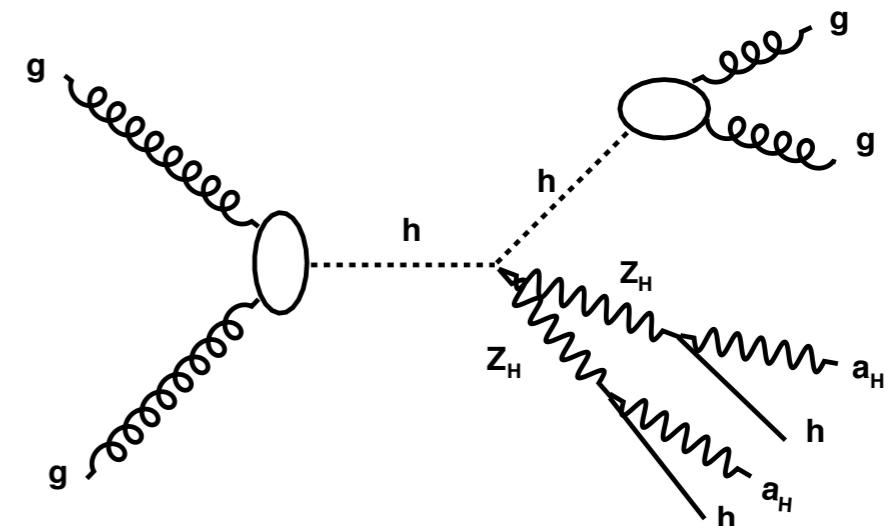
0 jet



1 jet



2 jet Gluon Fusion



Cross section is too small!

The Higgs pair production

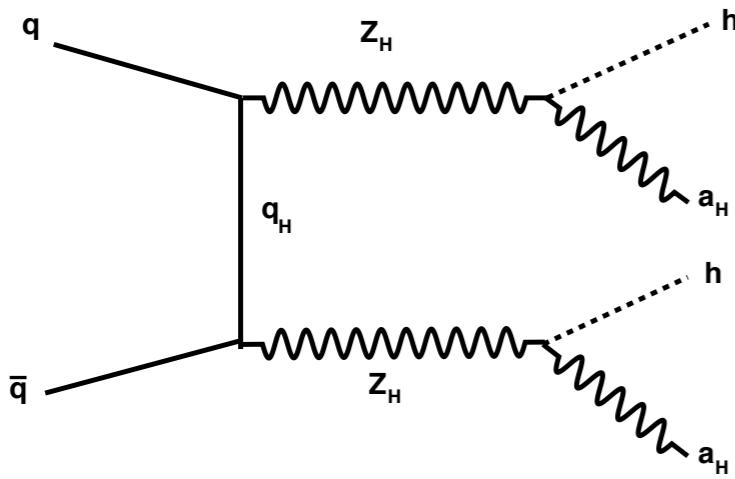
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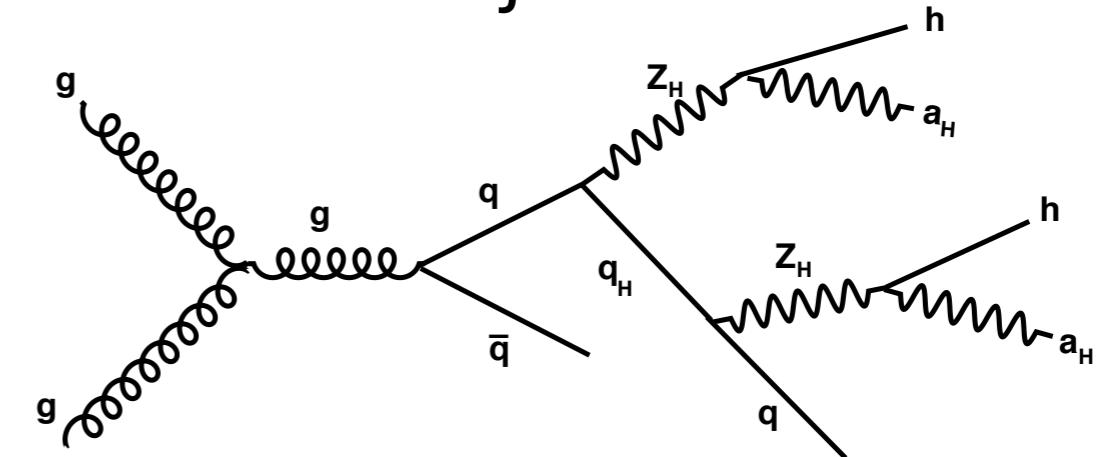
$$h \rightarrow b\bar{b}$$

$$h \rightarrow \tau^+ \tau^-$$

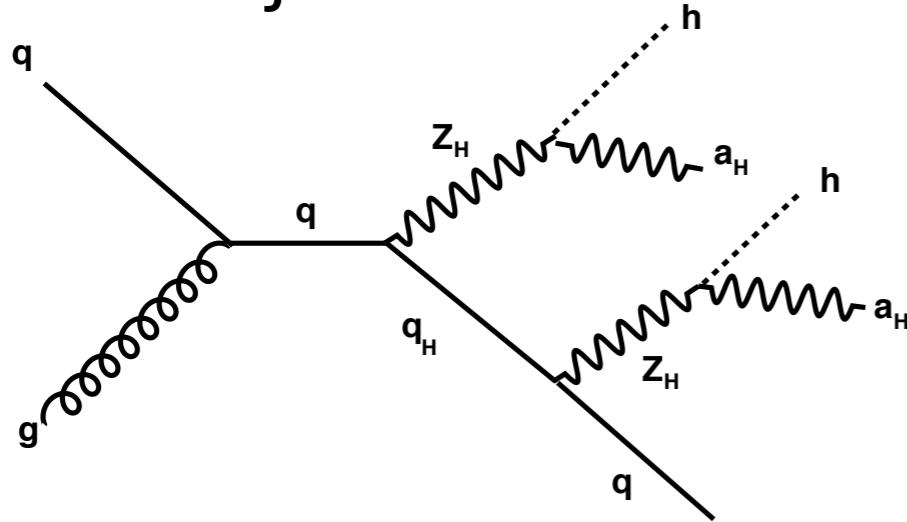
0 jet



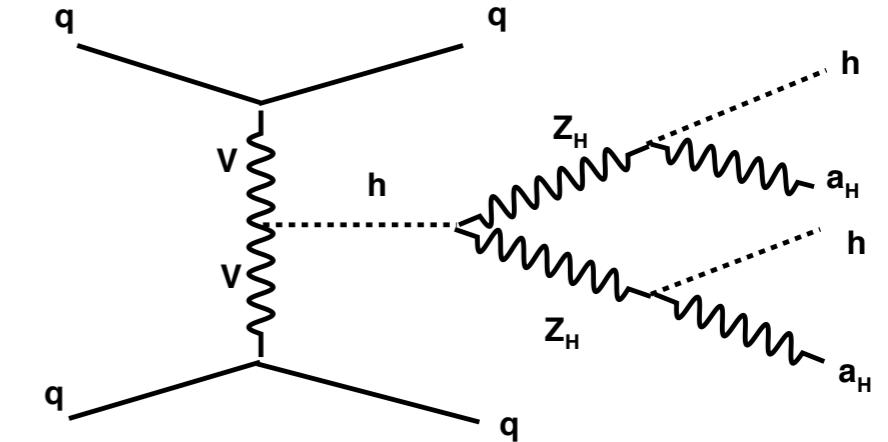
2 jet



1 jet

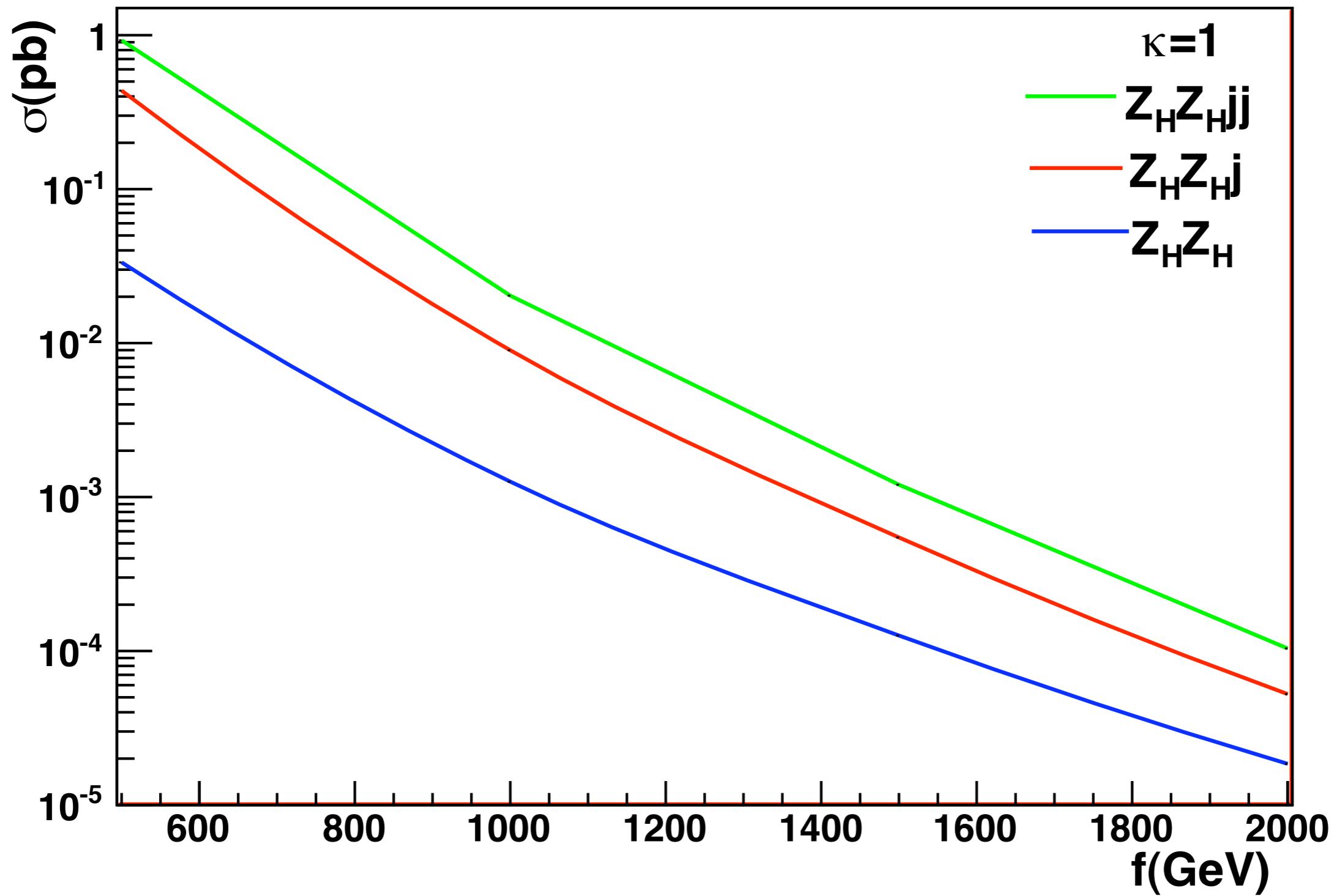


2 jet, VBF



Results

$pp \rightarrow Z_H Z_H$
 $pp \rightarrow Z_H Z_H j$
 $pp \rightarrow Z_H Z_H jj$ @LHC-14 TeV



Results $p p \rightarrow Z_H \ Z_H \ nj \rightarrow 2h \ 2A_H \ nj \rightarrow b \bar{b} \ b \bar{b} E_T \ nj$

Decay BR:

$$BR(Z_H \rightarrow h \ A_H) \sim 100 \%$$

$$BR(h \rightarrow b\bar{b}) = 57.8\%$$

Additional Cuts :

$$pt_{b,j} > 30 GeV$$

$$|\eta_{b,j}| < 4.5$$

$$\Delta R_{bb,jj} > 0.4$$

$$E_T > 100 GeV$$

b-tag efficiency : $\epsilon_b = 70\%$

Basic Cuts:

$$pt_j > 20 GeV$$

$$|\eta_j| < 5$$

$$\Delta R_{jj} > 0.4$$

signal for f=1TeV, K=1 @LHC-14

| process | cross section (fb) | |
|---------|--------------------|-----------------|
| | Basic Cuts | Additional Cuts |
| n=0 | 0.3066 | 0.175 |
| n=1 | 1.659 | 0.932 |

LHT signal event are generated by **Madgraph5** and will pass to pythia and PGS for detector simulation in the future.
And Consider for : $H \ H \rightarrow b \bar{b} \ \tau^+ \ \tau^-$

J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer and T. Stelzer, MadGraph 5 : Going Beyond, JHEP 1106, 128 (2011) [arXiv:1106.0522 [hep-ph]]

Conclusion

- The Higgs-boson pair production cross section in the SM is about 1 fb
- at the LHC-14. If we observed large Higgs-pair production, it would indicate some new physics.
- The Little Higgs model with T-parity is one of the well-motivated new physics models that can give a large enhancement to Higgs-boson pair production via ZH ZH pair production with $Z_H \rightarrow H_A H$ decay.
- We show that using the $H H \rightarrow 4b$, one can discriminate this model.

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Thanks!