ZHAOFENG KANG, KIAS,02/06/2015

NEW PHYSICS OPPORTUNITIES IN BOOSTED DI-HIGGS+MET

16th LHC Physics Monthly Meeting, KIAS

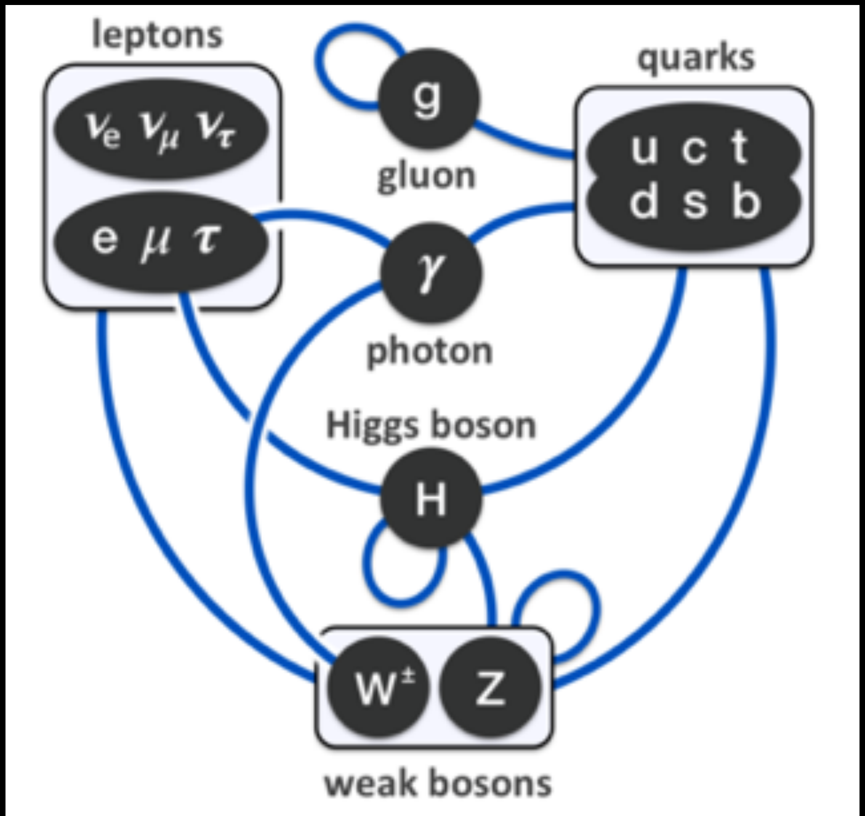
Based on 1504.04128, Z.K, P. Ko (KIAS), and **Jinmian Li (Adelaide)**

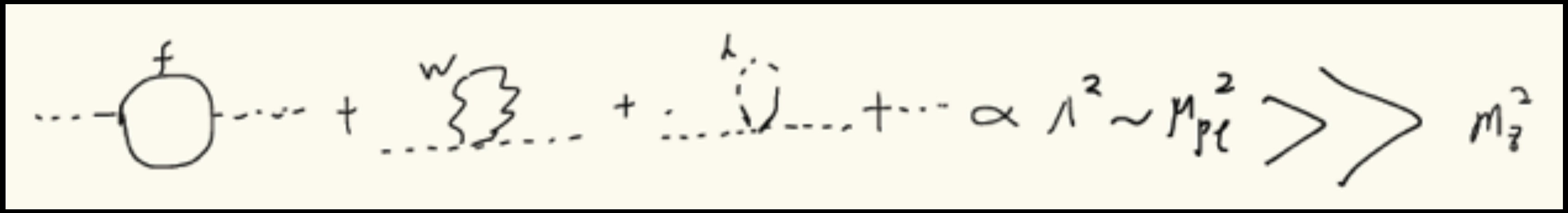
OUTLINE

- Higgs within&beyond SM
- Boosted di-Higgs+MET
- Back to models
- Conclusions

HIGGS WITHIN&BEYOND SM

- Higgs: A key role for electroweak unification
- Higgs: The mass source for all the SM members except for the three neutrinos (but still related to it).
- Higgs: A trouble maker, making the gauge hierarchy problem





HIGGS WITHIN&BEYOND SM

- Higgs: A window to a new world?

The hierarchy problem should be addressed, e.g., by SUSY and compositeness

The massive neutrinos should be addressed, e.g., by the seesaw mechanisms type-X

Dark matter (DM) should be incorporated. Likewise, it may also gain mass from the Higgs field?

If matter asymmetry is due to baryogensis, strongly first order of electroweak phase transition requires new coupling to Higgs

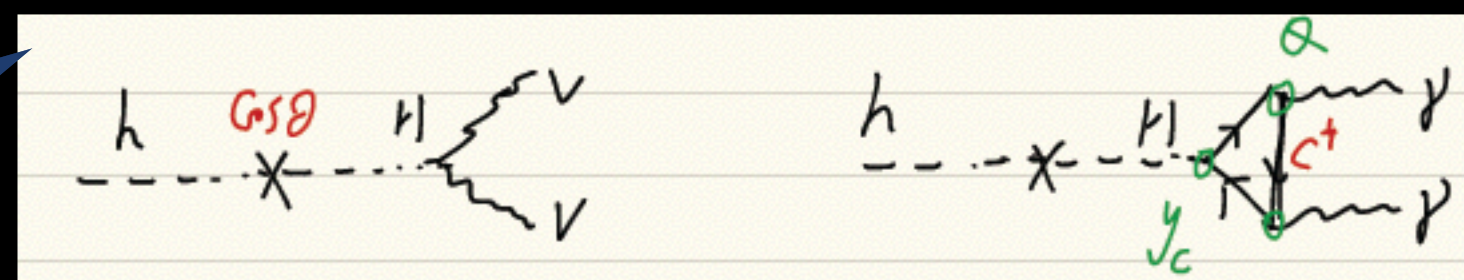
All in all, almost all new physics may be closely related to Higgs

HIGGS WITHIN&BEYOND SM

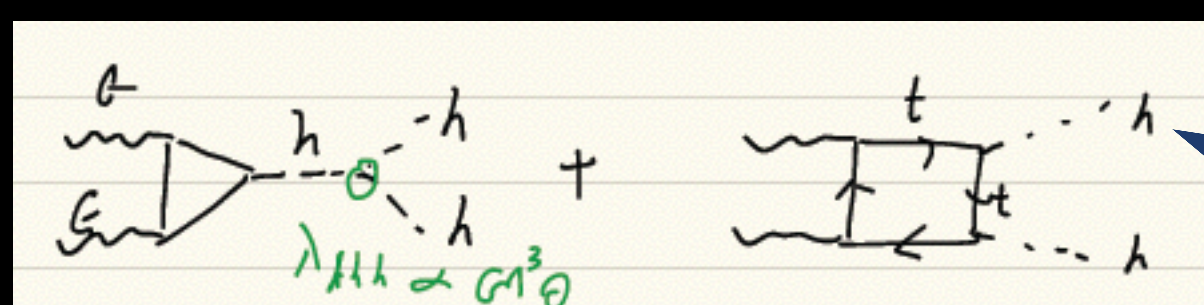
- After the discovery of Higgs: what is the next?

Precise measurements on the Higgs couplings like *hVV* and *hff*: sensitive to Higgs mixing; $h\gamma\gamma$: sensitive to charged particles

The precision can reach the 10% level in some channels



Probe di-Higgs so as to check the Higgs potential, i.e., the Higgs self-coupling $\lambda_{hhh}hhh$ with $\lambda_{hhh} = (3m_h^2 / v \text{ in SM})$



They do have cancelation, resulting in smaller cross-section, and can be probed only at the end of LHC

HIGGS WITHIN&BEYOND SM

- Boosted di-Higgs

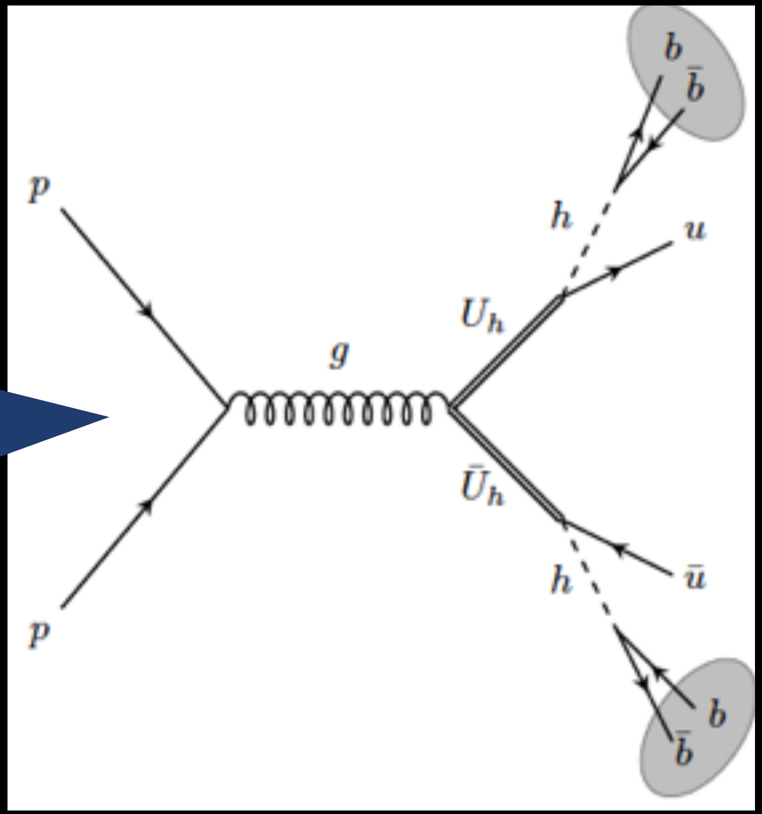
D.~E.~Ferreira de Lima, A.~Papaefstathiou and M.~Spannowsky, JHEP 1408 (2014) 030.

A crucial improvement to measure the Higgs self-coupling:

1. Usually, the pure hadronic 4b channel, despite of the dominant channel, has too large QCD backgrounds and thus is thought to be undetectable;
2. However, the boosted di-Higgs can help much to suppress BG and enhance sensitivity, making it detectable;
3. Combined with other channels it is shown that one can exclude $\lambda_{hhh}<1.2\ \lambda_{hhh,SM}$ at 95%. Then small new physics effect can be probed.

Besides, it can be used to probe heavy resonance which has decay $q\bar{q}(GG) \to S \to hh$;

Or accompanied with more jets from the composite Higgs model



M.~Backović, T.~Flacke, J.~H.~Kim and S.~J.~Lee, arXiv:1410.8131.

BOOSTED DI-HIGGS+MET

- Why this signature?

  At the one hand, searches for boosted 2*h* will be done; On the other hand, MET (dark matter or neutrinos) is well expected with 2*h* in new physics (later). So we propose this incidental (cheap?) signature.

- The simplified models for signatures

  If DM χ_1 (S_1) services as MET, the dark sector should contain the much heavier states other than DM——— $\lambda_f h\chi_1\chi_2, \quad \mu_s h S_1 S_2,$

  If neutrino services as MET, one expects the presence of right-handed neutrino (RHN)-like states with $\lambda_\nu h N \nu_L,$

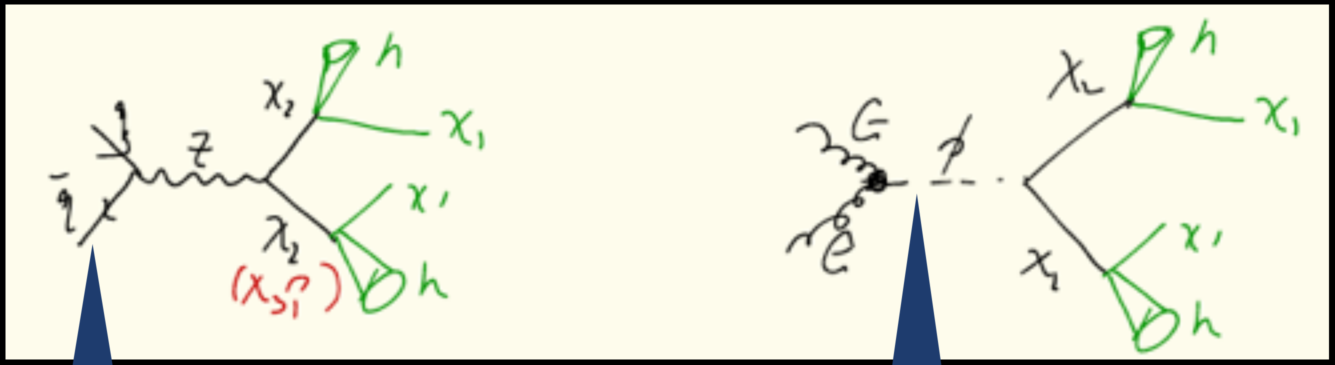
BOOSTED DI-HIGGS+MET

- More on the simplified models

1) In a concrete model there are probably more relevant dark states

2) The cross section of signature depends on the production and the decay branching ratio of the heavier states

3) We always work in the pair production of χ_2 (S_2) and two typical ways are available:



Drell-Yan process: the heavier dark states are expected to carry $SU(2)_L$ charge; Z may be Z′ and then quite large production rate is possible

Gluon-gluon-fusion: the heavier dark states Yukawa couple to a scalar which mixes with the SM-like Higgs boson. This mechanism benefits in resonant enhancement

BOOSTED DI-HIGGS+MET

- Backgrounds (BGs)

The main BGs are QCD 4*b*, *Zbb** (irreducible) and *tt** (reducible)

In them MET is due to detector resolution or the mismeasurement of the jet transverse momentum. Roughly, Gaussian distribution with standard deviation $0.5(\sum P_{i,T})^{1/2}$ GeV

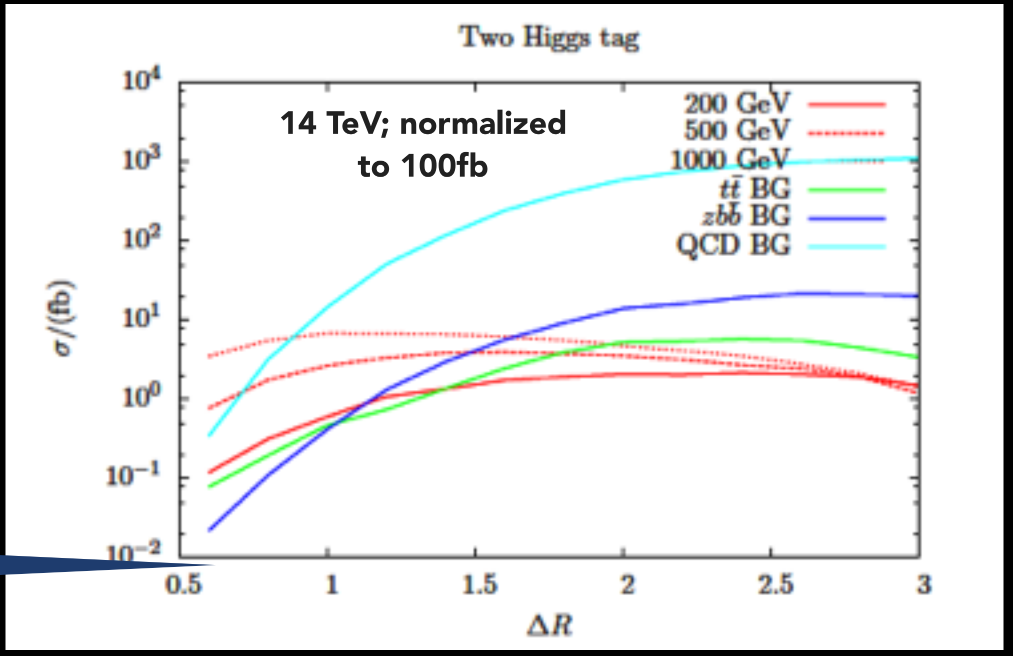
	semi-leptonic $t\bar{t}$	QCD	$Zb\bar{b}$
σ/fb	382000	861000	10904

Semileptonic mode with one lepton missed or misidentified as a jet; b-jets may from mis-tagged light flavor jets

- The power of (only) di-Higgs-tagging with efficiency ~20%

For a relatively heavy mother particle (≳500 GeV), all BGs can be suppressed except for the QCD BG.

The fat jet cone size ΔR and the Higgs mass cuts should be optimized



BOOSTED DI-HIGGS+MET

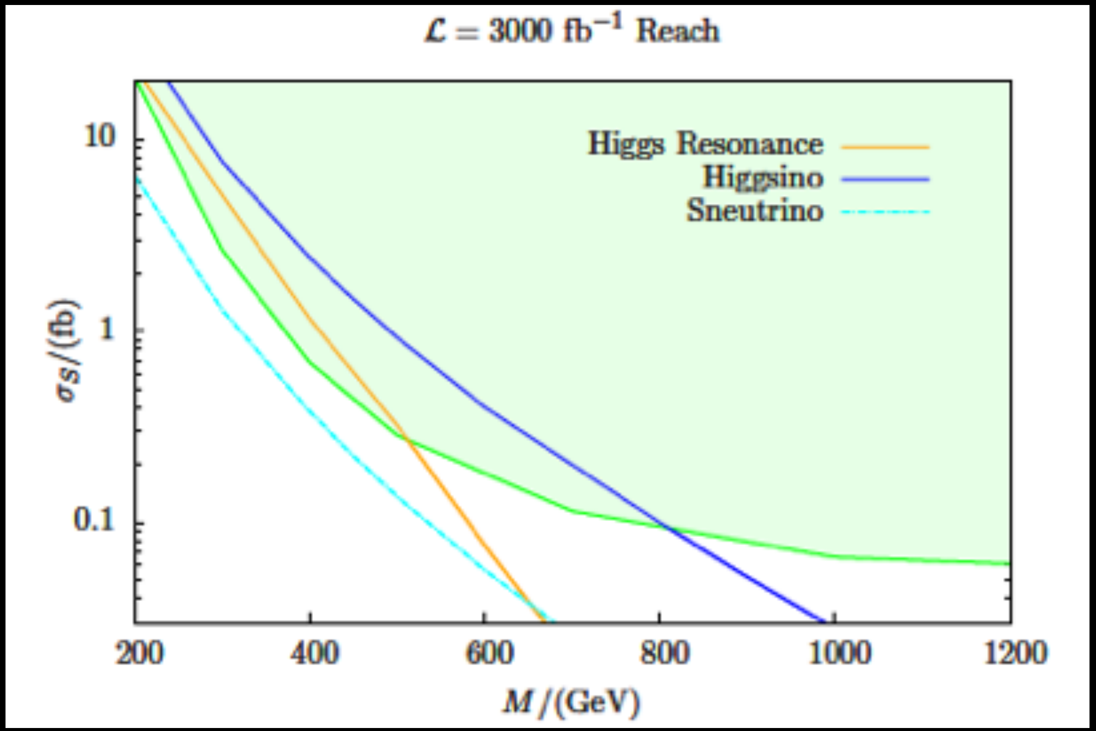
- Handle the QCD BGs via

  A large MET (the missed particle is assumed to be massless)

  MT2 (pair production), reflecting mass of the mother particle

- The limit of boosted di-Higgs+MET

  Probably, it gives the LHC limit of probing the new physic effect involving Higgs boson(s): It can reach new physics with cross section as low as 0.1 fb!



BACK TO MODELS

- In the dynamical type-I seesaw mechanism

In type-I seesaw RHNs are singlets and thus their productions rely on the active-sterile neutrino mixings which generically are very small

But RHNs may have non-trivial gauge or/and Yukawa dynamics like

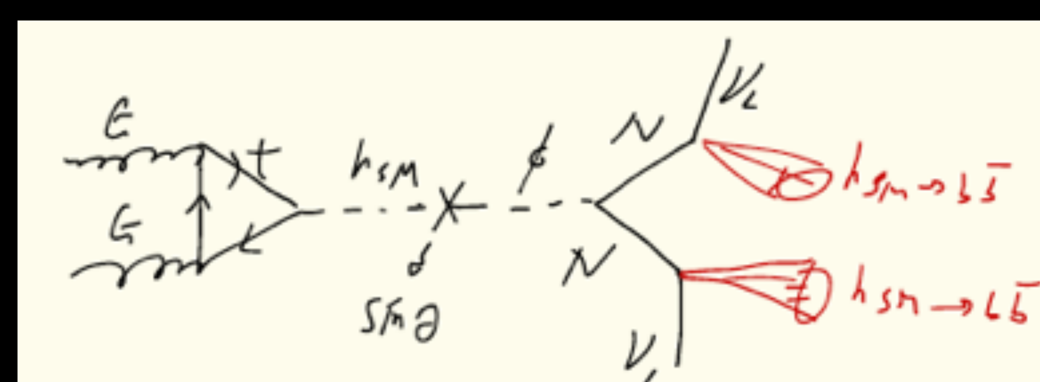
$$-\mathcal{L} = V(H,\Phi) + \left(\frac{1}{2}\lambda_{N,i}\Phi\bar{N}_i^c N_i + Y_{N,ij}\bar{\ell}H^\dagger N + h.c.\right) + \mathcal{L}_{\rm SM}$$

1. $\langle\Phi\rangle$~TeV for Majorana mass; A TeV scale Φ may mix with h_{SM} sizably, so NN pair is resonantly produced $GG\rightarrow\Phi\rightarrow NN$
2. In the local B-L models, LHC di-lepton resonance search $qq\rightarrow Z_{B-L}\rightarrow e^+e^-$ strongly constrains on $qq\rightarrow Z_{B-L}\rightarrow NN$.

Heavy RHN decay branching ratios are

$$\Gamma(\nu_h \to \nu_l h_{\rm SM}) \approx \Gamma(\nu_h \to \nu_l Z) = \frac{1}{4}\Gamma(\nu_h \to \ell W)$$

The Goldstone equilibrium theorem underlies the relationship, and we have $Br(N\rightarrow h_{SM}\,\nu_l)=1/6$.



BACK TO MODELS

- In the neutralino system in Bino-Higgsino limit

SUSY, with rich dark states, is a factory for our signature:

In this limit, Higgsinos constitute a pseudo Dirac particle with almost degenerate masses $\chi_2 \simeq \chi_3$; While χ_1 is a Bino-like LSP

Bino can be replaced by the singlino in the NMSSM

Equilibrium theorem works again in a manner of

$$\Gamma(\chi_2 \to h + \tilde{\chi}_1) = \Gamma(\chi_3 \to Z + \tilde{\chi}_1),$$
$$\Gamma(\chi_2 \to Z + \tilde{\chi}_1) = \Gamma(\chi_3 \to h + \tilde{\chi}_1).$$

Note that the pair production is (χ_2, χ_3) because the diagonal coupling to Z is suppressed; Consequently, Br($\chi_2 \to h\chi_1$)=Br($\chi_2 \to Z\chi_1$)=50% is favored

BACK TO MODELS

- Other examples in SUSY

Sneutrino system in the low scale supersymmetric seesaw where the RHN partner is the LSP and left-handed sneutrino is the decaying one $A_N \tilde{L} H_u \tilde{N} + c.c.$ that gives rise to decay $\tilde{\nu}_L \to h_{SM} + \tilde{N}$

Similar process can also be realized in the scalar dark matter models like doublet+singlet; triplet+singlet and so on…

NMSSM in a different scenario: A heavy singlino & light Higgsino $\lambda S H_u H_d$ gives rise to decay $\tilde{S} \to h_{SM} \tilde{H}_d^0$

Low scale SUSY-breaking: Higgsino-gravitino system $\tilde{H}_u^0 \to h_{SM} + \tilde{G}$

An unconventional scenario: the stop system with a stealthy stop but $\tilde{t}_2 \to \tilde{t}_1 h_{SM}$ with the lightest stop behaving as missing energy

BACK TO MODELS

1409.1338, Chen Liang-Wen, Zhang Ren-You, Ma Wen-Gan, Li Wei-Hua, Duan Peng-Fei and Guo Lei

- Last but not the least: little Higgs SU(5)/SO(5) with T-parity

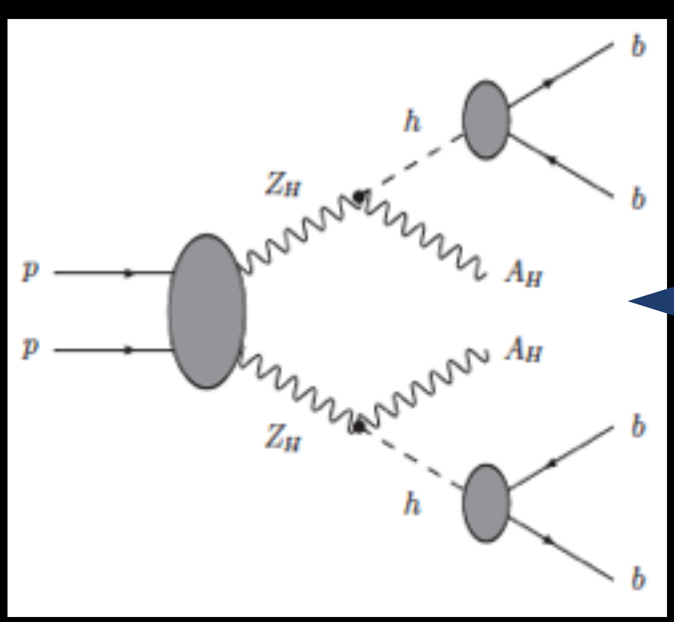
T-parity swamping two sets of gauge bosons

Gauging $G(2121)=[SU(2)\otimes U(1)]_1\otimes[SU(2)\otimes U(1)]_2\subset SU(5)$

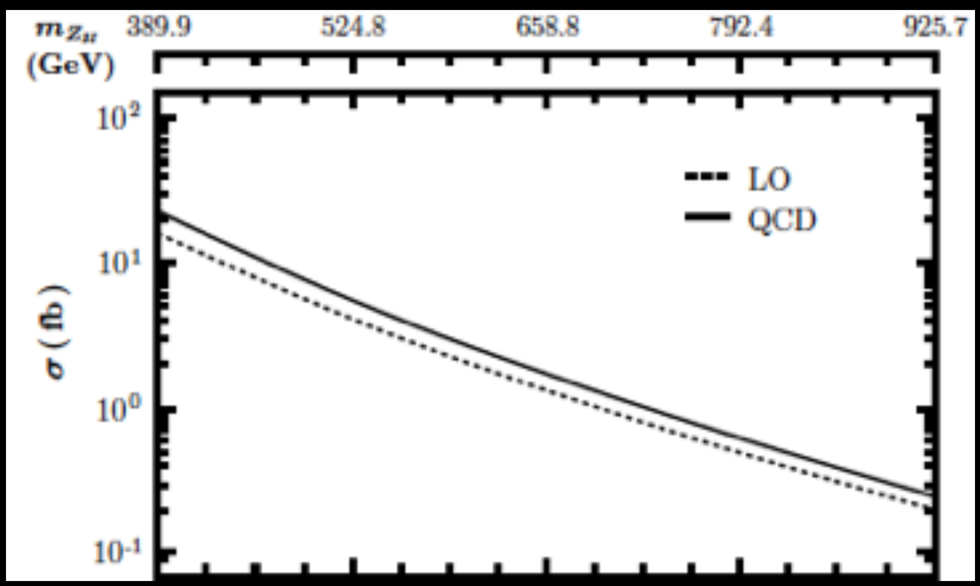
A nonlinear sigma field of SU(5)→SO(5) leads to G(2121)→SU(2)⊗U(1), leaving heavy T-odd gauge bosons W_H&Z_H&A_H (assumed to be DM)

$$m_{A_H} = \frac{1}{\sqrt{5}} g' f \left(1 - \frac{5}{8}\frac{v^2}{f^2}\right), \quad m_{Z_H} = m_{W_H} = gf\left(1 - \frac{1}{8}\frac{v^2}{f^2}\right)$$

Introduce T-odd mirror fermions with mass around the scale f



These fermions couple to Z_H and light quarks with almost full weak strength. T-channel exchanging give rise to….



CONCLUSIONS

- If the experimentalists are going to probe the boosted di-Higgs boson in the 4b channel, please add one more simple cut: MET

- This signature is well expected in new physics where MET may be a neutrino and dark matter. In particular, it may offer the unique chance to probe seesaw

- The discovery limit can be as low as 0.1 fb at the end of LHC, corresponding to RHN and Higgsinos about 0.5 and 1 TeV, respectively.

Thanks!