Theory Studies in China
--- status report of theory working group

朱守华（Shou-hua Zhu）
北京大学（Peking University）
2013/12

Physics at Circular Electron-Positron Collider (CEPC) and Super Proton-Proton Collider (SPPC)

Shou-Shan Bao,[a] Xiao-jun Bi,[b] Jun-Jie Cao,[c] Qing-hong Cao,[d,e] Ning Chen,[f] Bo Feng,[g] Lei Guo,[h] Hong-Jian He (convenor),[f] Chong Sheng Li,[d,e] Hong-Lei Li,[i] Tianjun Li,[j] Ying Li,[k] Zhao Li,[b] Wei Liao,[l] Yi Liao,[m] Chun Liu[j] Ji-Yuan Liu,[n] Tao Liu,[o] Cai-dian Lu,[b] Ming-xin Luo,[g] Wen-gan Ma,[h] Cong-Feng Qiao,[p] Hua-sheng Shao,[d] Jing Shu,[j] Zong-Guo Si,[a] Jian-Xiong Wang,[b] Kai Wang,[g] Xiao-Hong Wu,[l] Qi-shu Yan,[p] Jinmin Yang,[j] Li-lin Yang,[d,e] Shuo Yang,[q] Peng-fei Yin,[b] Ren-you Zhang,[h] Xin-min Zhang,[b] Yu-Feng Zhou,[j] Guo-huai Zhu,[g] Shou-hua Zhu (convenor),[d,e] more authors to be added[xxx]

37 authors and 185pages, all figures in this talk are from the report

Contents

- Where are we?
- Report of 6 theory working groups

    (1) Higgs physics

    (2) SM tests

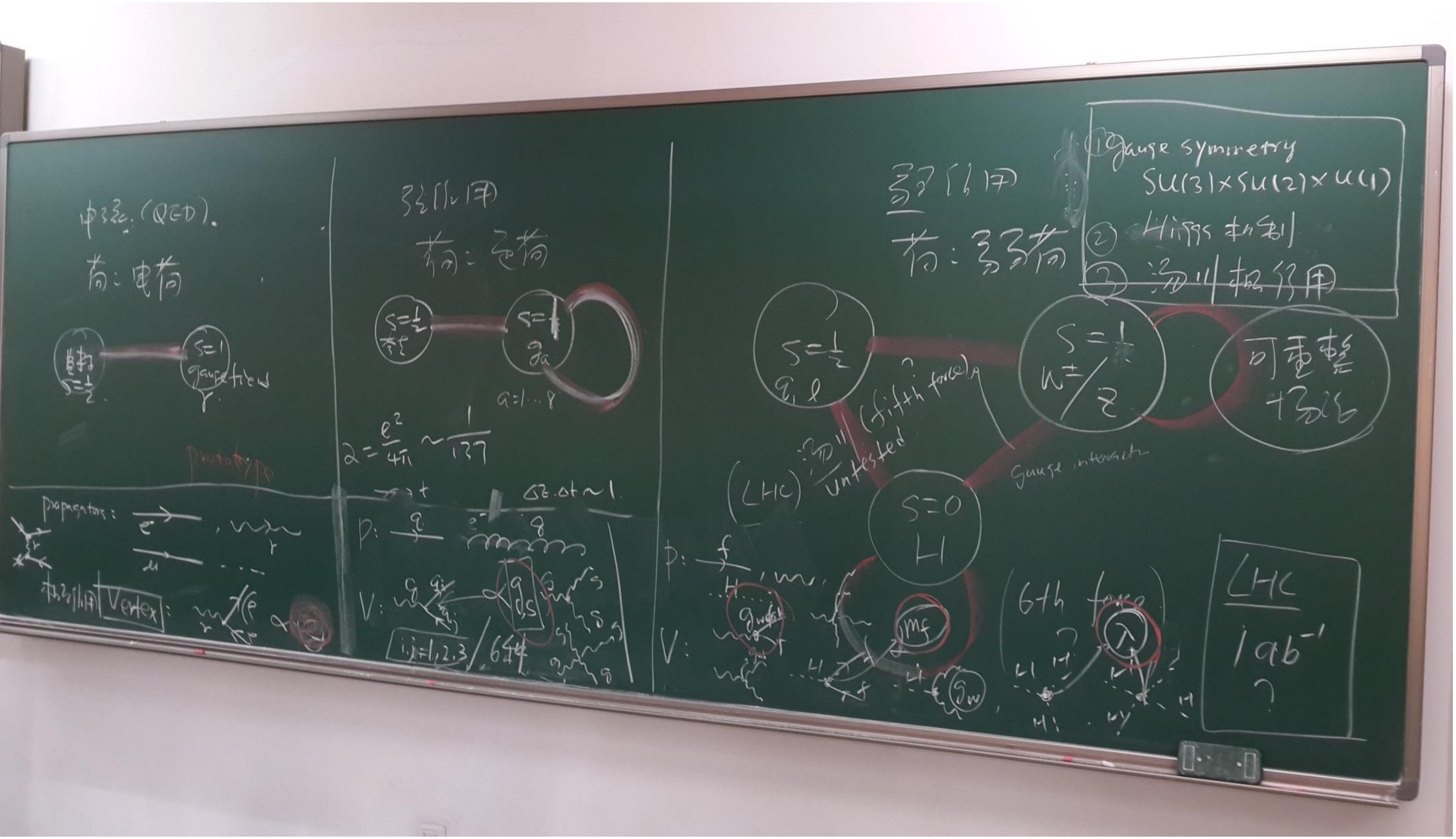
    (3) BSM: Supersymmetry (SUSY)

    (4) BSM: Non-SUSY (Composite Higgs, Neutrino-motivated models, Extra dimension…..)

    (5) Flavor physics

    (6) TeV Scale Cosmology
- Conclusion/Discussion

Where are we?



(QED)
gauge field
prototype
propagators:
Vertex
gauge symmetry
SU(3)×SU(2)×U(1)
Higgs
(fifth force)
untested
gauge interaction
(LHC)
S=0
H
6th force
LHC
1ab⁻¹

Clear Physics goal for CEPC/SPPC

- Is the X(125) the SM Higgs boson, by measuring its properties, mass/spin/CP nature/couplings with fermions/gauge bosons/itself…?
- Is there new physics, by discovering deviations from SM prediction/new decay modes of X(125)/new particles….?

Where are we (theory organization)

- 2012/11/7, the theory working group formed
- 2012/12/20, first group meeting at Tsinghua U
- 2013/8/25, small scale meeting at Dalian (TeV working group workshop)
- 2013/9/14, Kick-off meeting, adding “flavor” and “TeV cosmology” working groups
- 2013/11, second group meeting at Peking U
- 2013/12/16, preliminary report

General remarks for the theory workgroups

- Everyone are welcome to join and contribute!
- New results are encouraged to be published at journals

6+1 working groups

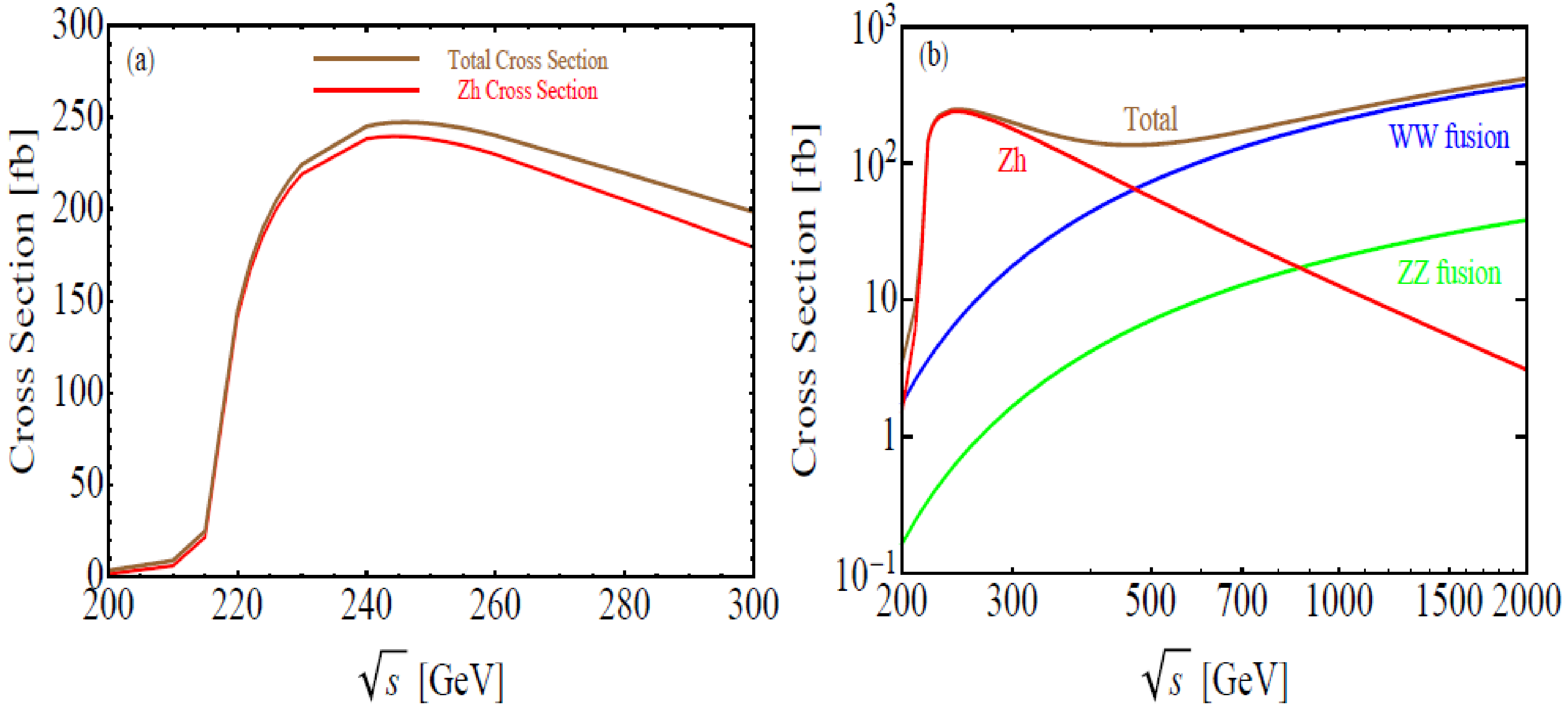
- Sm tests (conveners: Qing-hong Cao/Li-lin Yang/Zhao Li/Chong Sheng Li)
- Higgs Physics (Hong-jian He/Shou-hua Zhu)
- BSM: SUSY(Tianjun Li/Jin-min Yang)
- BSM: Non-SUSY(Qi-shu Yan/Jing Shu/Wen-Gan Ma/Li Liao)
- Flavor Physics(Cai-Dian Lu/Zong-Guo Si)
- MC tools(Qi-shu Yan)

1. Higgs physics

3 ways to probe new physics via Higgs

- probe I: precisely measuring the couplings between the SM-like Higgs boson and the SM particles, and its other properties
- probe II: searching for anomalous productions and exotic decays of the SM-like Higgs boson
- probe III: searching for nonstandard Higgs bosons predicted by new physics

SM Higgs production



Precision measurement

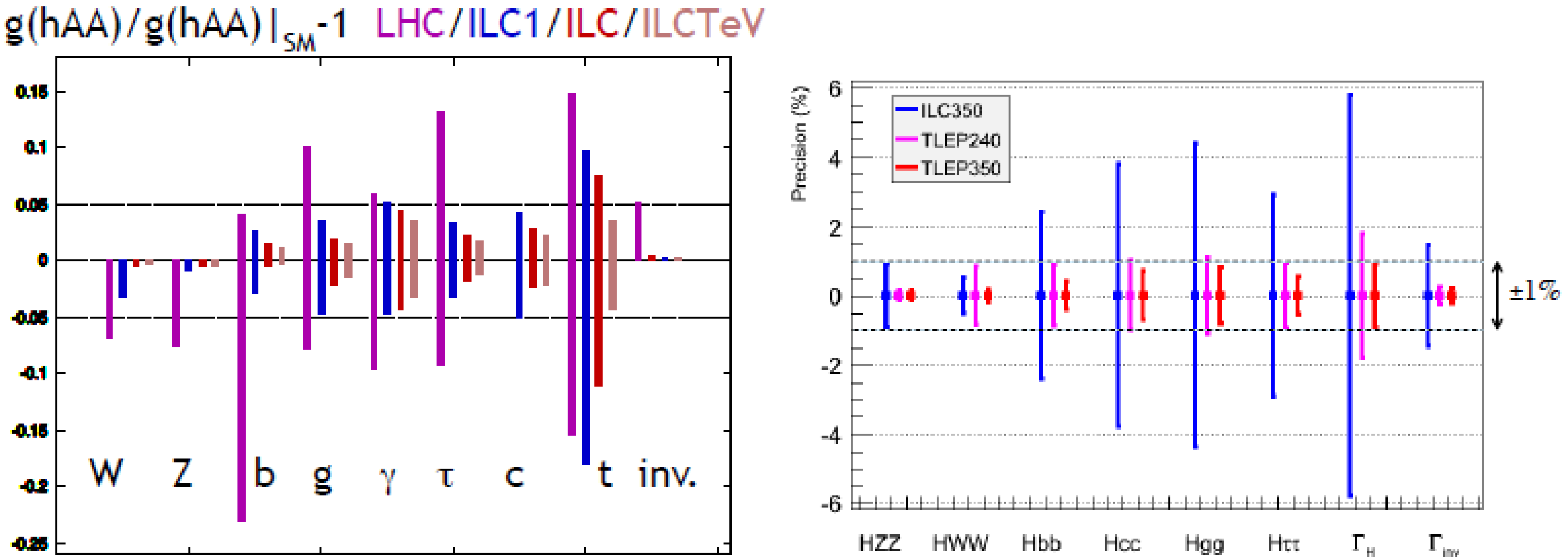


Figure 23. Left: The estimated accuracies of measuring the Higgs boson couplings between LHC and ILC experiments, with four sets of errors representing results for LHC-14 TeV (300 fb^{-1} with one detector), the ILC-250 GeV, the ILC-500 GeV, and the extension of the ILC-1 TeV. Right: The estimated accuracies of measuring the Higgs boson couplings between ILC and TLEP experiments. The dashed lines indicate the $\pm 1\,\%$ band, which are relevant for multi-TeV new physics.

From precision to underlying new physics

- Higgs Non-SM CP properties may explain the baryon asymmetry in the universe
- Yukawa couplings can help understand the mass origin of the SM fermions, and the Higgs
- Self-couplings can reveal how the electroweak (EW) symmetry gets broken.

Exotic decay

- category I: visible decays
- category II: semi-visible decays
- category III: invisible decays

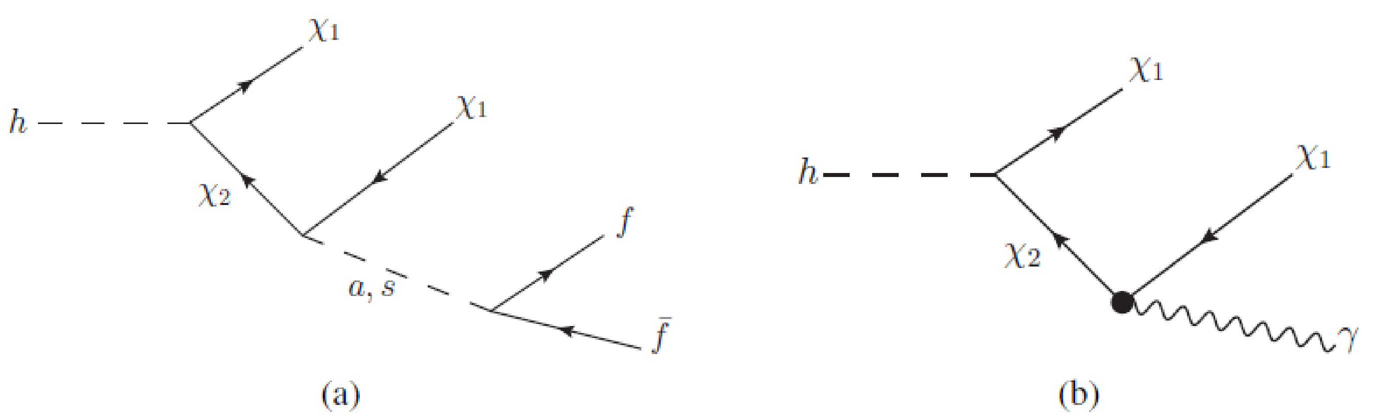
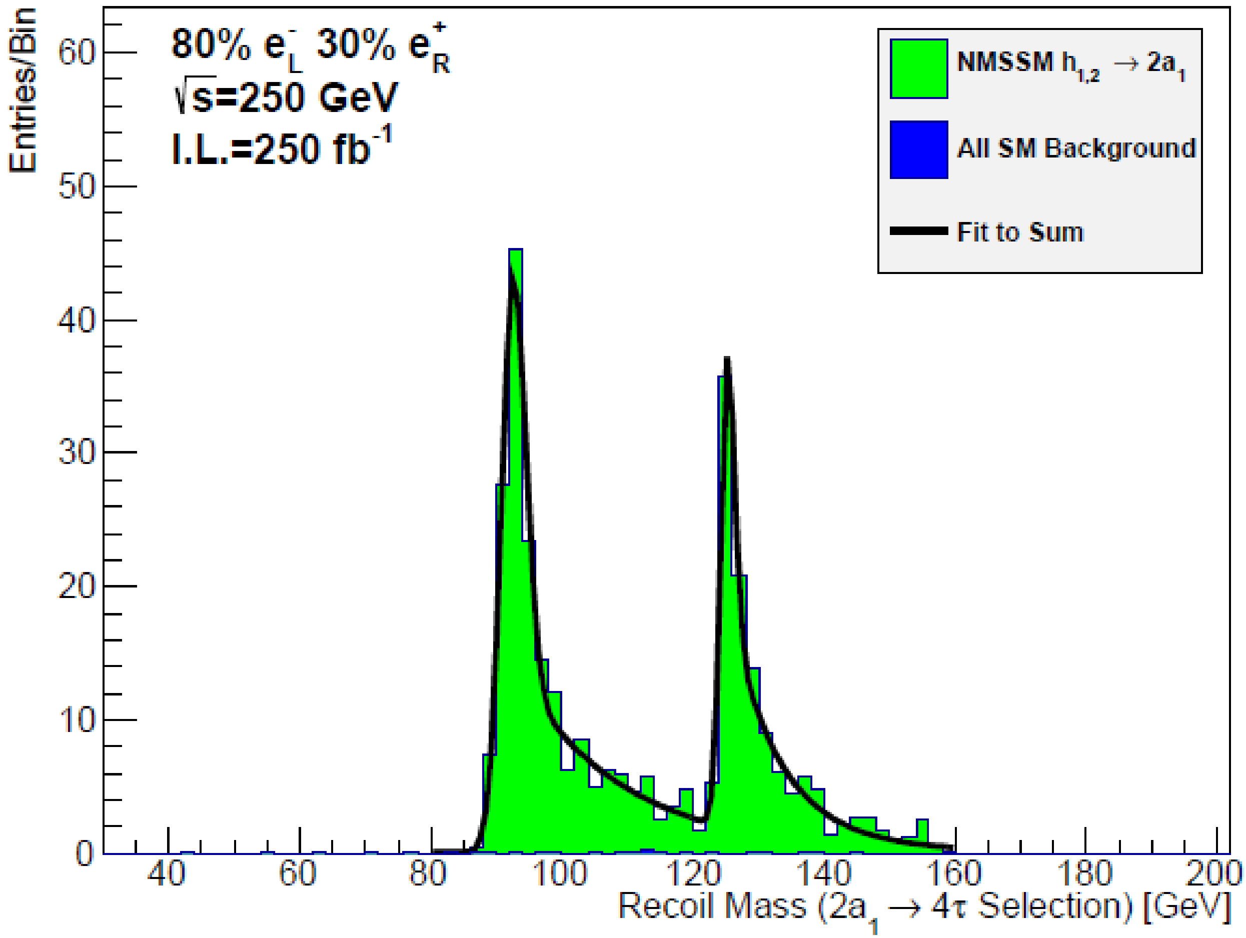


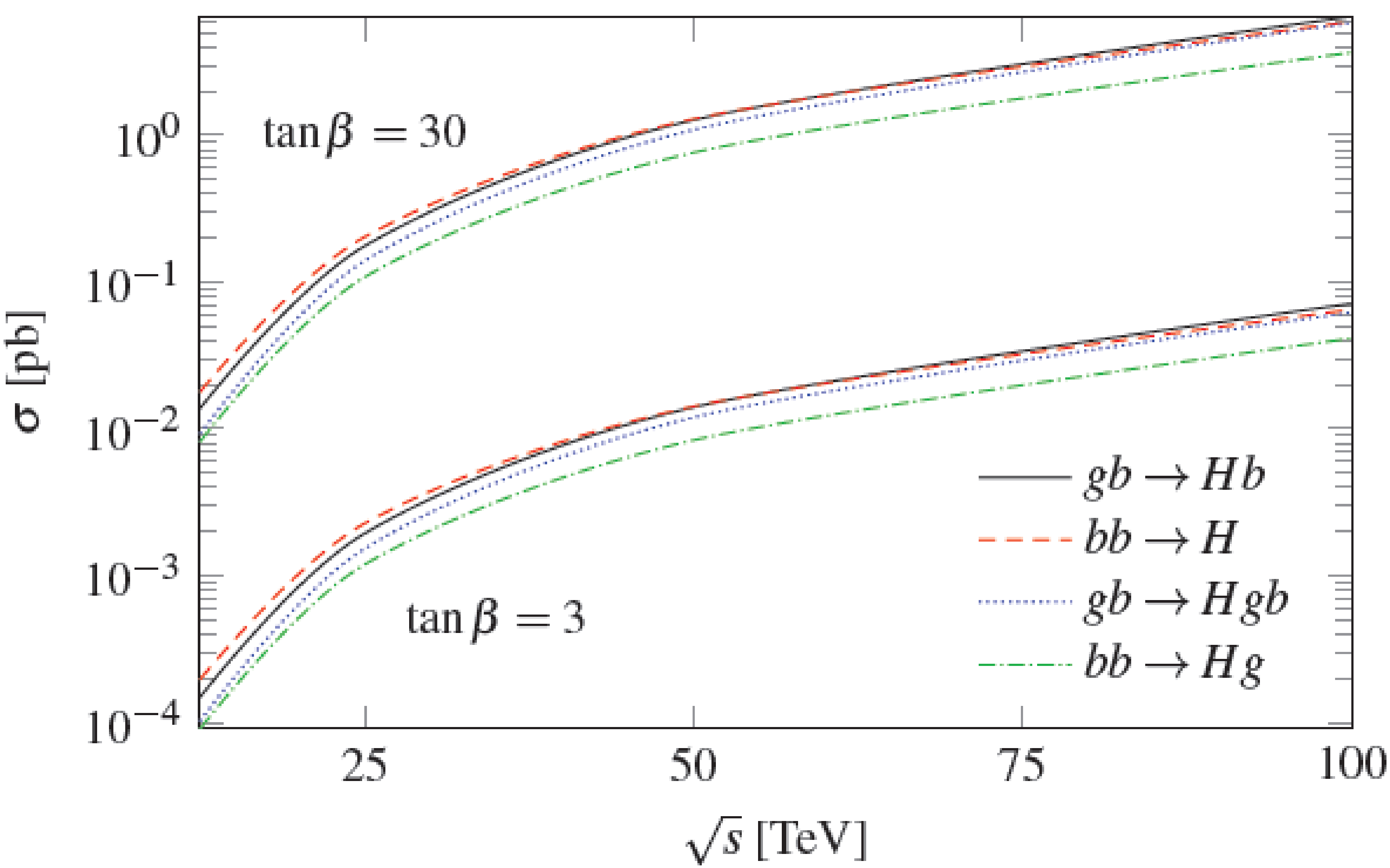
Figure 4. New decay topologies of the SM-like Higgs boson in the PQ symmetry limit with $\lambda \lesssim 0.1$. Non-negligible (b) requires $\min(m_s, m_a) > m_{\chi_2} - m_{\chi_1}$. (See [75, 76].)

Exotic visible decay

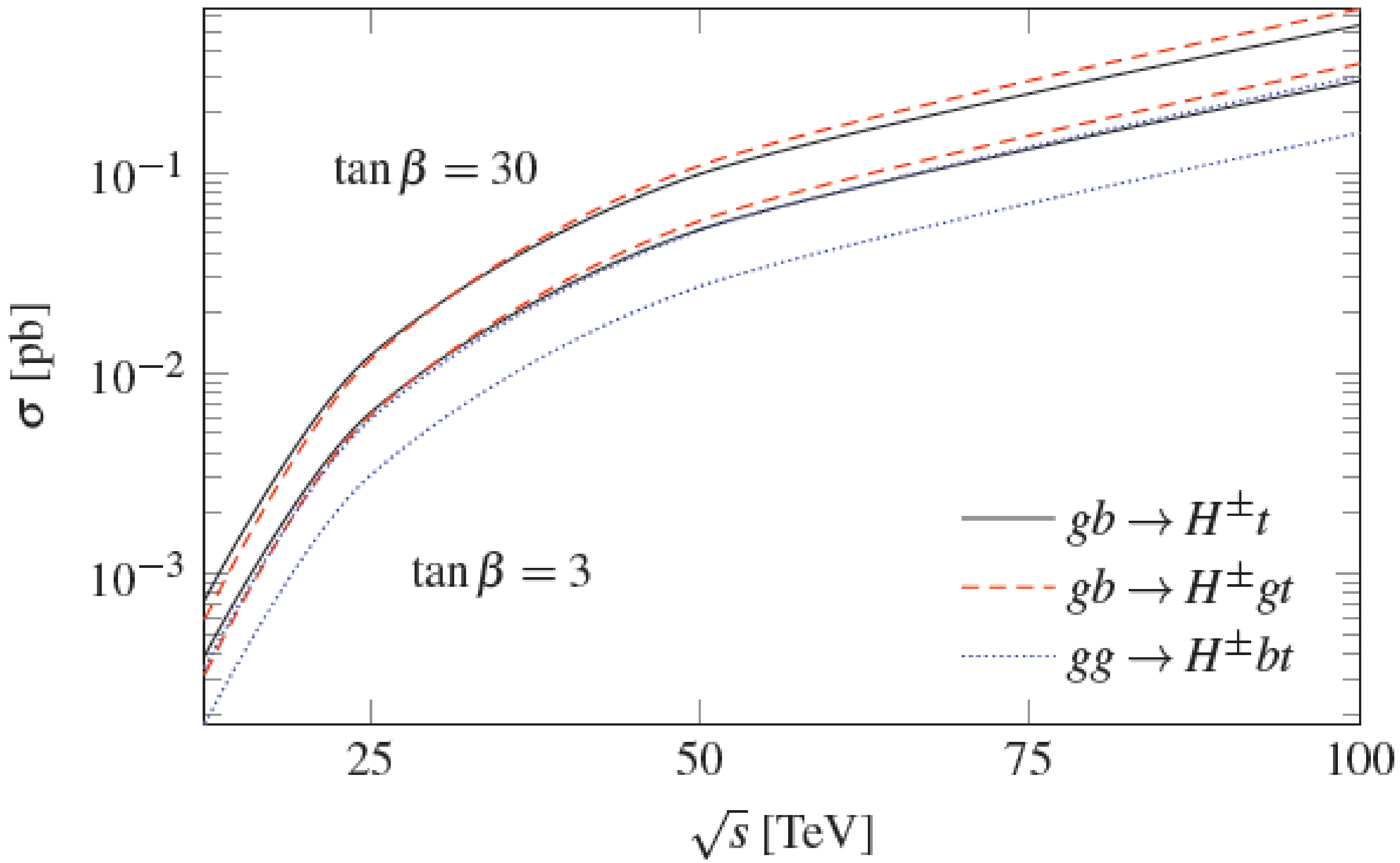


$$m^{\text{rec}} \equiv \sqrt{s - 2\sqrt{s}E_Z + m_Z^2}$$

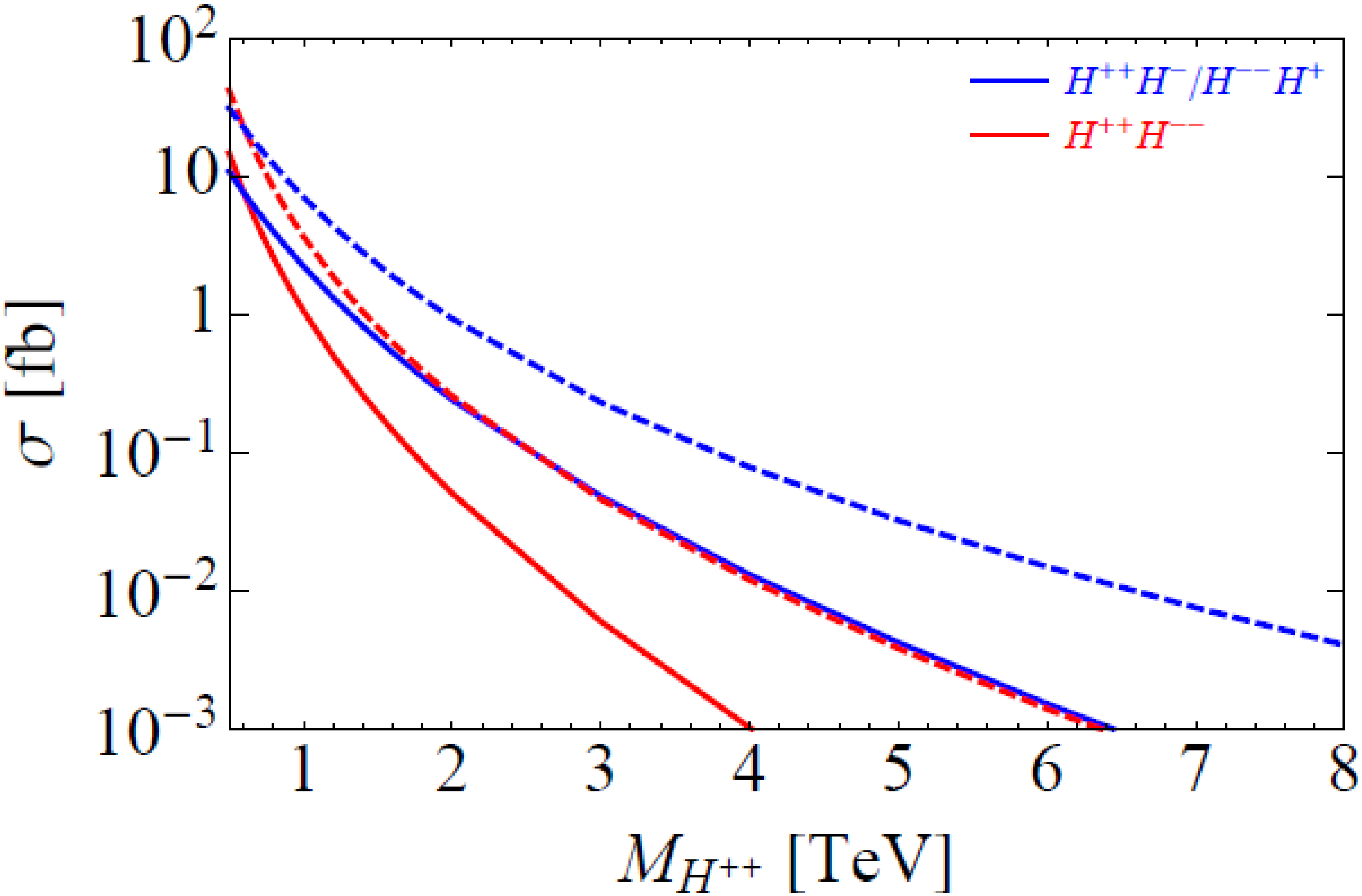
Neutral extra Higgs (1TeV)



Charged Higgs (1TeV)



Doubly charged Higgs (50 vs 100 TeV)



2. SM test

Larger PDF uncertainty at SPPC

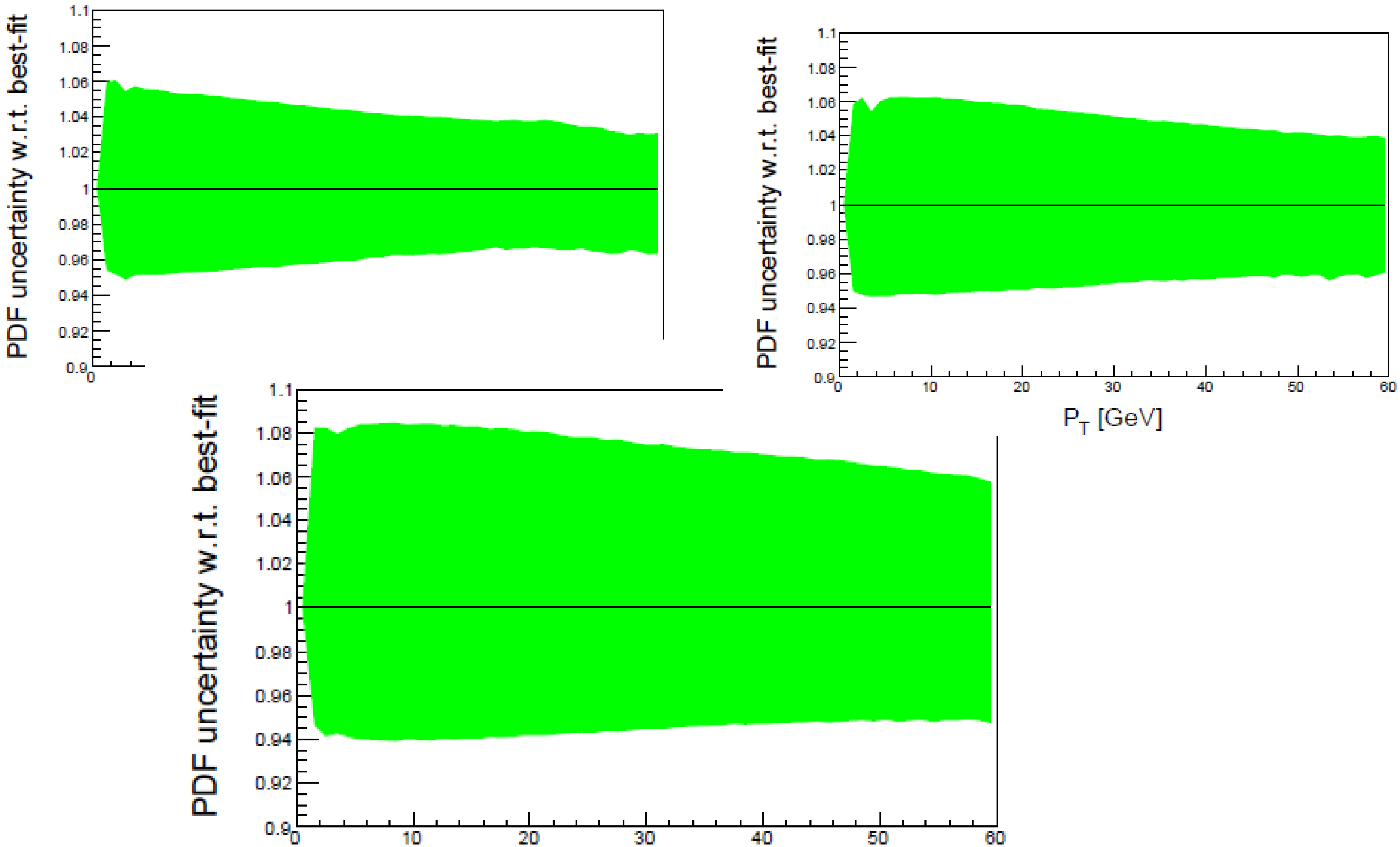
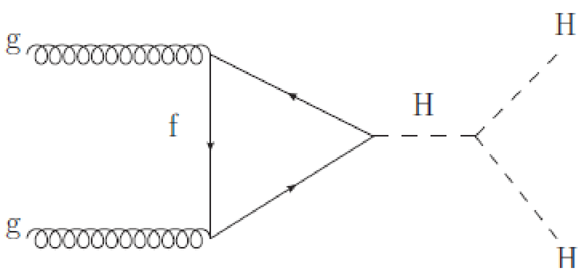


Figure 35. The transverse momentum distribution of diphoton pair at the 8 TeV LHC, 14 TeV LHC and 50 TeV SppC, respectively from top to bottom using CT10nlo PDF set.

Measuring the Higgs self-coupling using ratios of cross sections



$\sqrt{s}$ [TeV]	14	33	50	100
σ_{NLO} [fb]	33.9	208	446	1419
σ_{NNLO} [fb]	41.1	249	530	1672

$$C_{HH} = \frac{\sigma(pp \to HH)}{\sigma(pp \to H)},$$

Channel	600 fb^{-1} (2σ)	600 fb^{-1} (1σ)	3000 fb^{-1} (2σ)	3000 fb^{-1} (1σ)
$b\bar{b}\tau^+\tau^-$	$(0.22, 4.70)$	$(0.57, 1.64)$	$(0.42, 2.13)$	$(0.69, 1.40)$
$b\bar{b}W^+W^-$	$(0.04, 4.88)$	$(0.46, 1.95)$	$(0.36, 4.56)$	$(0.65, 1.46)$
$b\bar{b}\gamma\gamma$	$(-0.56, 5.48)$	$(0.09, 4.83)$	$(0.08, 4.84)$	$(0.48, 1.87)$

Table 23. The expected confidence intervals for λ at 1σ and 2σ confidence levels with $y_t = 1$.

3: BSM: Supersymmetry

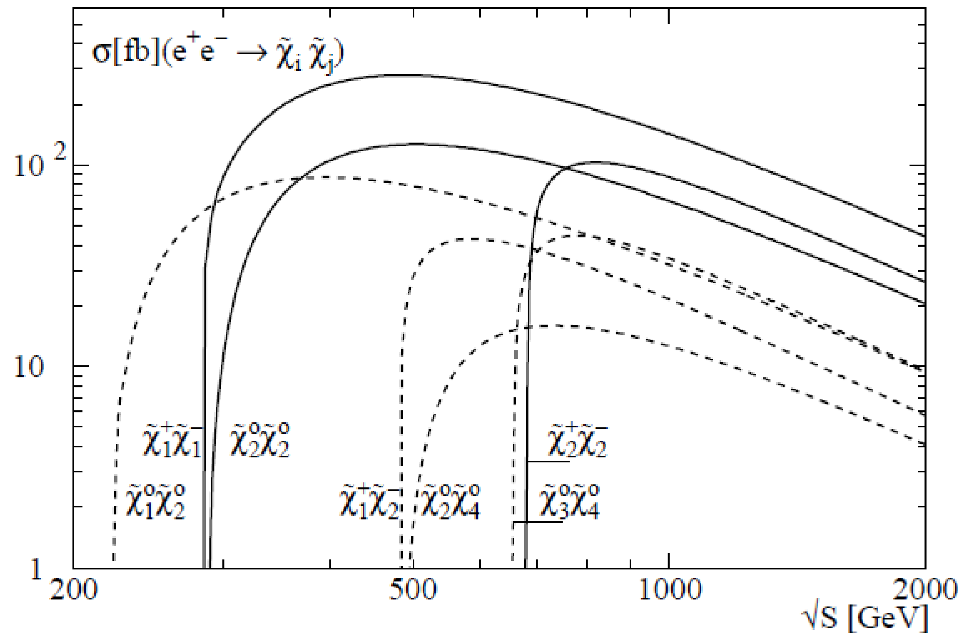
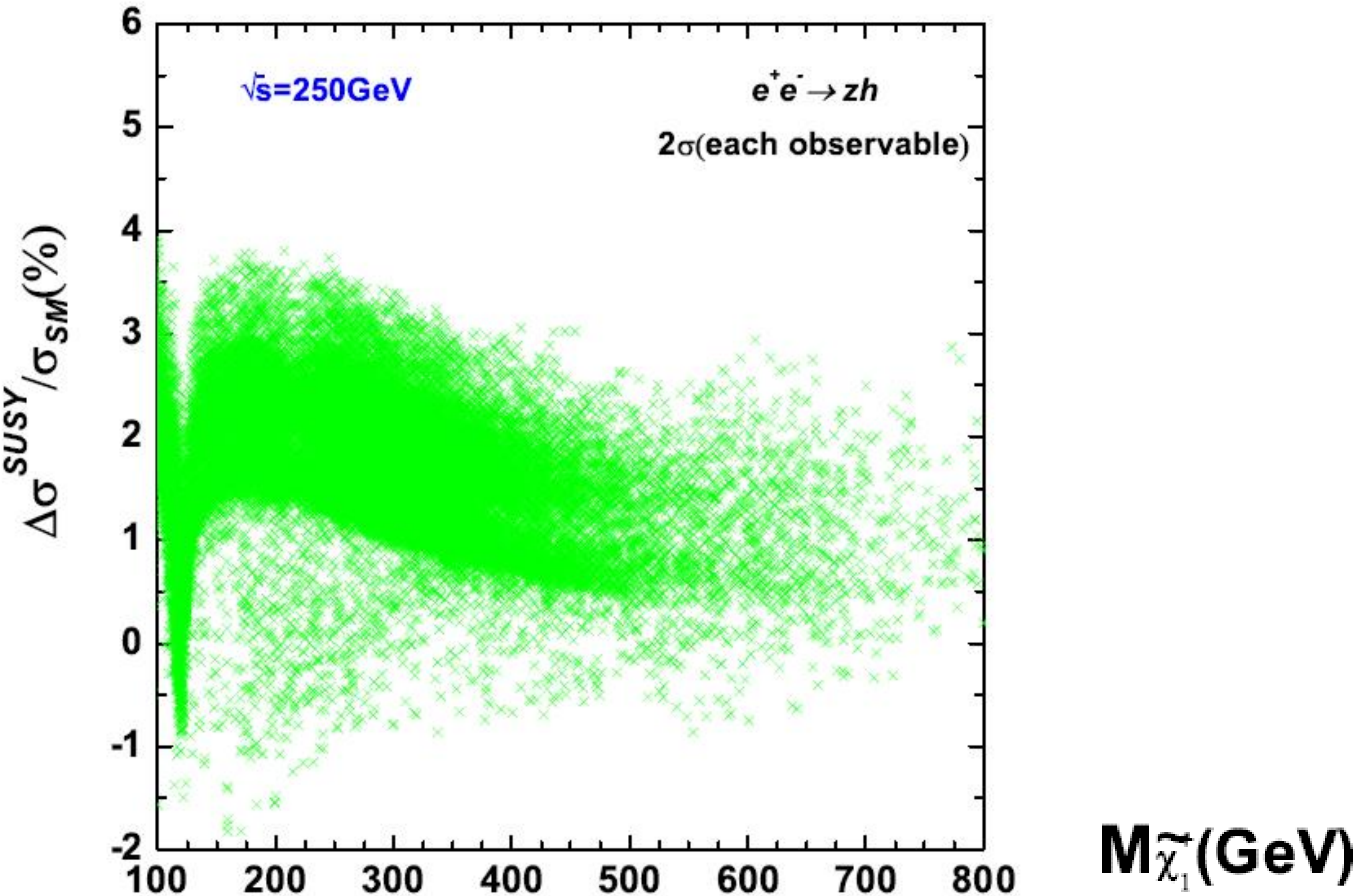
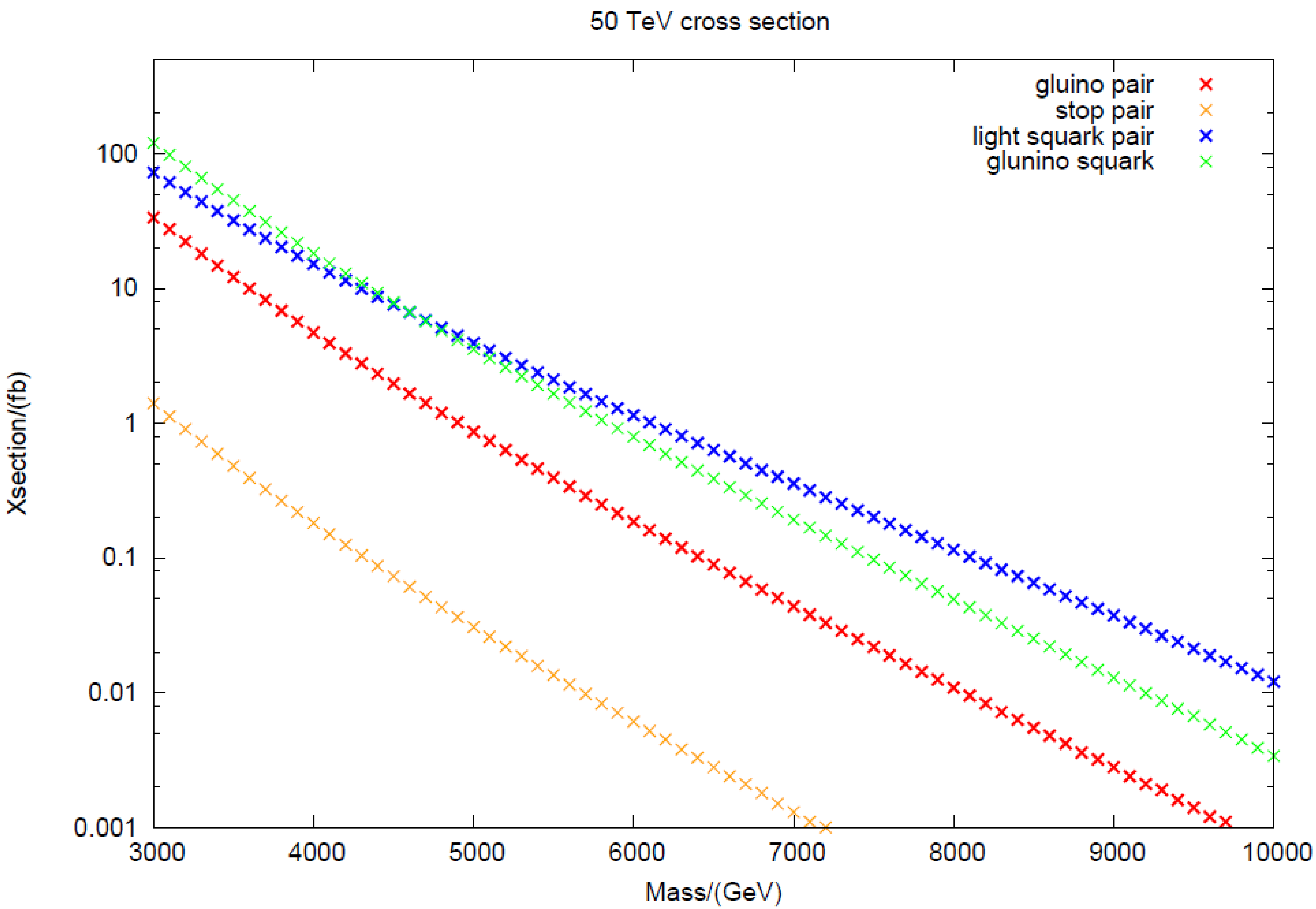
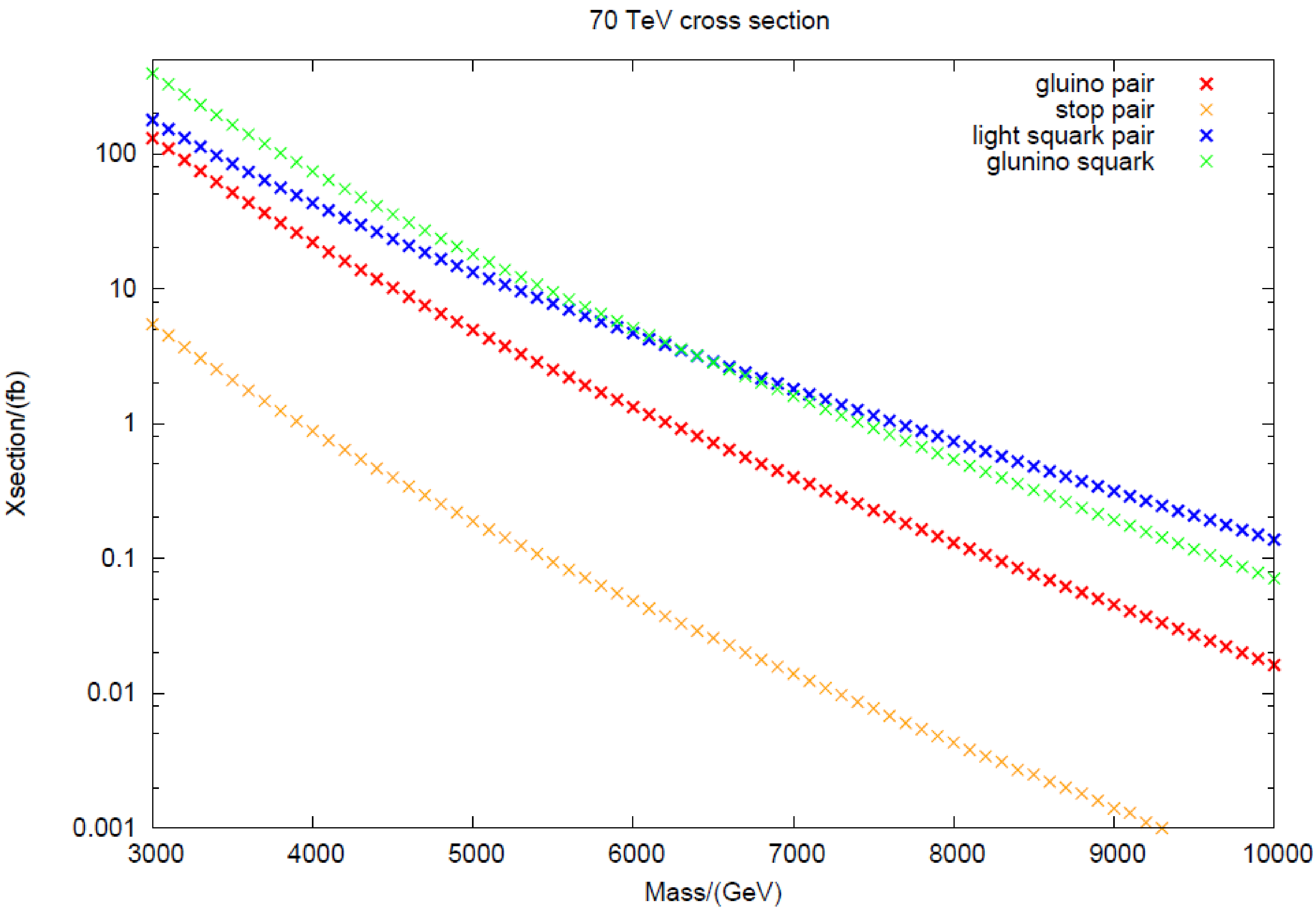


Figure 42. The cross subsections as a function of the collider energy for the benchmark point in Eqs. (3.8) and (3.9). The solid lines indicate cases where CP violating phases do not influence the explicitly CP conserving observable.



√s=250GeV
$e^+e^- \to zh$
2σ(each observable)
$\Delta\sigma^{SUSY}/\sigma_{SM}(\%)$
$M_{\tilde{\chi}_1}$(GeV)
6
5
4
3
2
1
0
-1
-2
100
200
300
400
500
600
700
800


50 TeV cross section
gluino pair
stop pair
light squark pair
glunino squark
Xsection/(fb)
100
10
1
0.1
0.01
0.001
3000
4000
5000
6000
7000
8000
9000
10000
Mass/(GeV)


70 TeV cross section
gluino pair
stop pair
light squark pair
glunino squark
Xsection/(fb)
100
10
1
0.1
0.01
0.001
3000
4000
5000
6000
7000
8000
9000
10000
Mass/(GeV)

4: BSM: Alternatives

Going beyond conventional seesaws

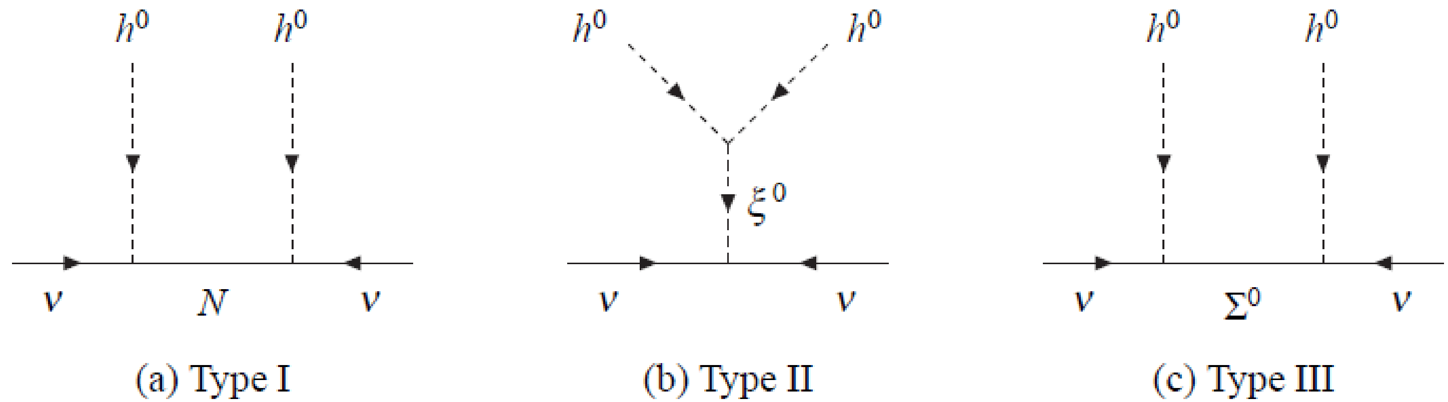


Figure 50. The neutrino mass generating mechanisms of three conventional seesaw models.

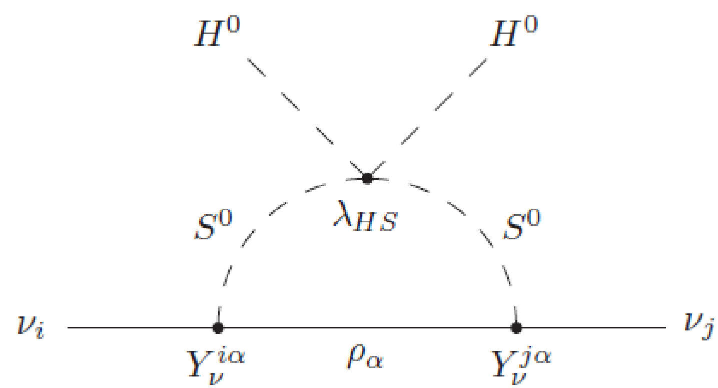


Figure 60. Feynman diagram for neutrino mass generation in the colored seesaw mechanism introducing a scalar colored octet $S \sim (8, 2, 1/2)$ and two fermionic octets $\rho_\alpha \sim (8, 1, 0)$ [348].

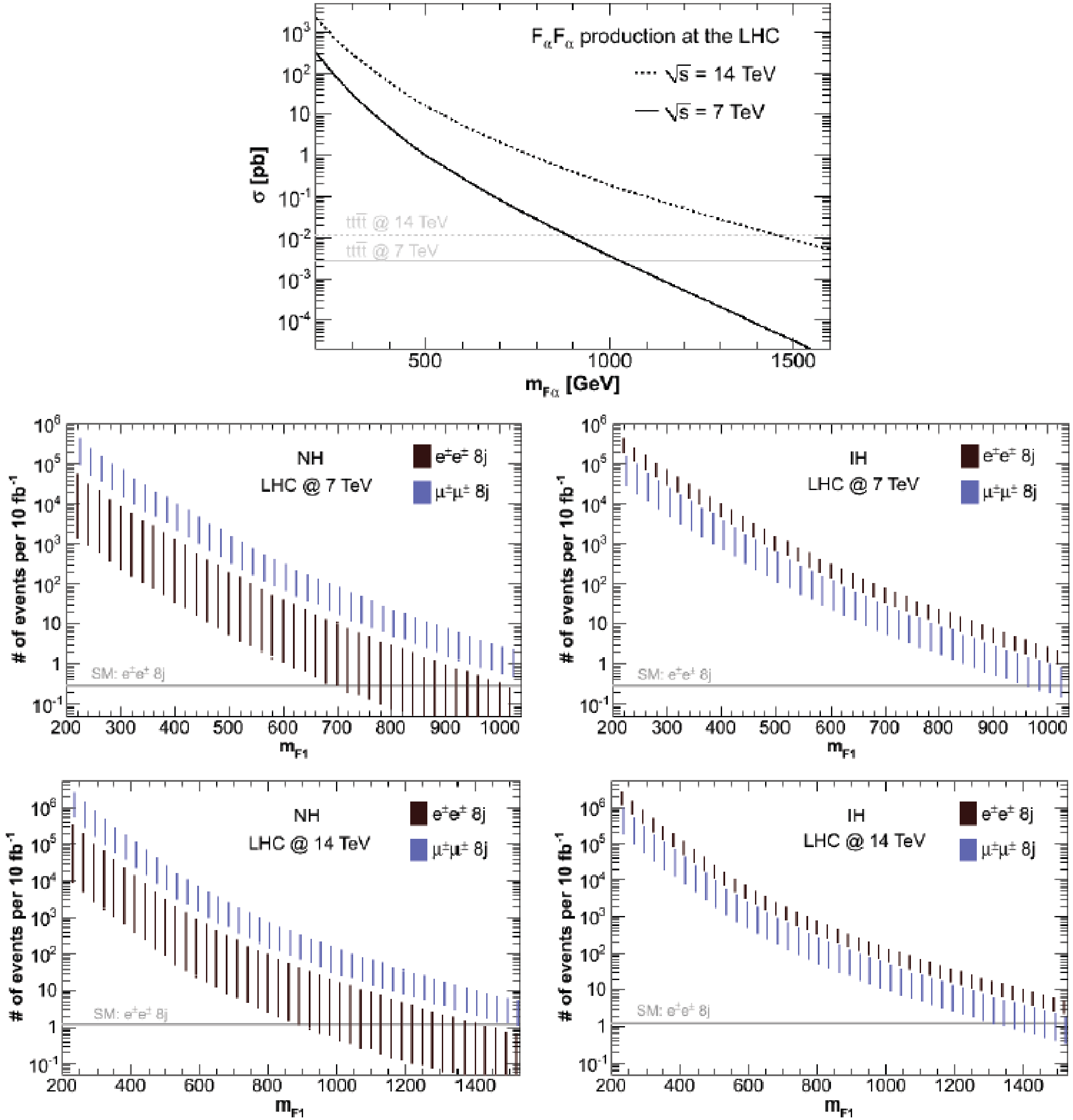


Figure 61. Cross subsubsection for the pair production of color octet fermions and rates for like-sign dilepton events in the color-octet seesaw model [348].

5: Flavor Physics

Flavor physics

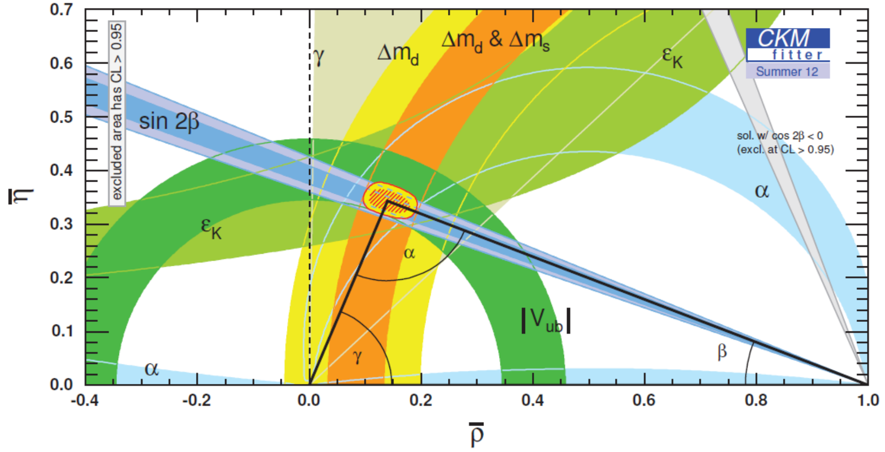


Figure 66. Unitarity triangle in the complex plane.

- New physics scale=Flavor scale? Complementary to high scale physics
- New CP violation sources ?
- SPPC as the top factory
- Rare decay modes of b/top?
- ….

6: TeV Cosmology

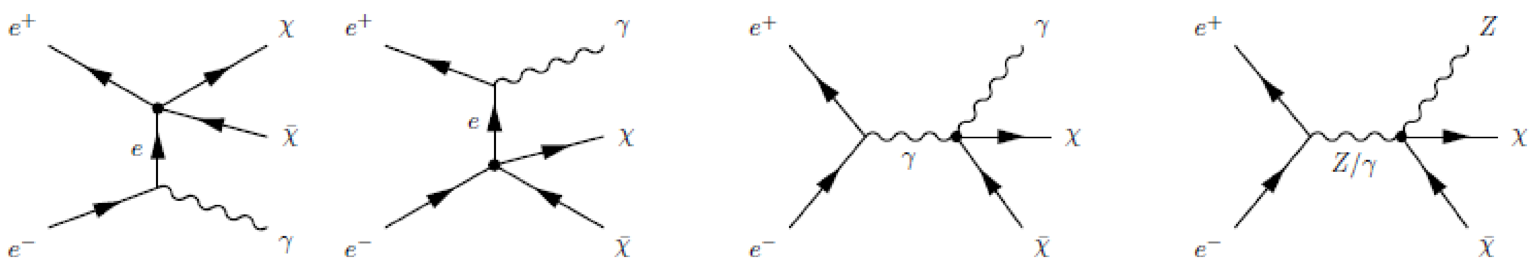
Constrain the effective interaction

We have given an study to constrain the interaction between DM and SM particle with effective operators.

Operators: $\mathcal{O}_e = \frac{1}{\Lambda^2}\bar{\chi}\Gamma_\chi\chi\bar{e}\Gamma_e e, \quad \Gamma_\chi, \Gamma_e \in \{1, \gamma_5, \gamma^\mu, \gamma^\mu\gamma_5, \sigma^{\mu\nu}\}$

$$\mathcal{O}_Z = \frac{1}{\Lambda_1^3}\bar{\chi}\chi B_{\mu\nu}B^{\mu\nu} + \frac{1}{\Lambda_2^3}\bar{\chi}\chi W^a_{\mu\nu}W^{a\mu\nu},$$

Signals: mono-gamma, mono-Z

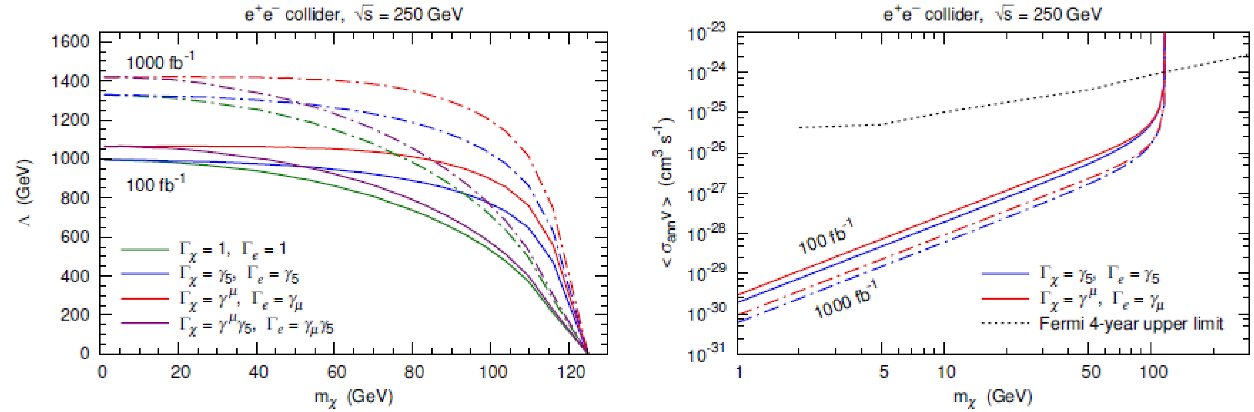


(a) DM coupled to electrons. (b) DM coupled to photons. (c) DM coupled to Z bosons.

Figure 1. DM production processes $e^+e^- \to \chi\bar{\chi}\gamma$ and $e^+e^- \to \chi\bar{\chi}Z$.

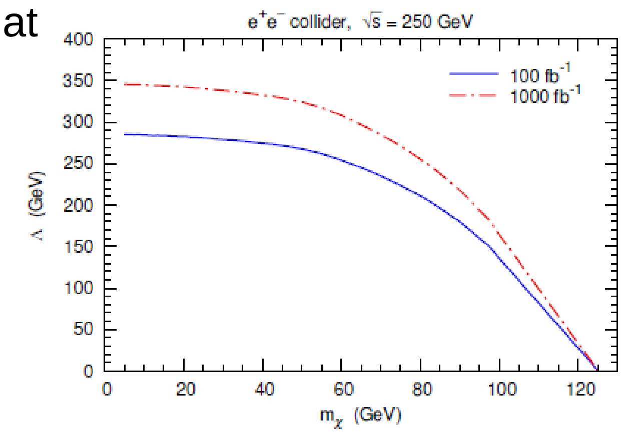
We have simulated the signals and background with a ILD-like detector.

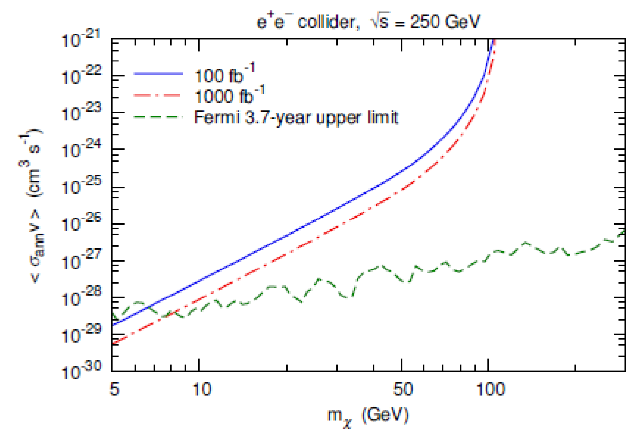
Constraints on O_e reach ~1.5 TeV, much stronger than indirect detection by Fermi.



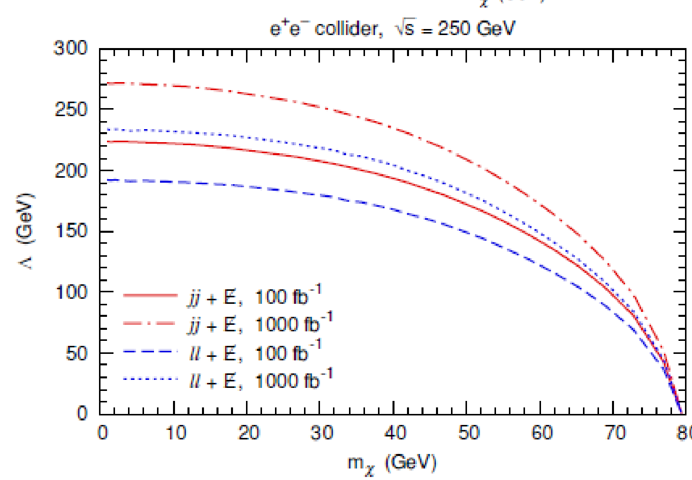
(a) m_χ-Λ plane. (b) m_χ-$\langle\sigma_{\rm ann}v\rangle$ plane.

Constraints on the Og only at ~300 GeV. Generally weaker than the Fermi gamma-line search sensitivity.





Mono-Z constrain \Lambda ~ 250GeV.



EW baryogenesis at the CEPC

1, 1st order strong phase transition requires: 1) light scalar particle S ~ 100GeV or 2) considerable change of Higgs potential, therefore the Higgs self-coupling. \delta \lambda ~ 100%, while TLEP constrain \delta \lambda ~ 30% (CEPC may also give constraint with smaller luminosity.)

2, CP violation term may induce effective anomalous Higgs coupling to top or gauge bosons. We intend to check the anomalous coupling to constrain the scenario of EW baryogensis.

$$\mathcal{O}^t = c_t \, e^{i\xi} \, \frac{(\phi^2 - \frac{v^2}{2})}{\Lambda^2} \, \Gamma_t \, \overline{\Psi_L} \tilde{\Phi} t_R \qquad \kappa \; c_t \sin\xi \geq 4 \times 10^{-2}$$

$$O_W = c_W \frac{g^2}{8\pi^2} \frac{\phi^2}{\Lambda^2} \mathrm{Tr} W_{\mu\nu} \tilde{W}^{\mu\nu} \qquad \text{Taking } \Lambda \sim 1TeV$$

$$c_w \geq 0.1 - 1$$

3, the effective operators may lead to change of br of Higgs decay inevitably. The precise measurement of br will give strong constranits on the EW baryogensis scenario.

Conclusion/Discussion

- Great efforts by domestic theorists! First preliminary report/framework was available, need lots of more work!
- Need more domestic/foreign theorists input, worldwide efforts!
- Keep eyes on LHC new input!

Thanks for your attention!