

Theory Studies in China

--- status report of theory working group

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

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

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 - (5) Flavor physics
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- Conclusion/Discussion

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)

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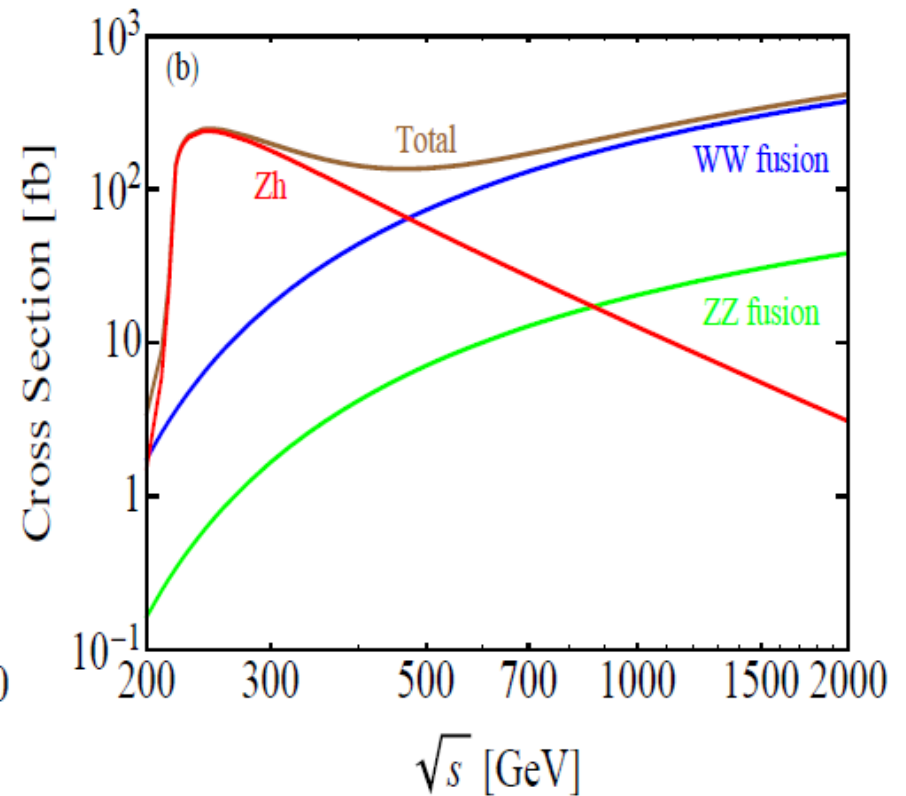
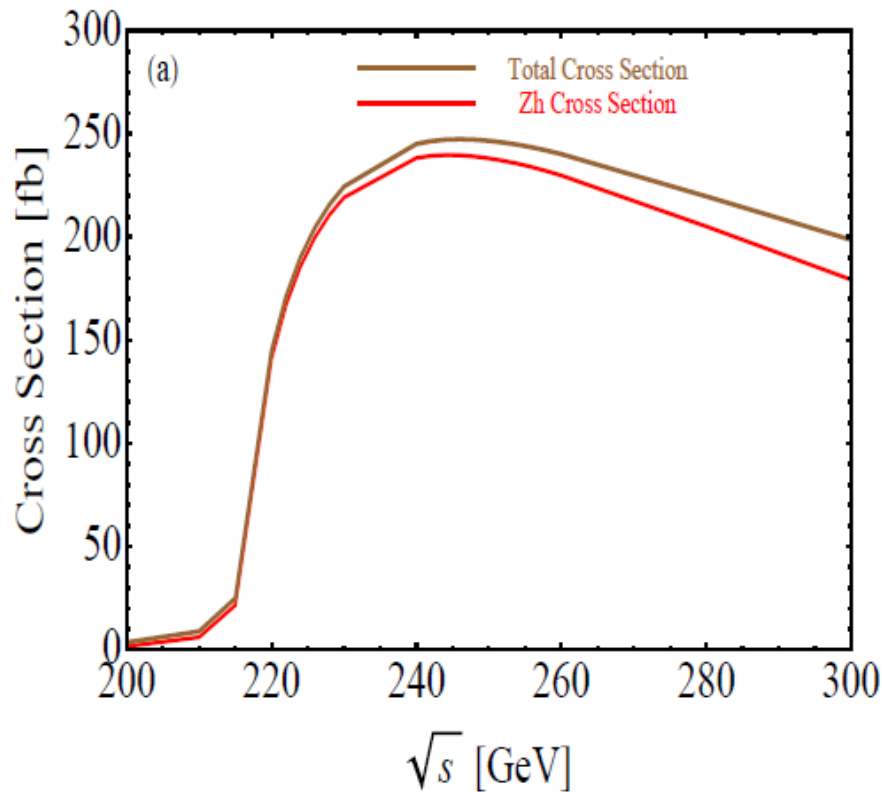
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3 ways to probe new physics via Higgs

- 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

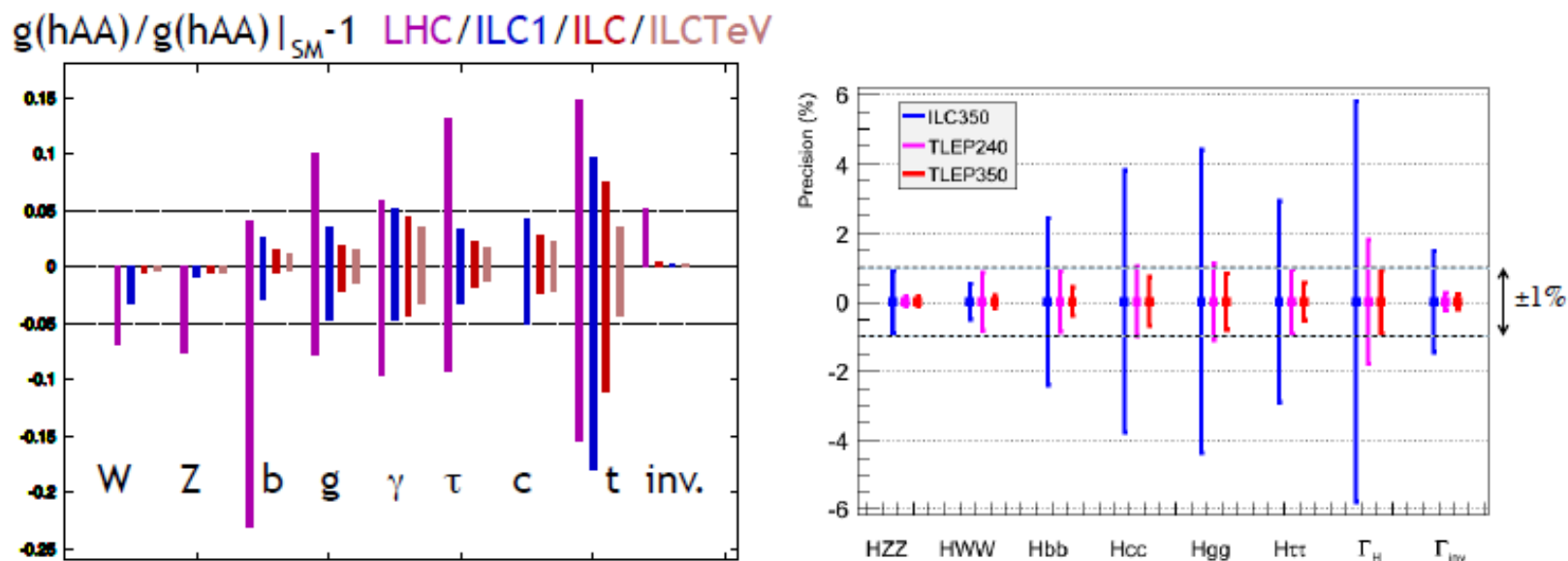


Figure 23. Left: The estimated accuracies of measuring the Higgs boson couplings between LHC and ILC experiments, with four sets of errors representing results for LHC-14 TeV (300 fb^{-1} with one detector), the ILC-250 GeV, the ILC-500 GeV, and the extension of the ILC-1 TeV. Right: The estimated accuracies 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

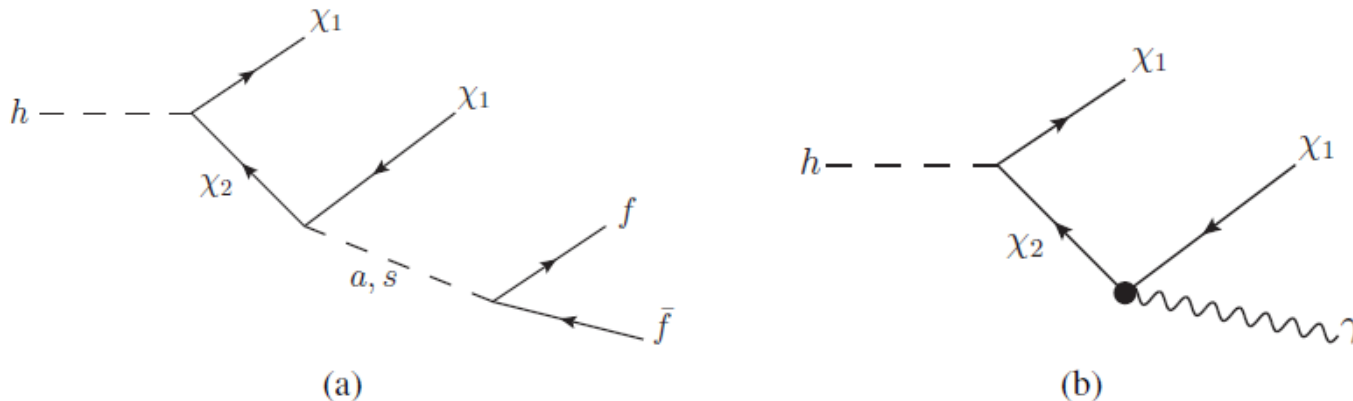
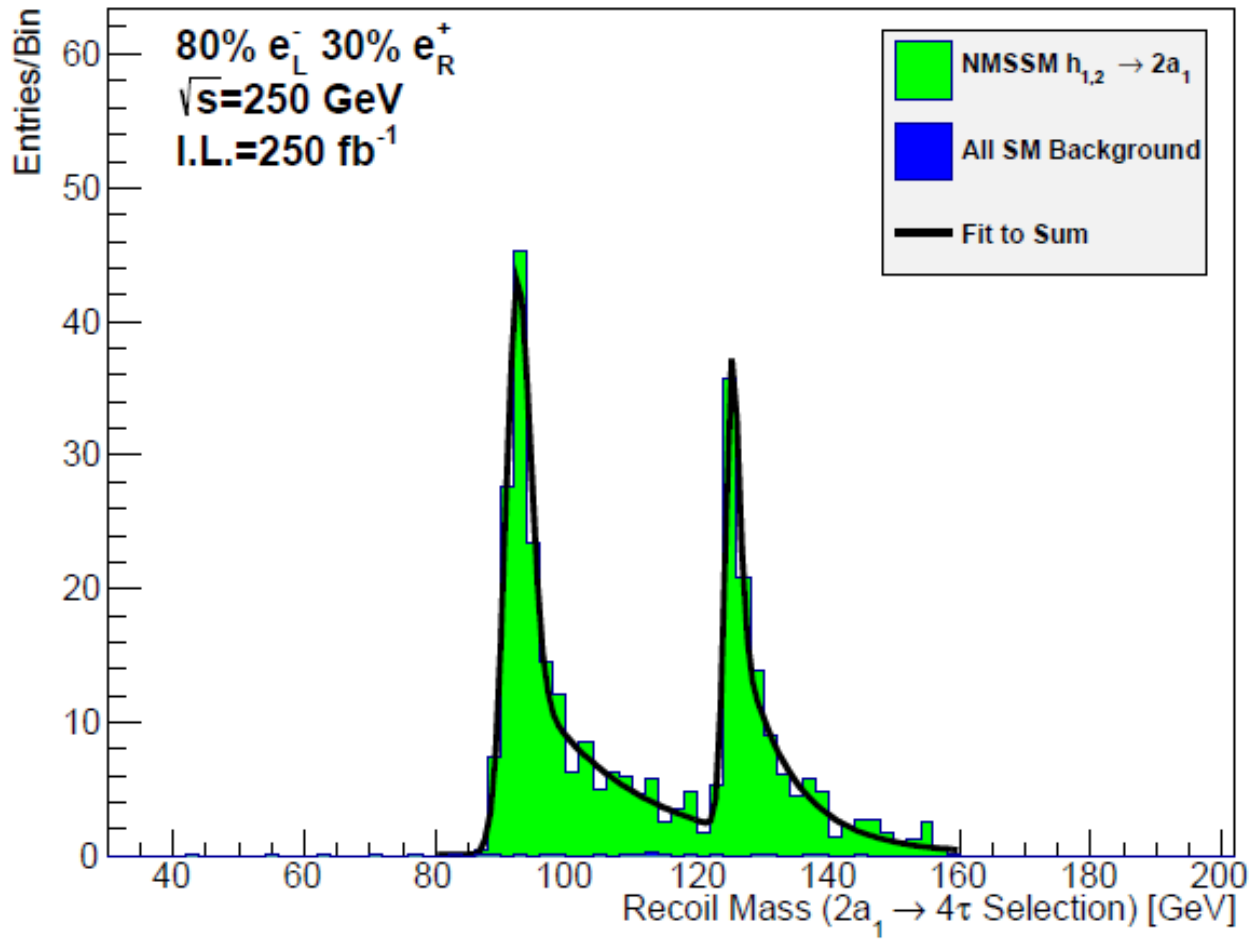


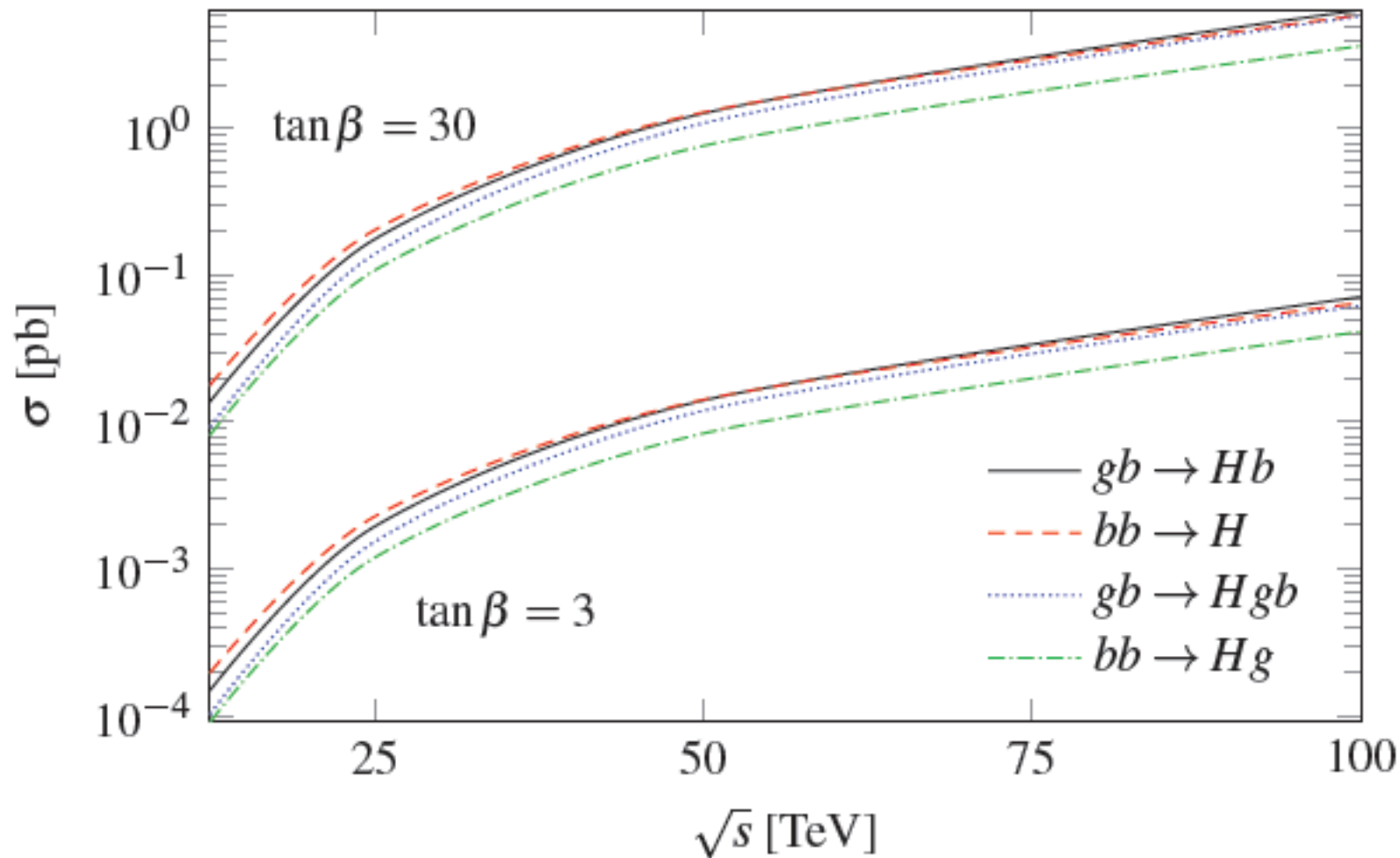
Figure 4. New decay topologies of the SM-like Higgs boson in the PQ symmetry limit with $\lambda \lesssim 0.1$. Non-negligible (b) requires $\min(m_s, m_a) > m_{\chi_2} - m_{\chi_1}$. (See [75, 76].)

Exotic visible decay

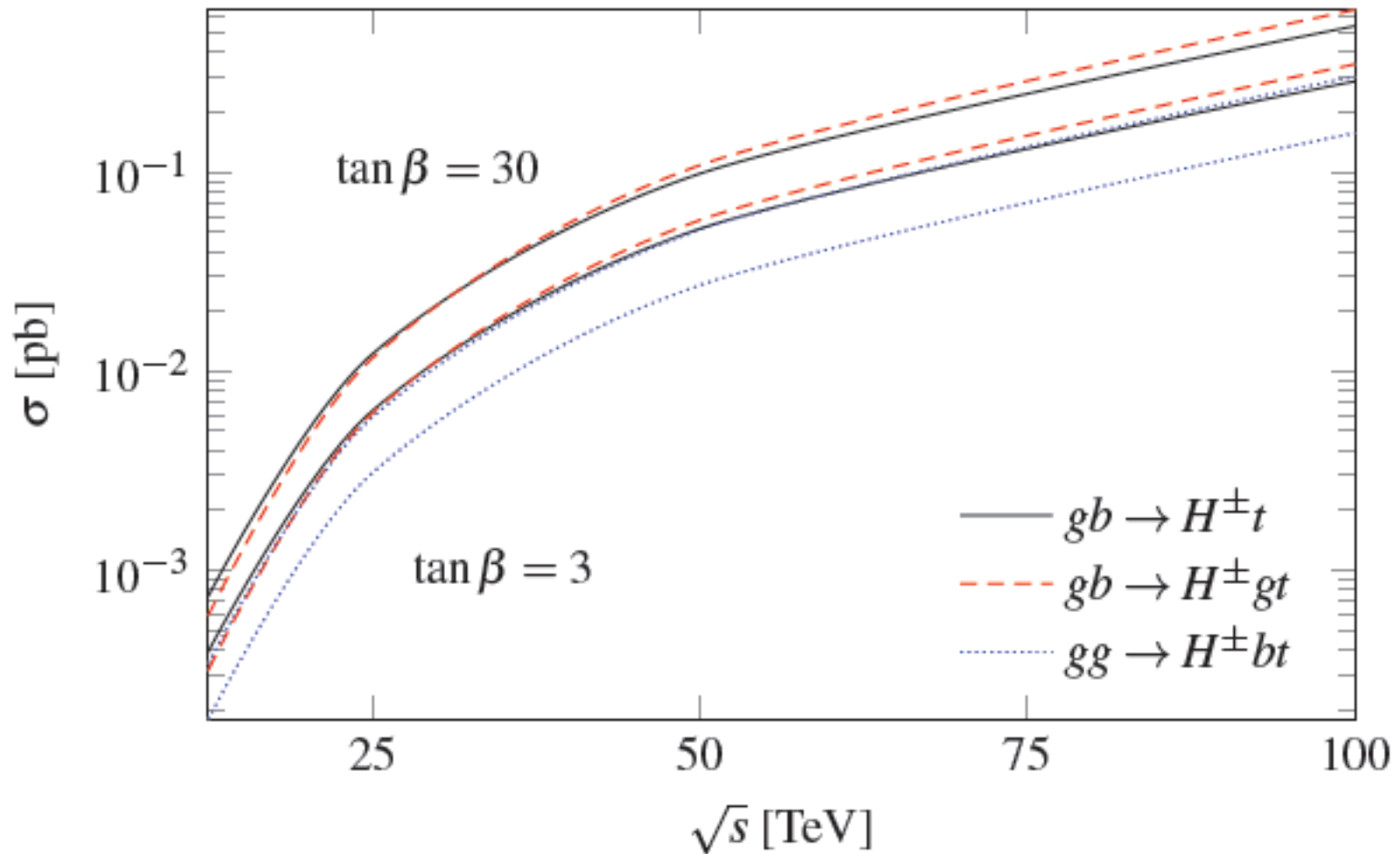


$$m^{\text{rec}} \equiv \sqrt{s - 2\sqrt{s}E_Z + m_Z^2}$$

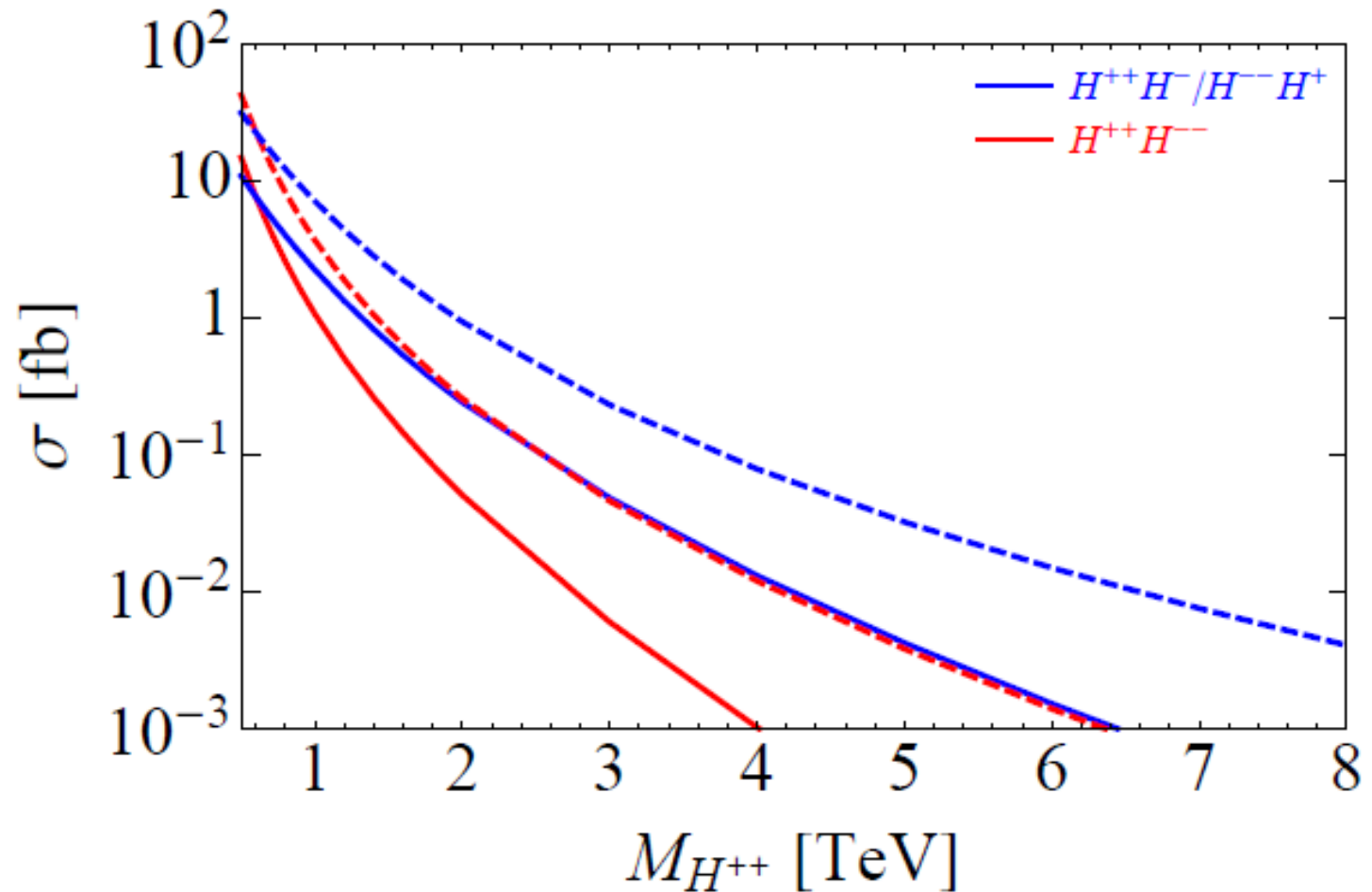
Neutral extra Higgs (1TeV)



Charged Higgs (1TeV)



Doubly charged Higgs (50 vs 100 TeV)



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Larger PDF uncertainty at SPPC

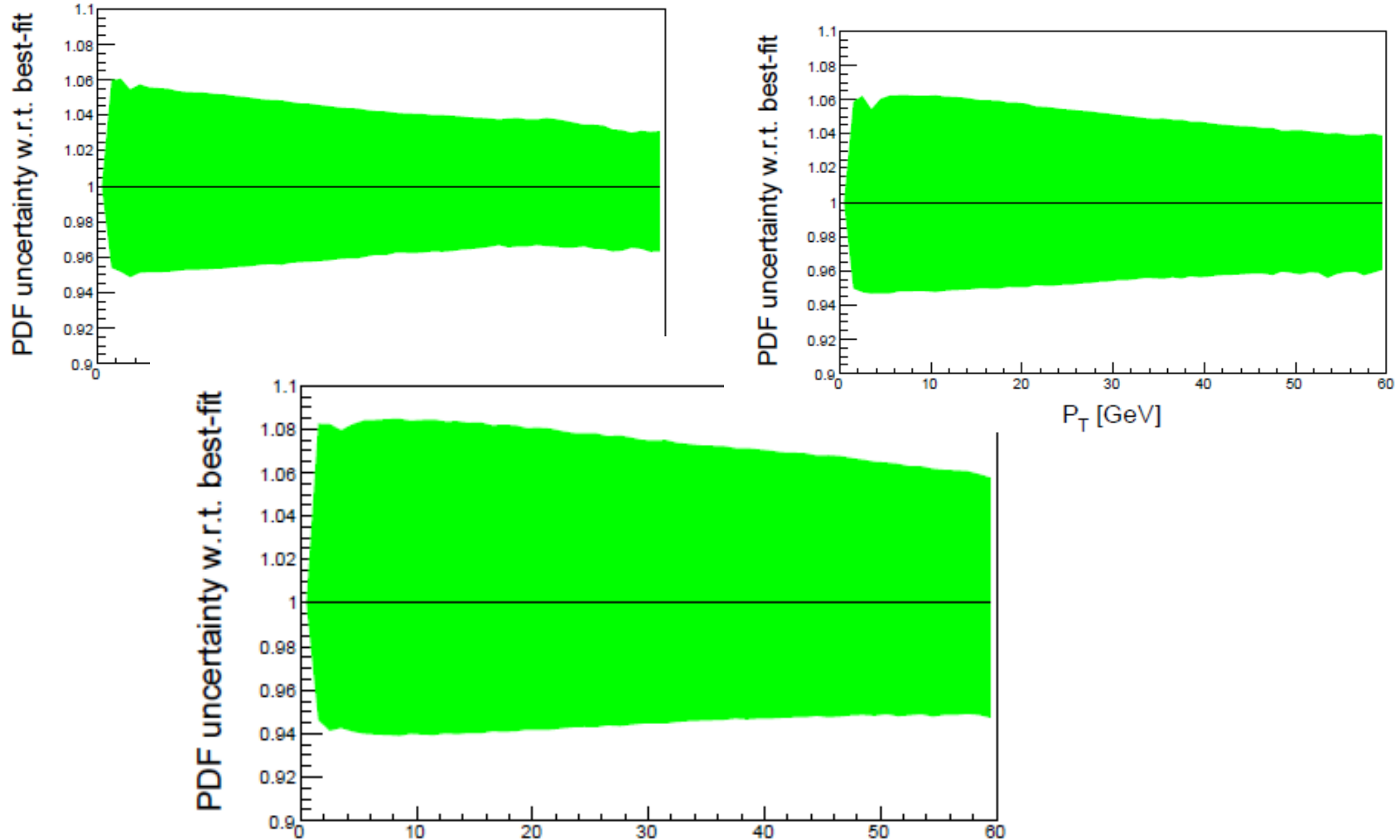
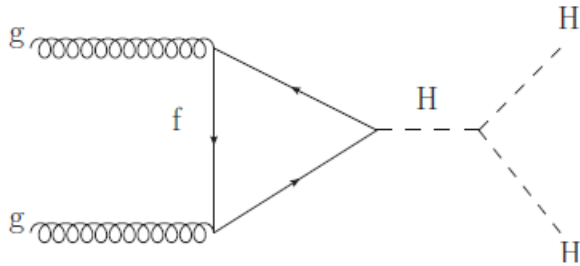


Figure 35. The transverse momentum distribution of diphoton pair at the 8 TeV LHC, 14 TeV LHC and 50 TeV SppC, respectively from top to bottom using CT10nlo PDF set.

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

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

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 $y_t = 1$.

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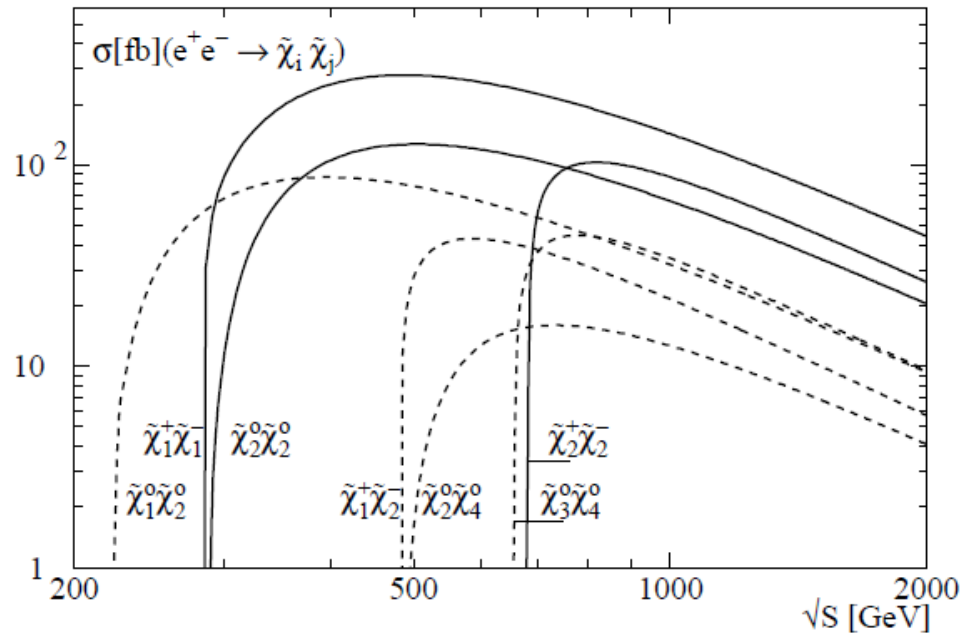
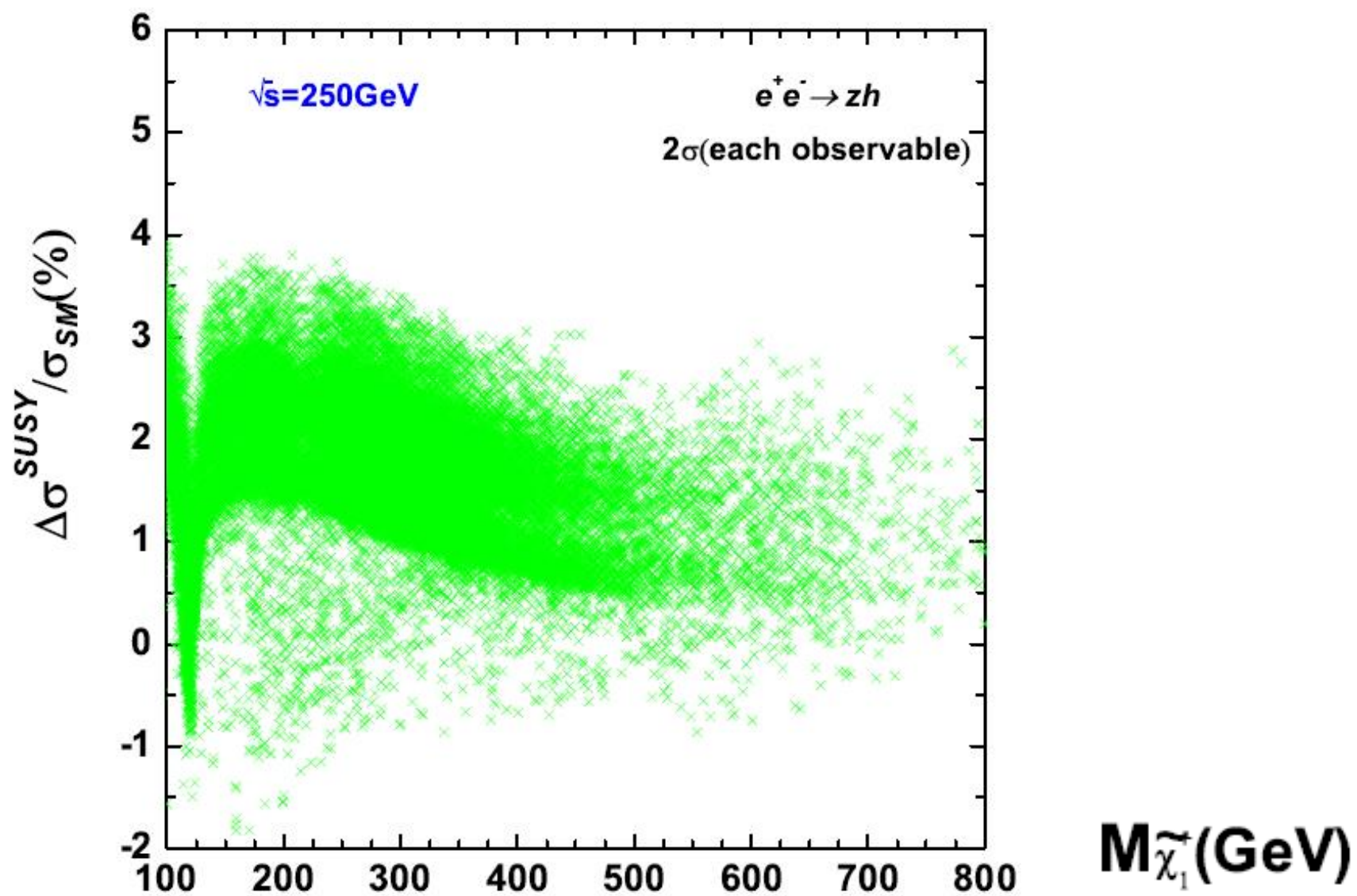
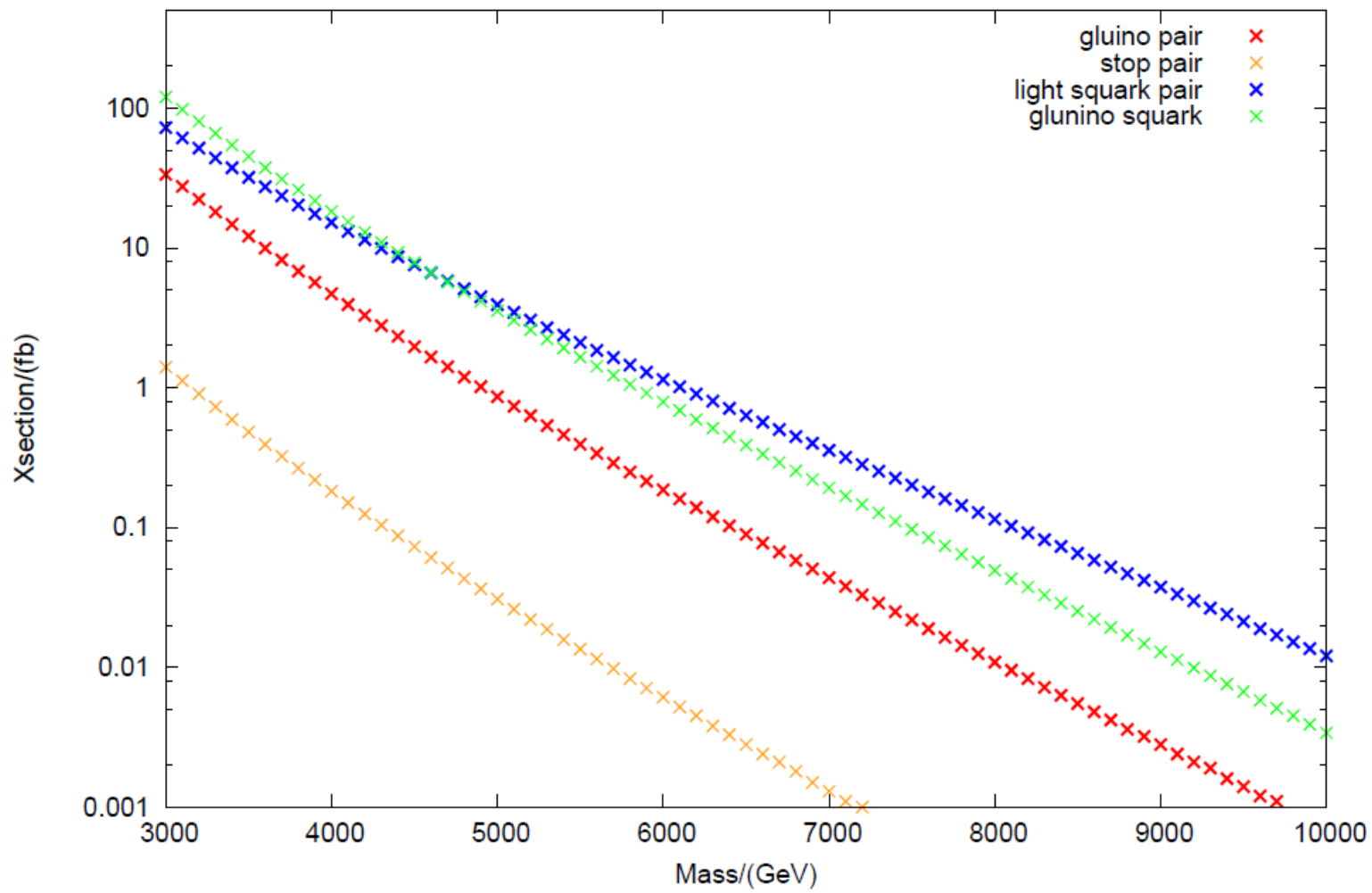


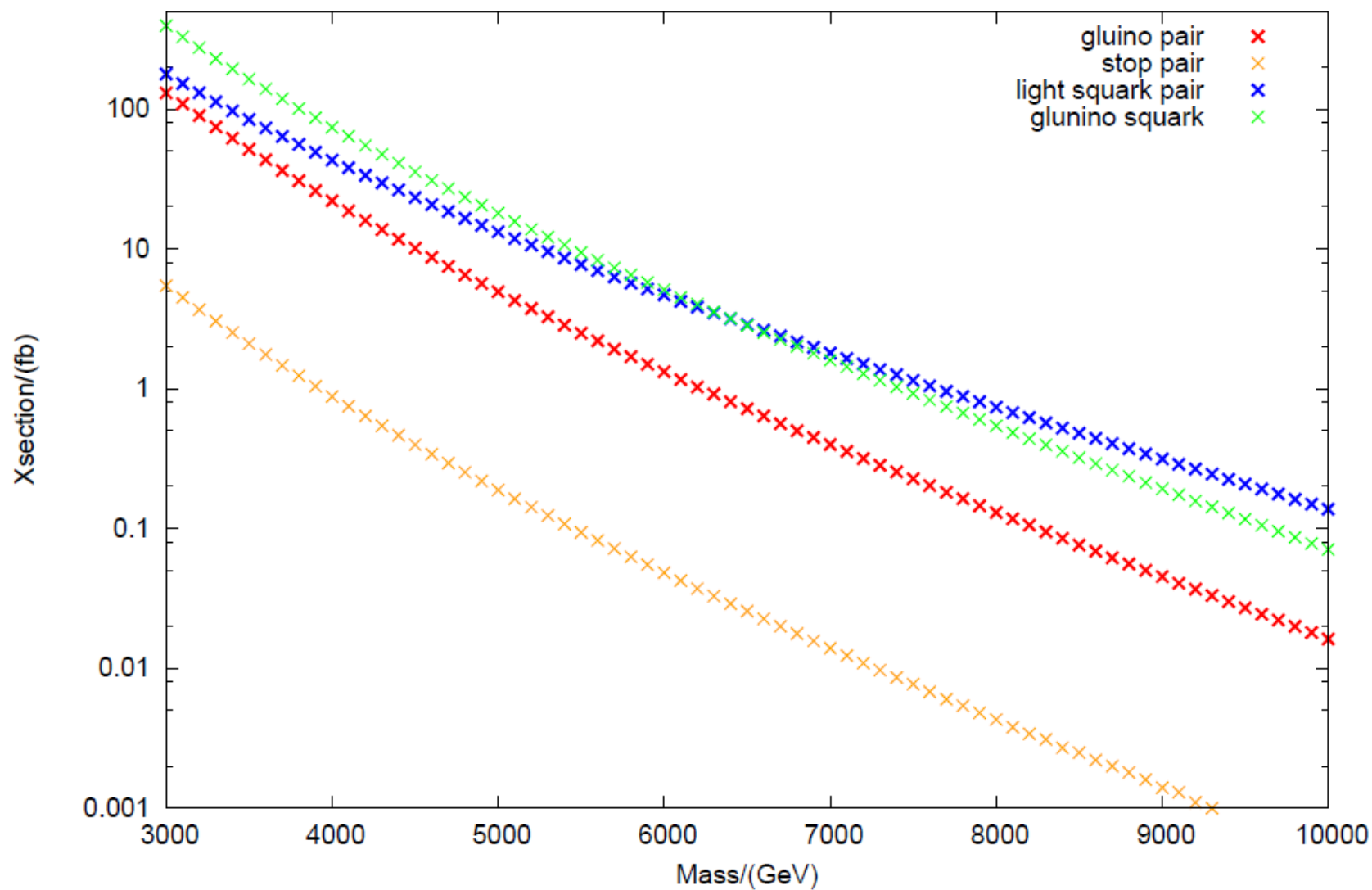
Figure 42. The cross subsections as a function of the collider energy for the benchmark point in Eqs. (3.8) and (3.9). The solid lines indicate cases where CP violating phases do not influence the explicitly CP conserving observable.



50 TeV cross section



70 TeV cross section



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Going beyond conventional seesaws

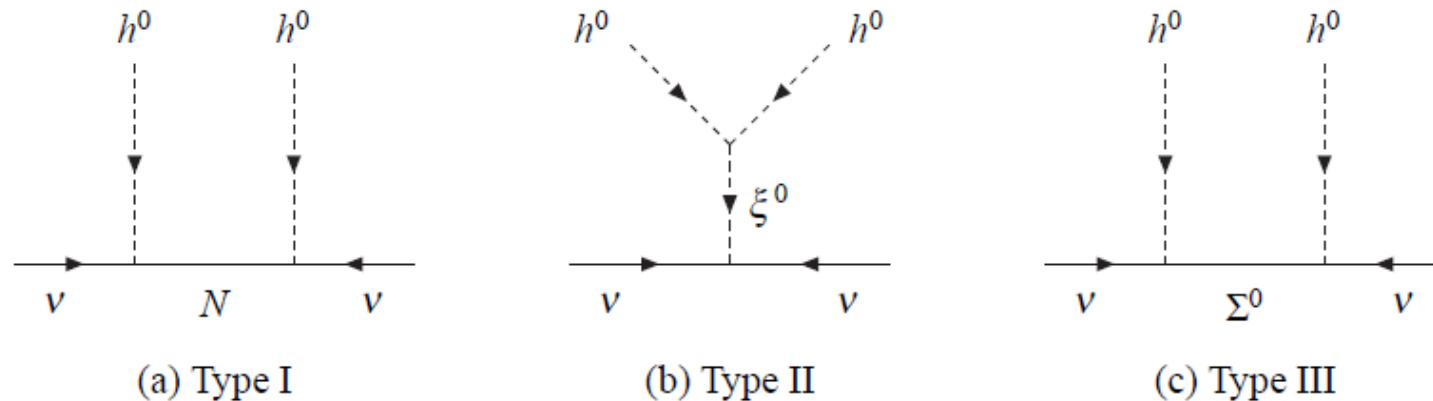


Figure 50. The neutrino mass generating mechanisms of three conventional seesaw models.

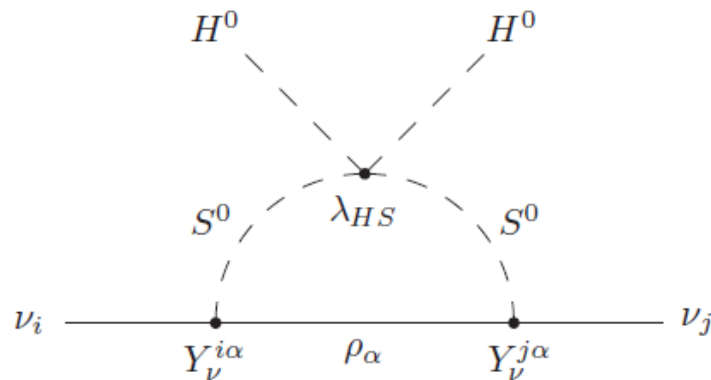


Figure 60. Feynman diagram for neutrino mass generation in the colored seesaw mechanism introducing a scalar colored octet $S \sim (8, 2, 1/2)$ and two fermionic octets $\rho_\alpha \sim (8, 1, 0)$ [348].

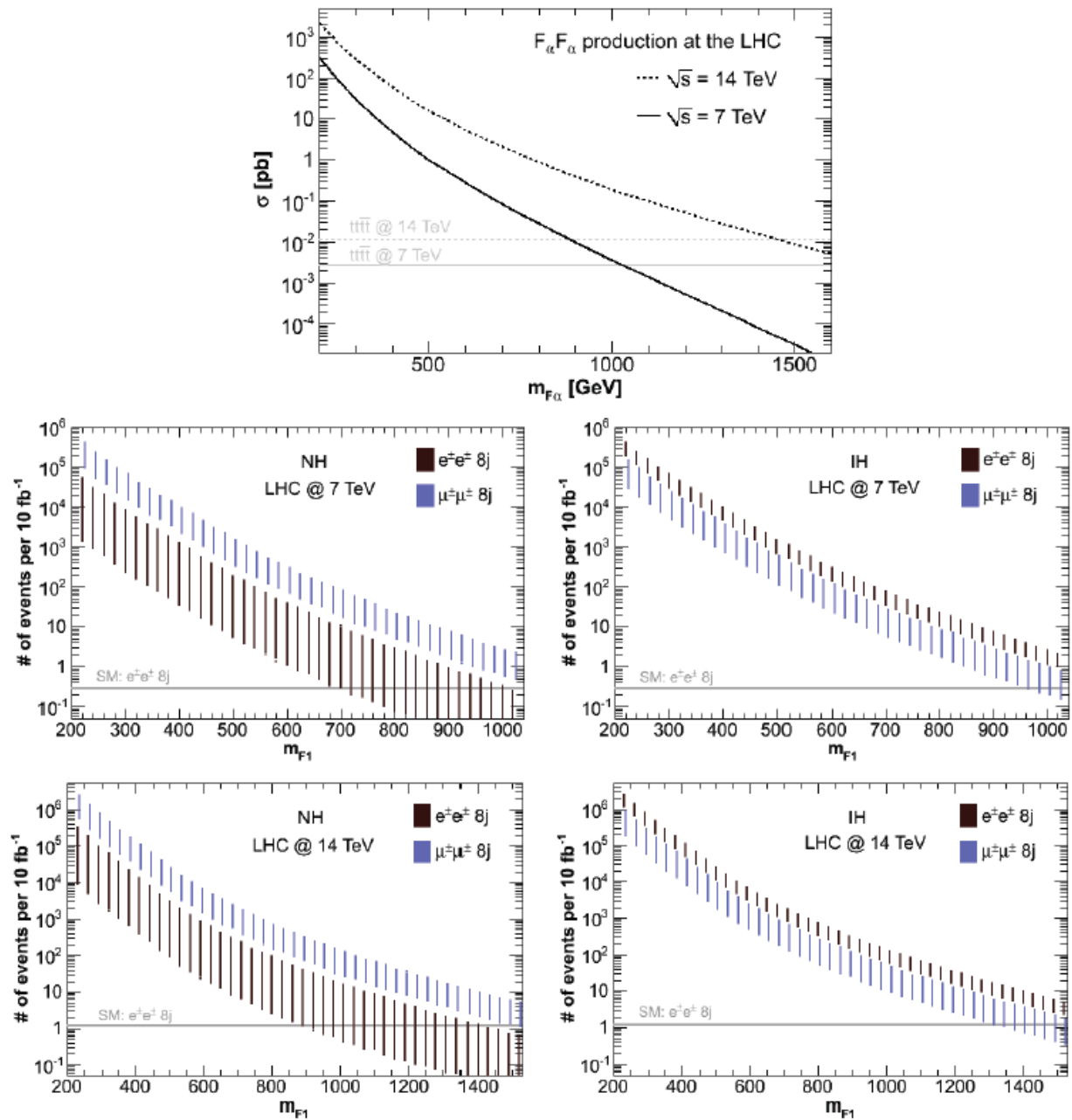


Figure 61. Cross subsection for the pair production of color octet fermions and rates for like-sign dilepton events in the color-octet seesaw model [348].

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Flavor physics

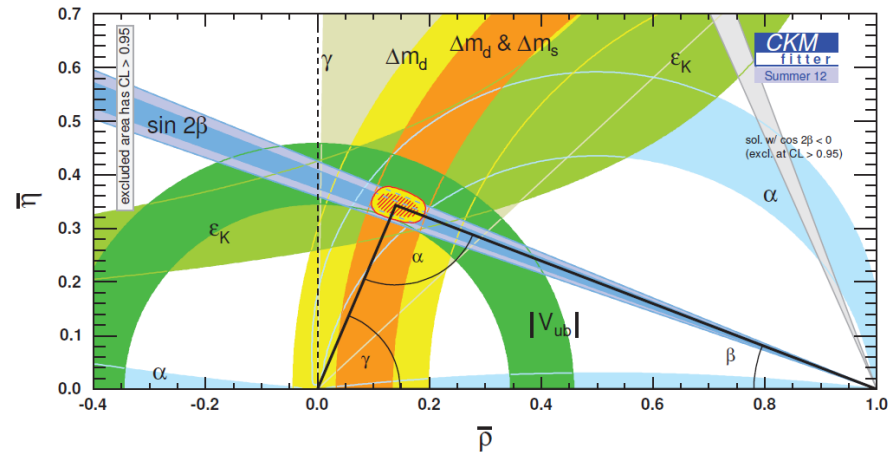


Figure 66. Unitarity triangle in the complex plane.

- 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

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Constrain the effective interaction

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

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

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

Signals: mono-gamma, mono-Z

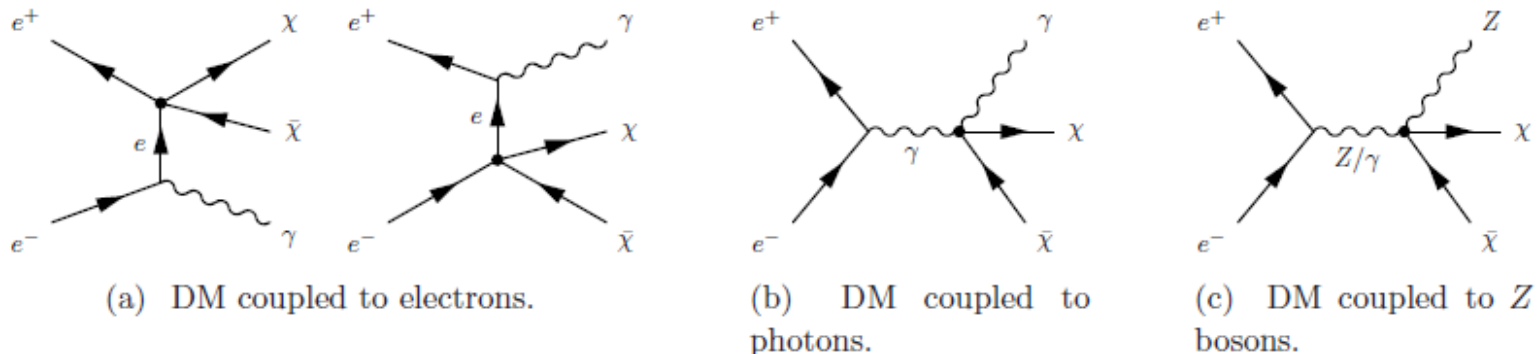
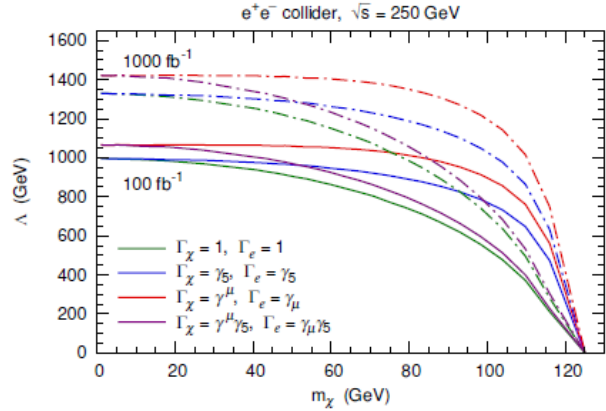


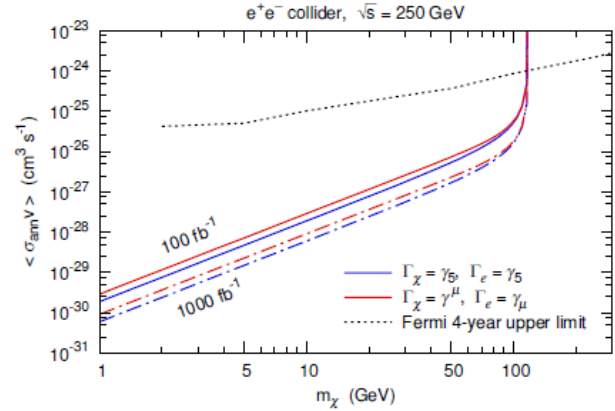
Figure 1. DM production processes $e^+e^- \rightarrow \chi\bar{\chi}\gamma$ and $e^+e^- \rightarrow \chi\bar{\chi}Z$.

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.

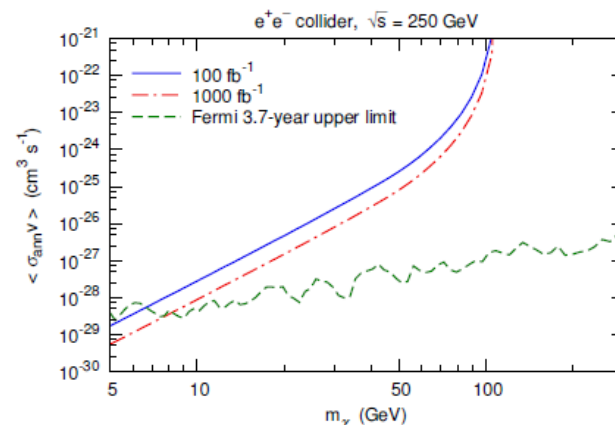
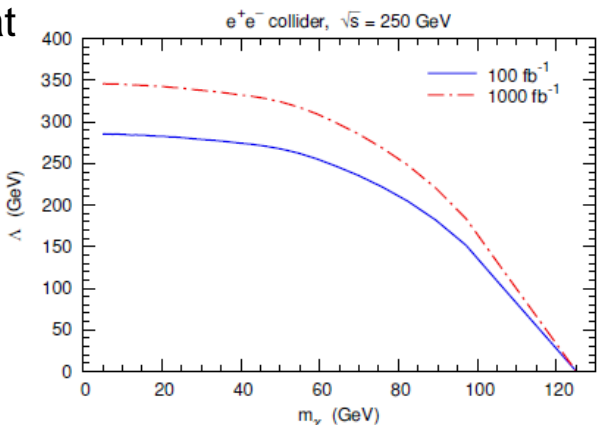


(a) m_χ - Λ plane.

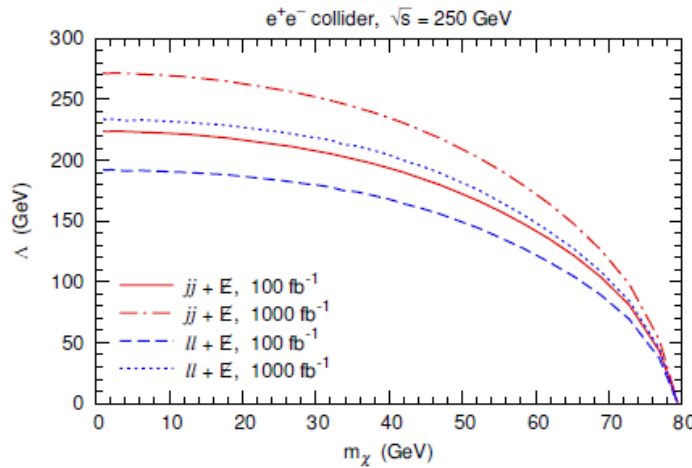


(b) m_χ - $\langle\sigma_{\text{ann}}v\rangle$ plane.

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



Mono-Z constrain $\Lambda \sim 250$ GeV.



EW baryogenesis at the CEPC

1, 1st order strong phase transition requires: 1) light scalar particle $S \sim 100\text{GeV}$ or 2) considerable change of Higgs potential, therefore the Higgs self-coupling. $\Delta\lambda \sim 100\%$, while TLEP constrain $\Delta\lambda \sim 30\%$ (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 baryogenesis.

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

$$\mathcal{O}_W = c_W \frac{g^2}{8\pi^2} \frac{\phi^2}{\Lambda^2} \text{Tr} W_{\mu\nu} \tilde{W}^{\mu\nu} \quad \text{Taking } \Lambda \sim 1\text{TeV},$$

$$c_w \geq 0.1 - 1$$

3, the effective operators may lead to change of br of Higgs decay inevitably. The precise measurement of br will give strong constraints on the EW baryogenesis 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!