HPNP2023

"Higgs as a Probe of New Physics 2023"

Exposing new scalars hiding behind the Higgs boson

Based on
*Phys. Rev. D **107** (2023) 055040, in collaboration with Qing-Hong Cao, Kun Cheng, Yandong Liu, Xin-Kai Wen, and Changlong Xu*

Hao Zhang

Theoretical Physics Division, Institute of High Energy Physics, Chinese Academy of Sciences

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CP violation — New Physics?

- Sakharov’s conditions

CP violation — New Physics?

- The extension of the Higgs sector is one of the most popular candidates of the origin of the CP violation beyond the SM.

- An (very famous) example: 2HDM

$$V(H) = \frac{\lambda}{2}\left(H^\dagger H\right)^2 - \mu^2 H^\dagger H$$

$$V(H_1, H_2) = m_{11}^2 H_1^\dagger H_1 + m_{22}^2 H_2^\dagger H_2 - m_{12}^2 (H_1^\dagger H_2 + H_2^\dagger H_1) + \frac{\lambda_1}{2}(H_1^\dagger H_1)^2 + \frac{\lambda_2}{2}(H_2^\dagger H_2)^2$$

$$+\lambda_3 (H_1^\dagger H_1)(H_2^\dagger H_2) + \lambda_4 (H_1^\dagger H_2)(H_2^\dagger H_1) + \frac{\lambda_5}{2}[(H_1^\dagger H_2)^2 + (H_2^\dagger H_1)^2]$$

$$+\lambda_6 [(H_1^\dagger H_1)(H_1^\dagger H_2) + (H_1^\dagger H_1)(H_2^\dagger H_1)] + \lambda_7 [(H_2^\dagger H_2)(H_1^\dagger H_2) + (H_2^\dagger H_2)(H_2^\dagger H_1)]$$

T. D. Lee, ***A Theory of Spontaneous T Violation***, Phys. Rev. D **8** (1973) 1226;
S. Weinberg, ***Gauge Theory of CP Nonconservation***, Phys. Rev. Lett. **37** (1976) 657.

New scalars — Where are they?

- New scalars: charged Higgs bosons, CP-even Higgs bosons, CP-odd Higgs bosons, generic neutral Higgs bosons…
- None of them is discovered at the LHC.
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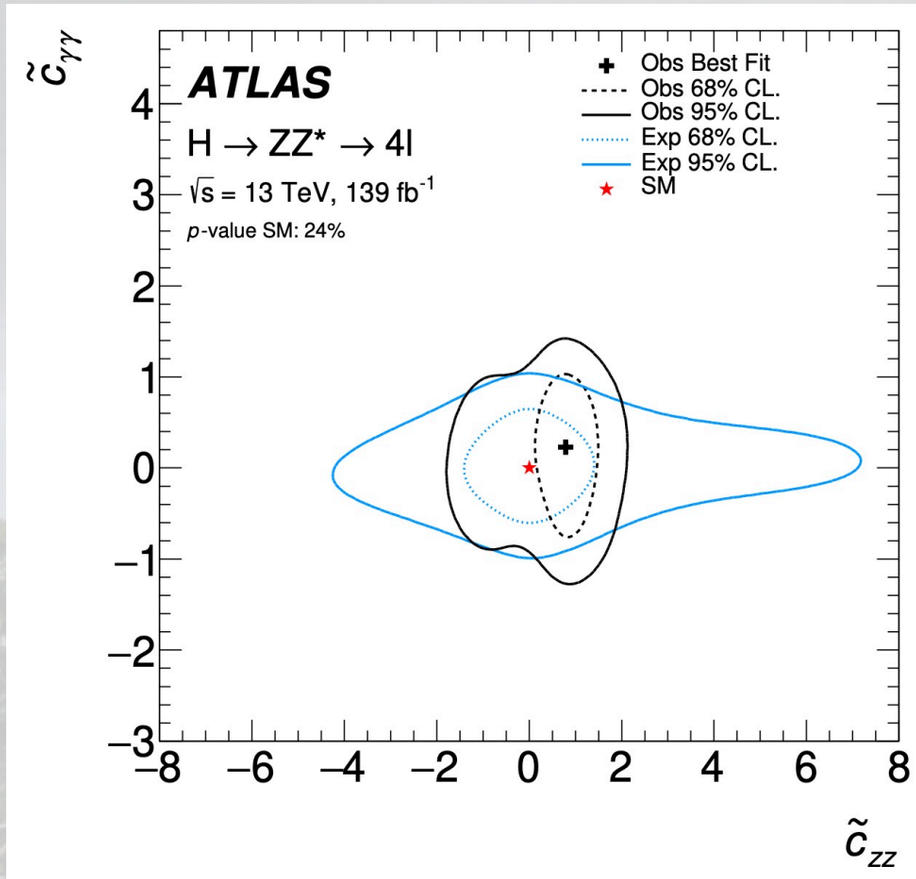
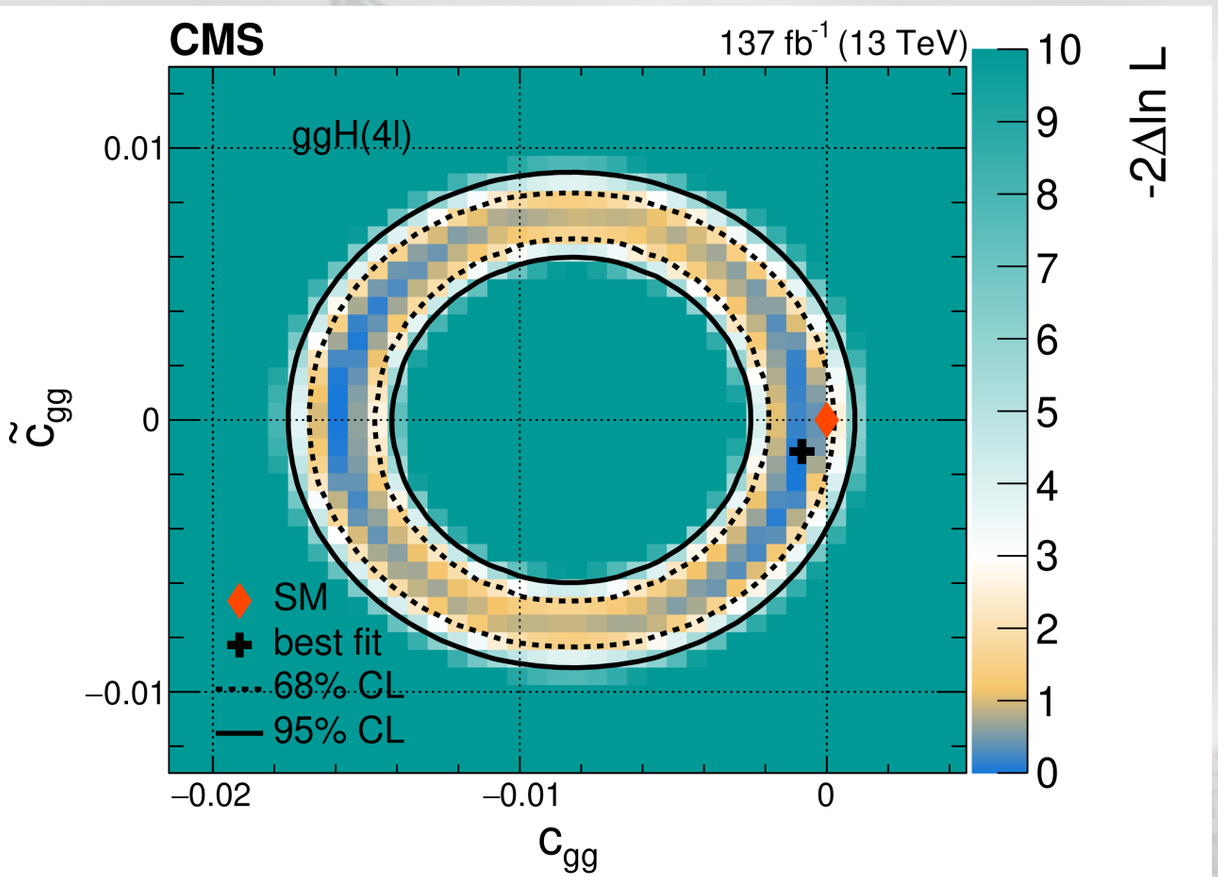
- Other possibilities?

New scalars — Where are they?

- CP property of the 125GeV Higgs boson
- HVV





ATLAS collaboration, arXiv:2304.09612[hep-ex];
CMS collaboration, Phys. Rev. D **104** (2021) 052004.

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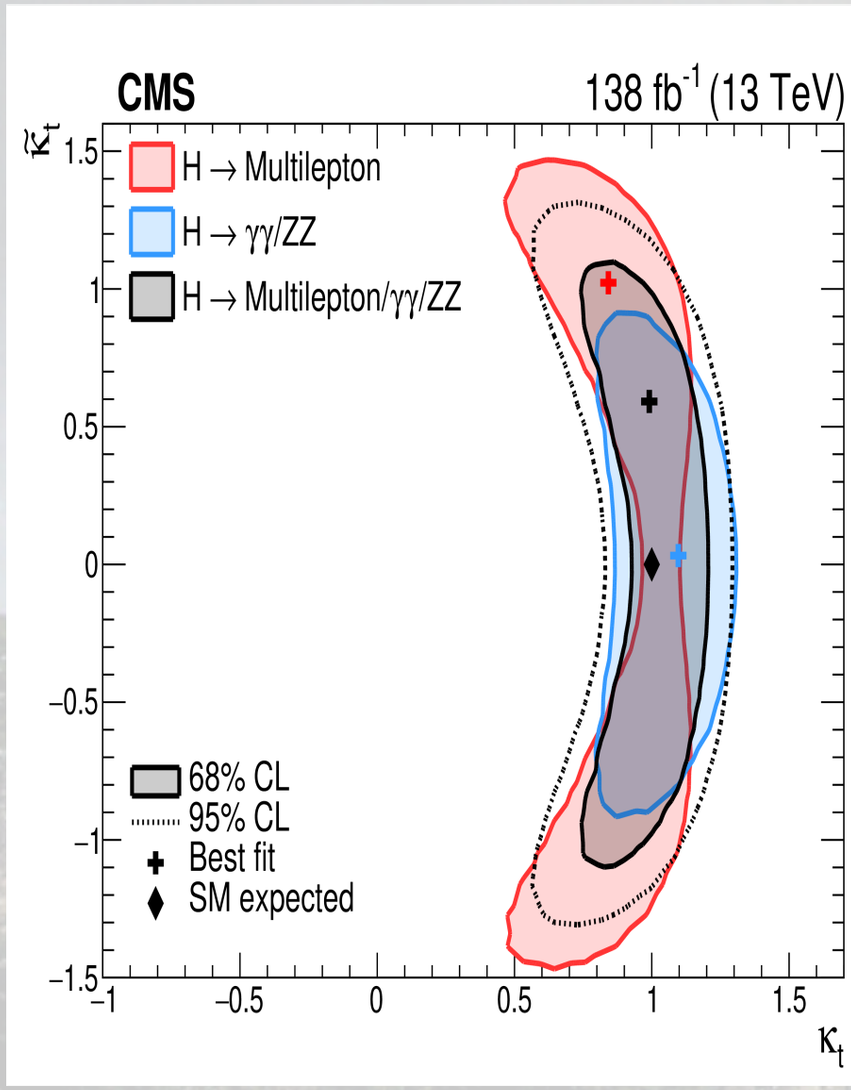

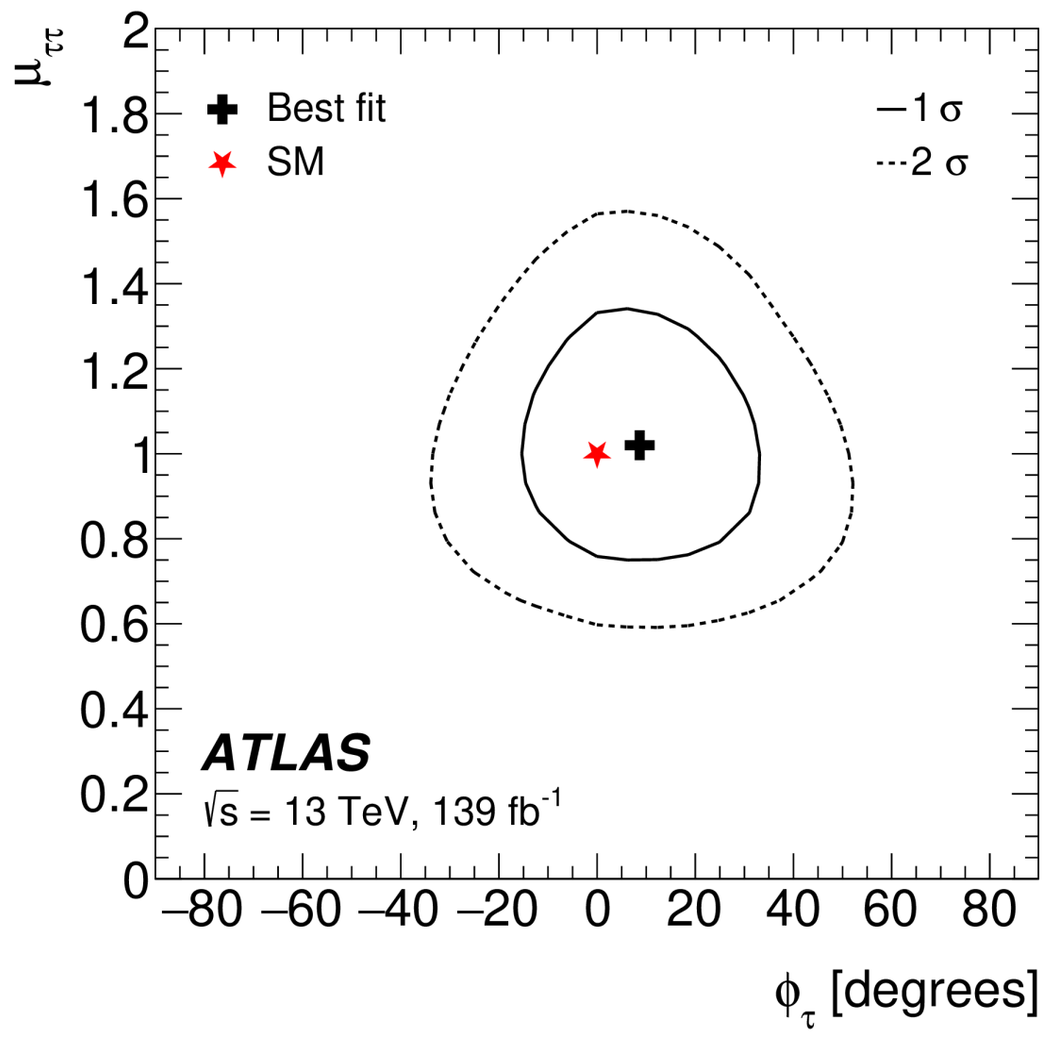

CMS collaboration, arXiv:2208.02686[hep-ex];
ATLAS collaboration, arXiv:2212.05833[hep-ex].

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  - ✓ One 125GeV Higgs boson, but is not CP eigenstate;
  - ✓ Two 125GeV Higgs bosons, one is CP-even, the other is CP-odd;
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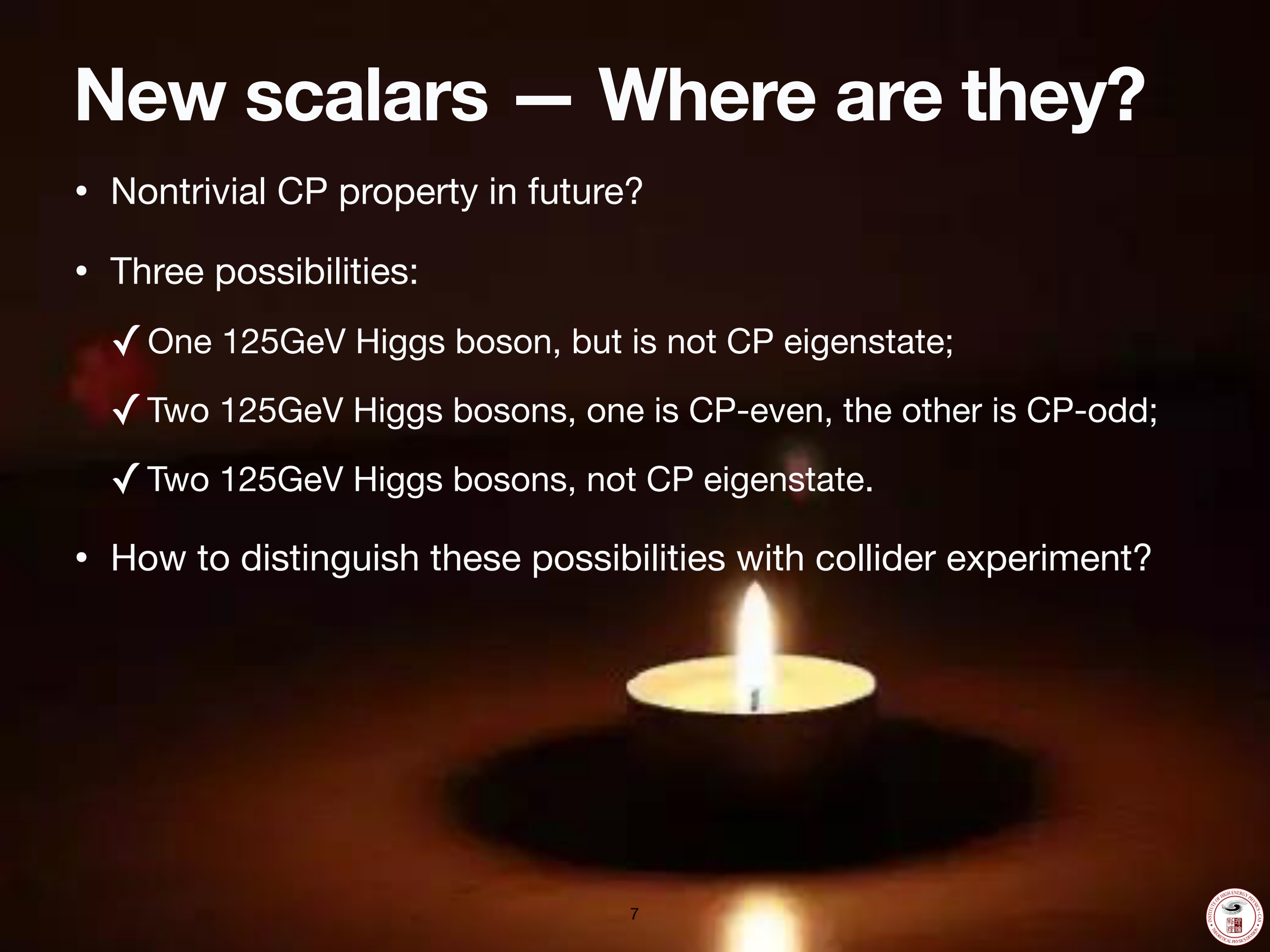
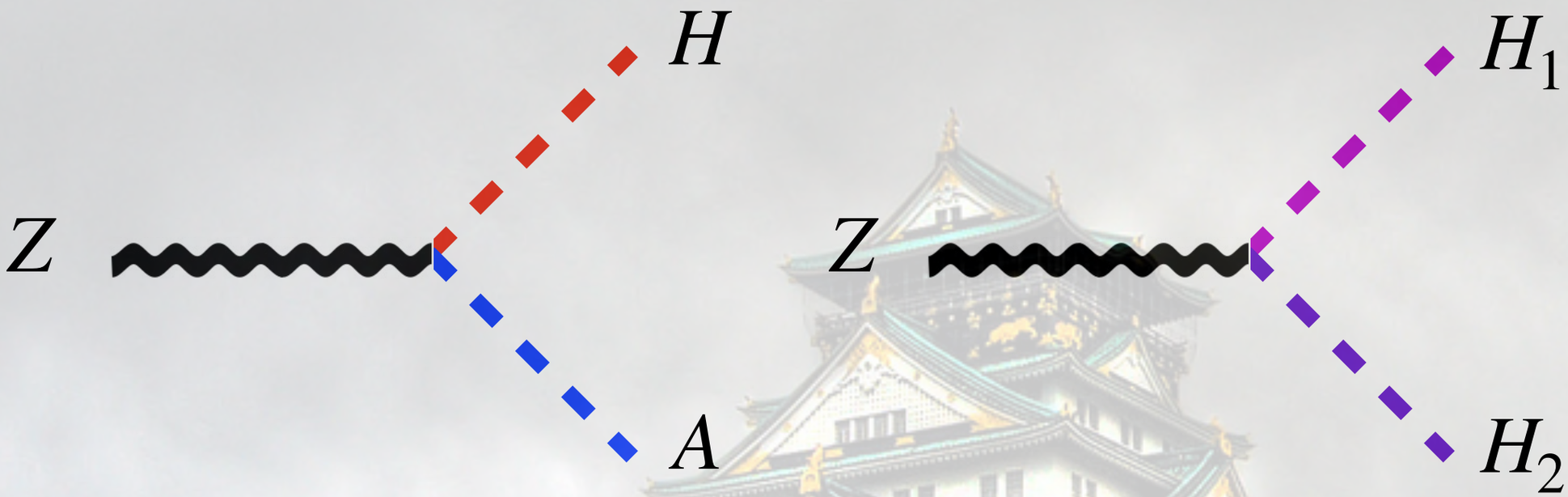
- How to distinguish these possibilities with collider experiment?



Search for the “shadow” Higgs

- The smoking gun of the shadow Higgs boson

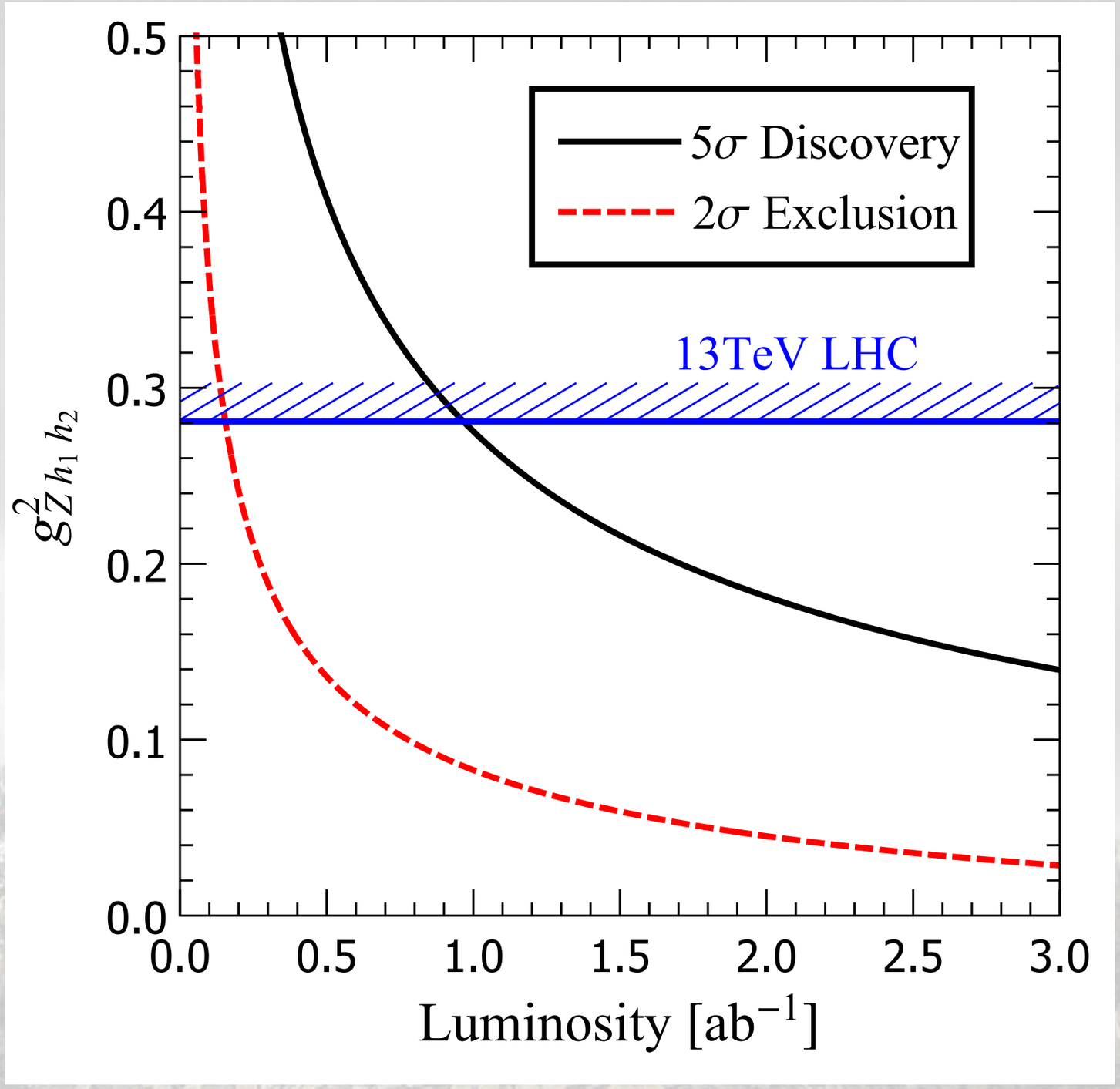


$$\mathscr{L}_{\text{int}} = ig_{ZH_1H_2}(H_1\partial_\mu H_2 - H_2\partial_\mu H_1)Z^\mu$$

- More di-Higgs event!

Search for the “shadow” Higgs

- LHC phenomenology



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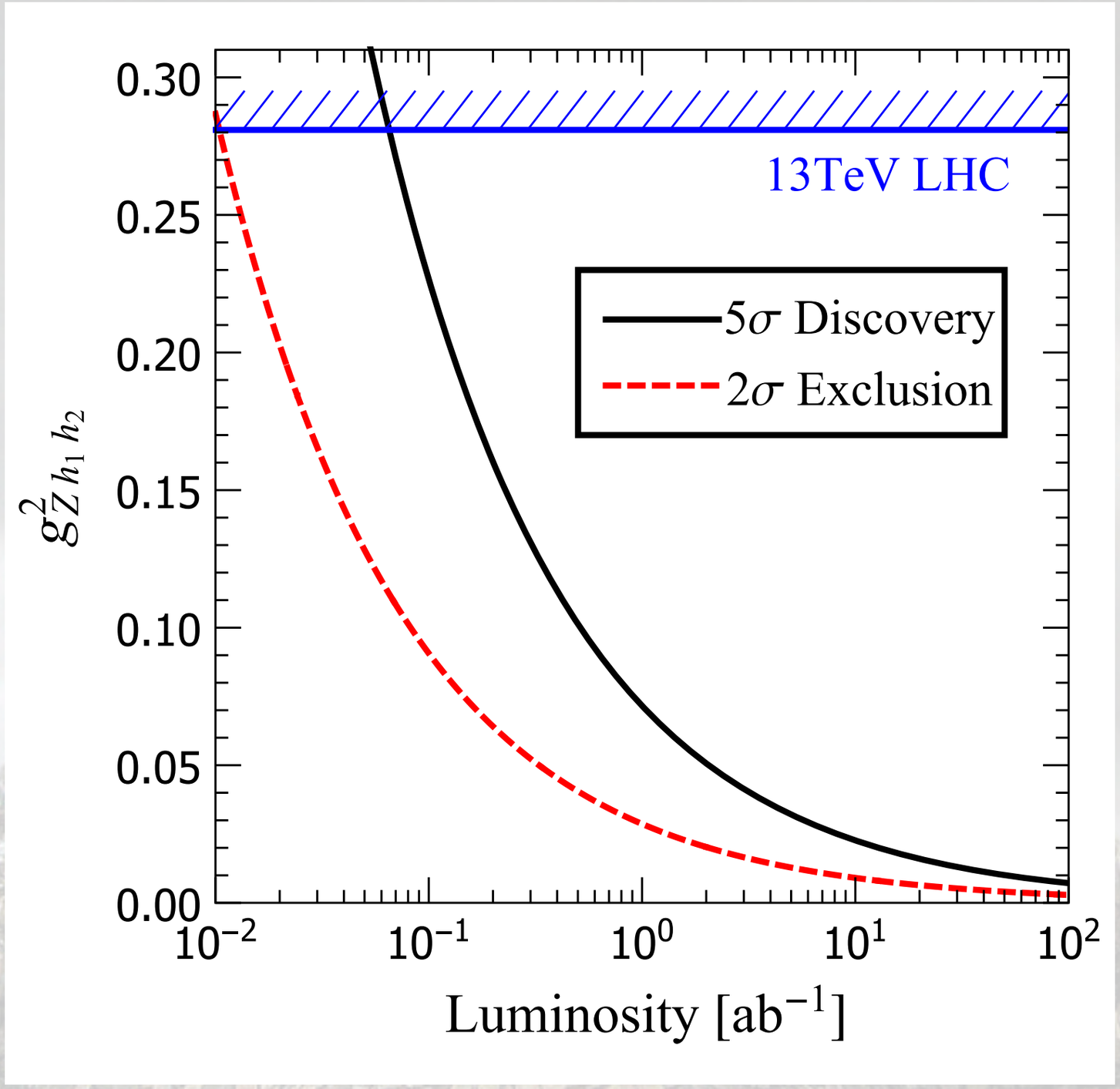

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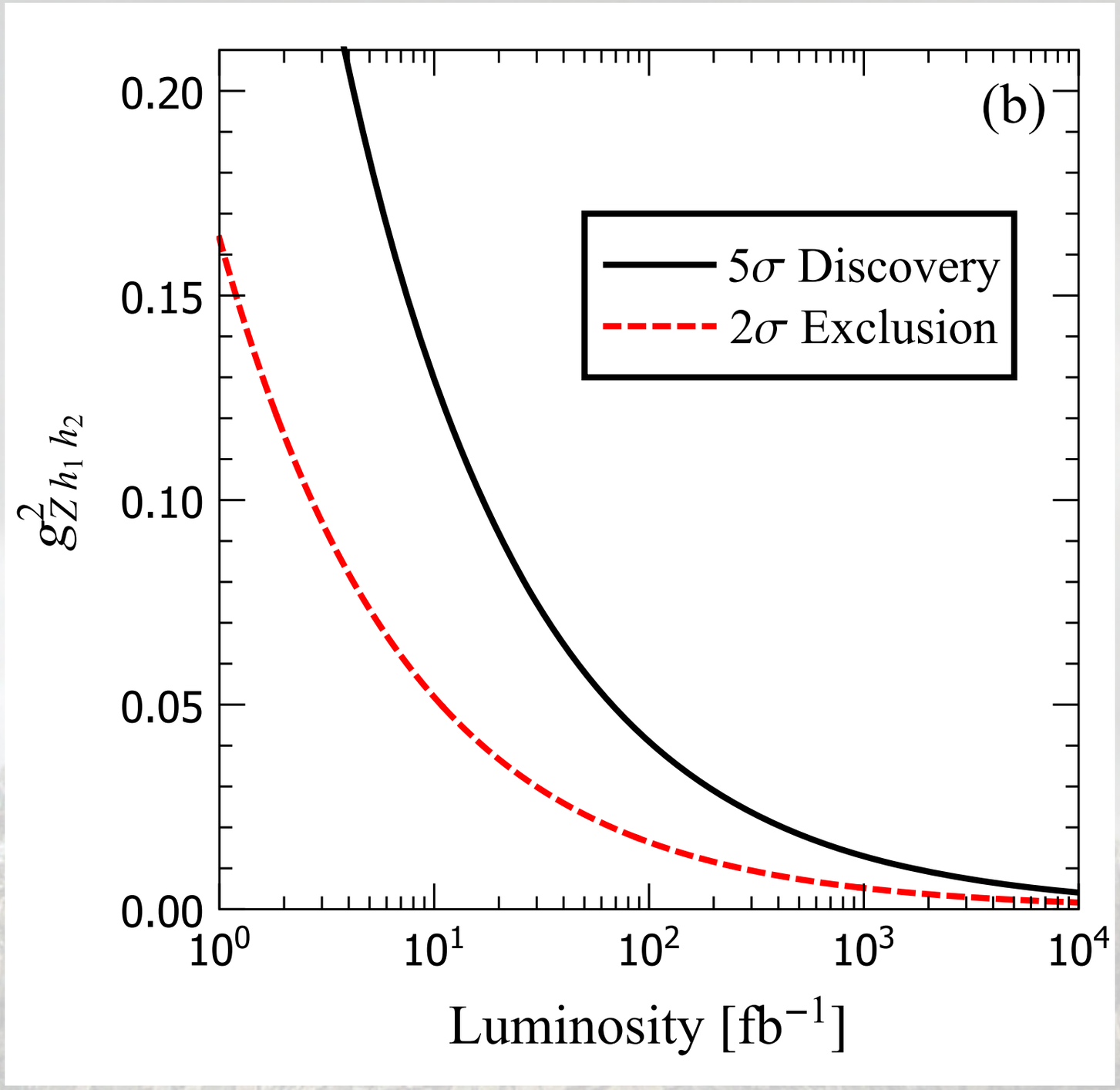

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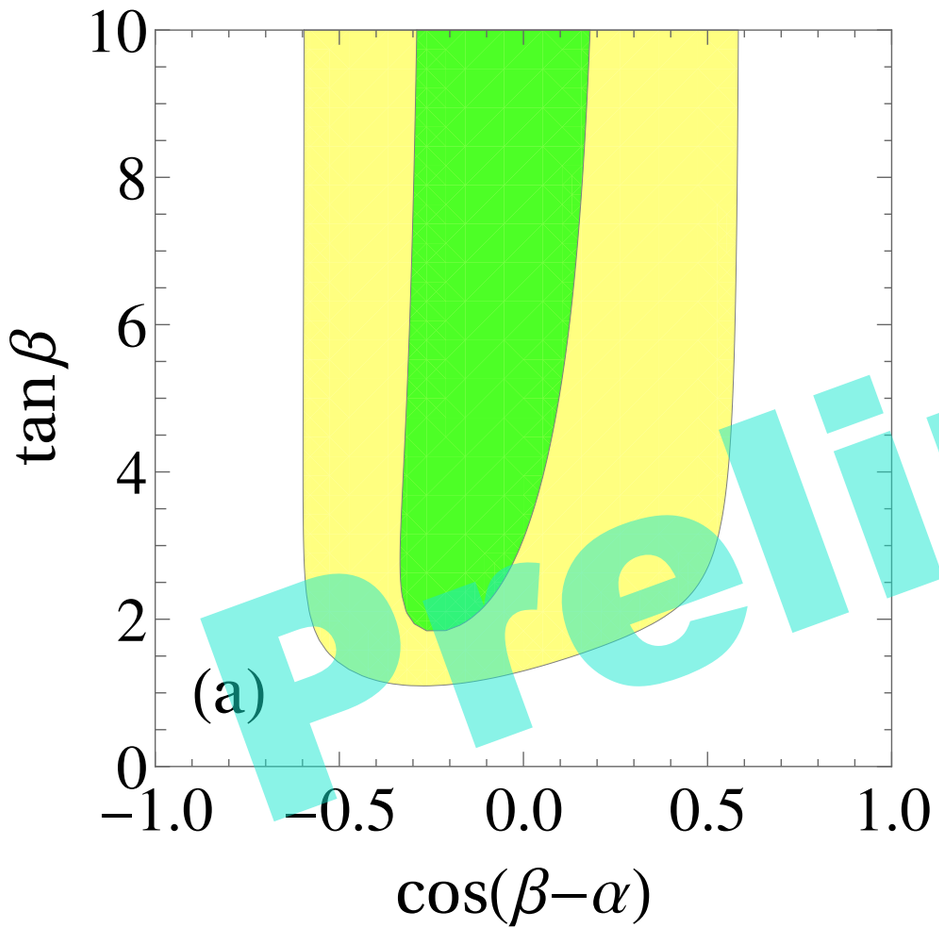
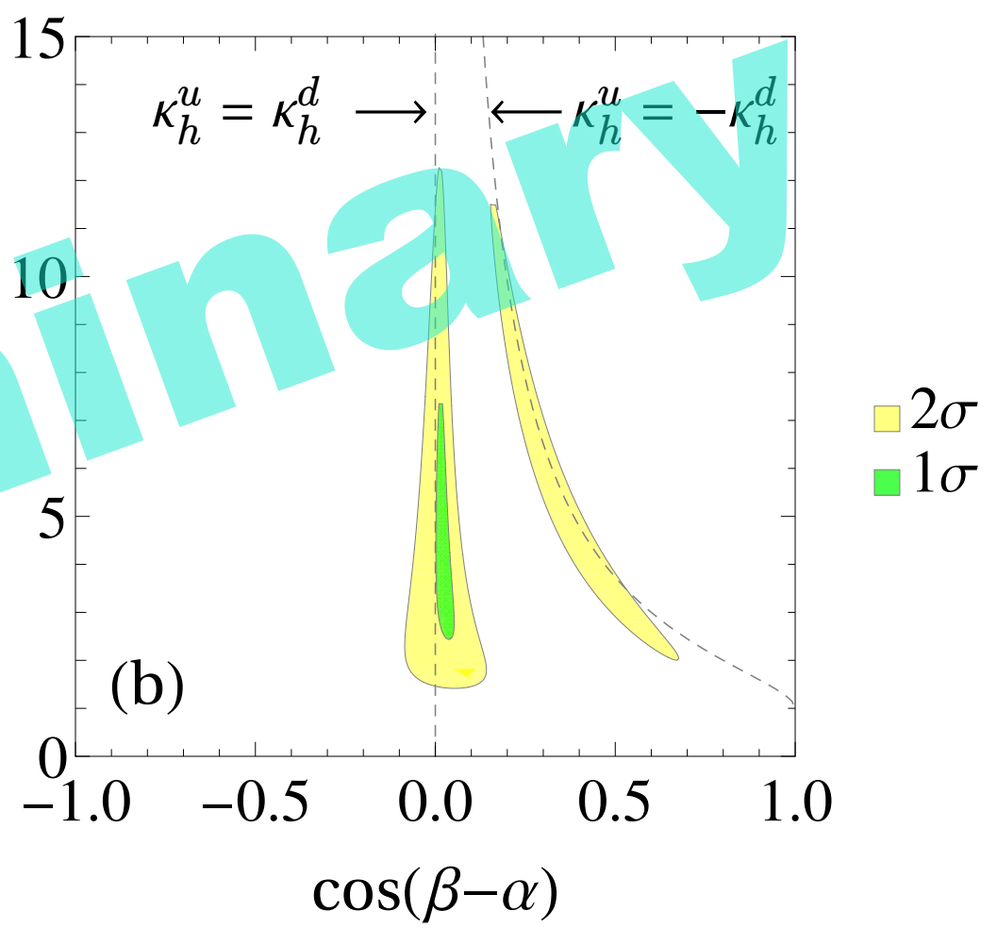
- More realistic model (2HDM)
- The work will be submitted to arXiv soon.





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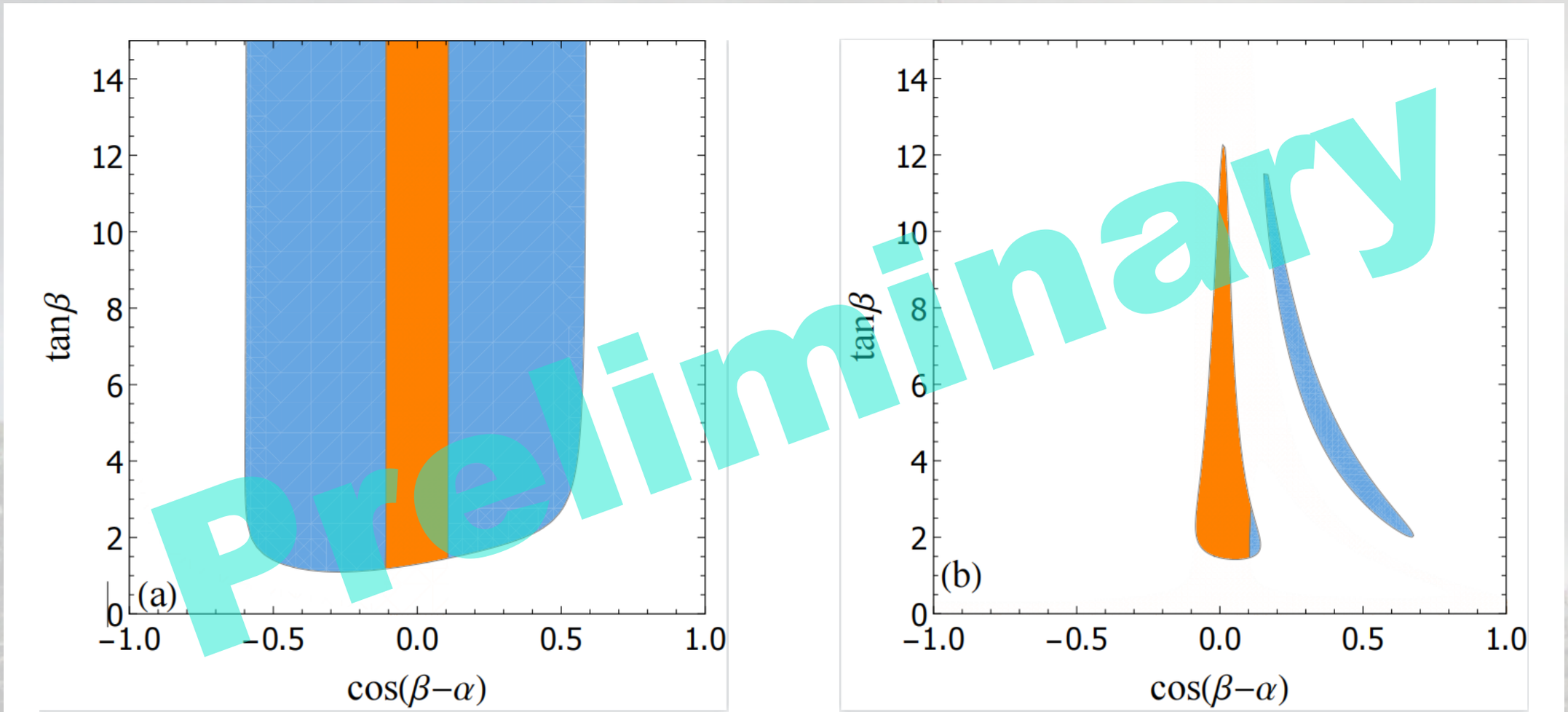

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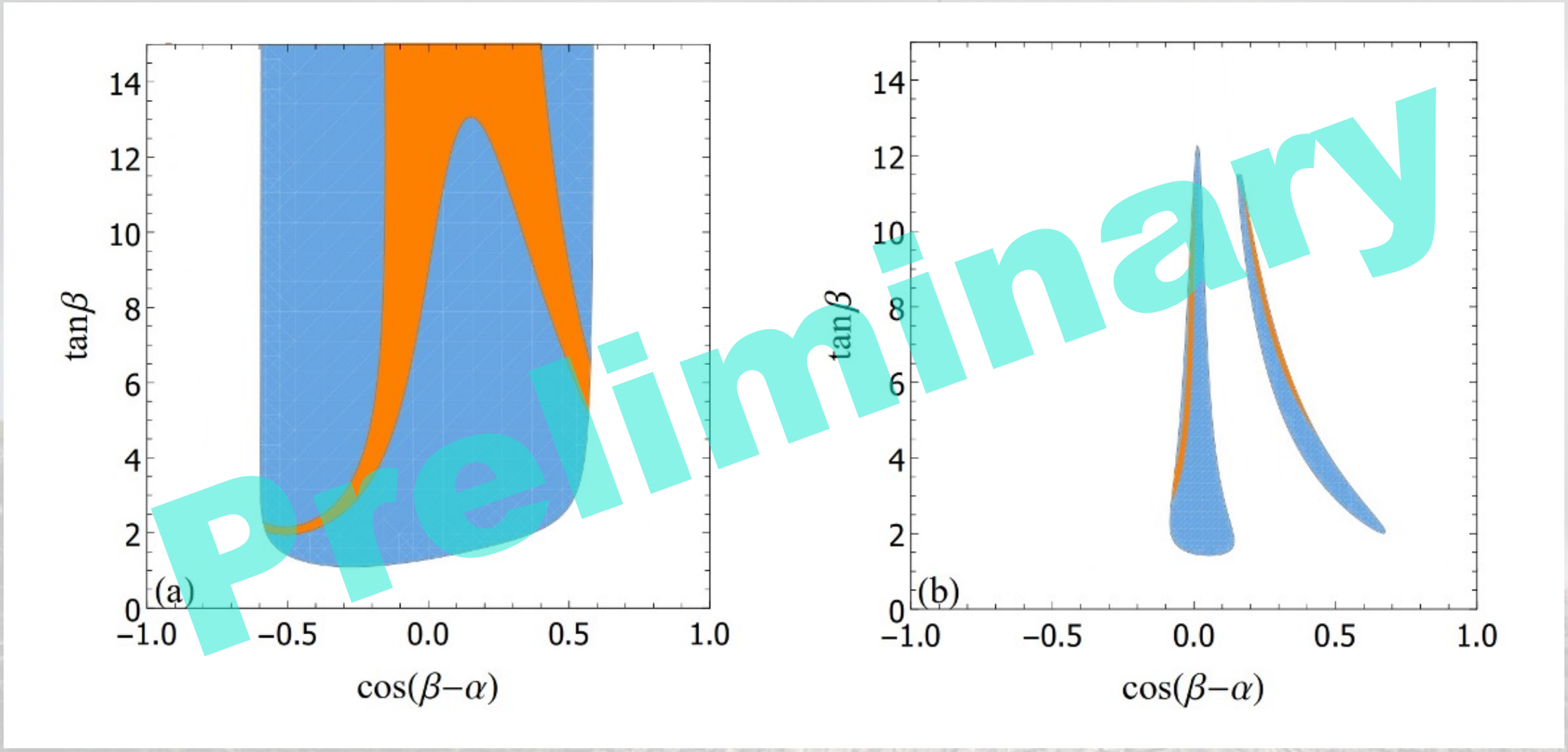

Thank you!