Comparative Analysis of Positivity Probing: Diphoton Channel at CEPC vs. Photon-Fusion Processes at LHC

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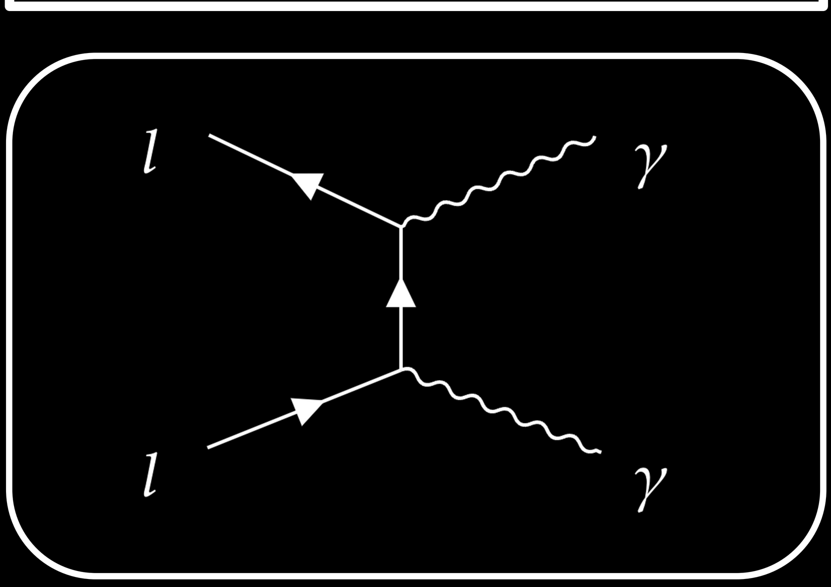
Current work with Prof. Jiayin Gu

Introduction

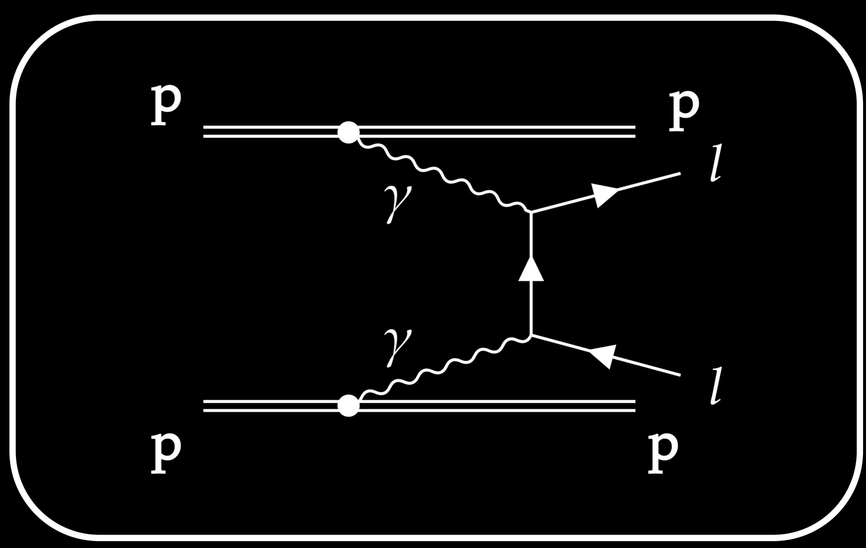
Certain dim-8 operators are subject to the so-called positivity bounds, assuming the underlying UV physics is consistent with the fundamental principles of quantum field theory, including unitarity, locality, analyticity and Lorentz invariance. Prior studies have identified constraints on dim-8 operators through the diphoton channel, particularly at CEPC. In this study, we probe into the exclusive photon-fusion processes at the LHC to extract constraints on dim-8 operators.

CEPC
Diphoton Channel



$$\frac{d\sigma\,(\gamma\gamma\to\ell^+\ell^-)}{d|\cos\theta|} = \frac{e^4}{8\pi s}\left[\frac{1+c_\theta^2}{1-c_\theta^2} + (a_L+a_R)\frac{s^2\,(1+c_\theta^2)}{8e^2v^4}\right]$$

LHC
Photon Fusion process



$$\frac{d\sigma\,(AB\to A\,(\gamma\gamma\to l^+l^-)\,B)}{d|\cos\theta|} = \int \frac{dE_{\gamma_1}}{E_{\gamma_1}}\frac{dE_{\gamma_2}}{E_{\gamma_2}}\frac{d^2N^{(AB)}_{\gamma_1/Z_1,\gamma_2/Z_2}}{dE_{\gamma_1}\,dE_{\gamma_2}}\frac{d\sigma\,(\gamma\gamma\to l^+l^-)}{d|\cos\theta|}$$

The parameters a_L and a_R are dim-8 operators in EFT. The positivity bounds, derived from QFT principles, are

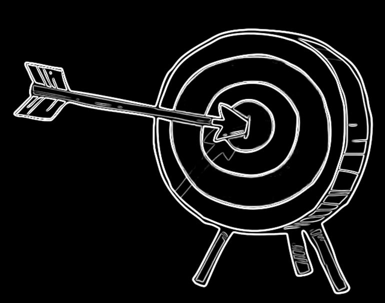
$$a_L, a_R > 0,$$

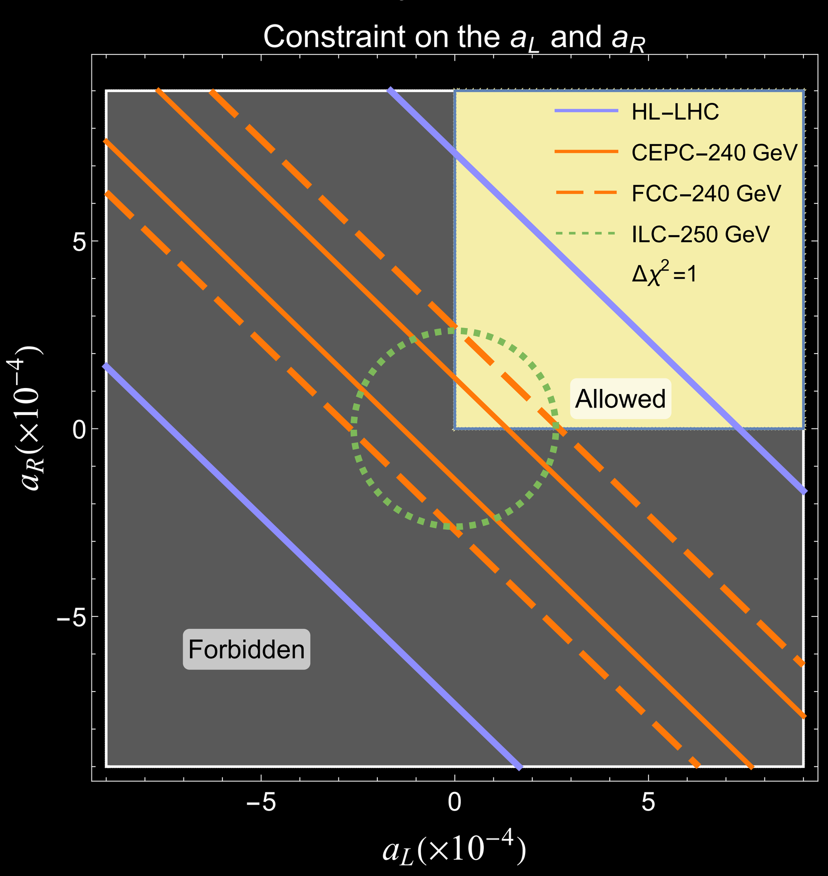
which implies cross sections are slightly larger than the SM case.
In LHC scenario, we use the photon PDF provided by Ref. [1].

Comparison Analysis

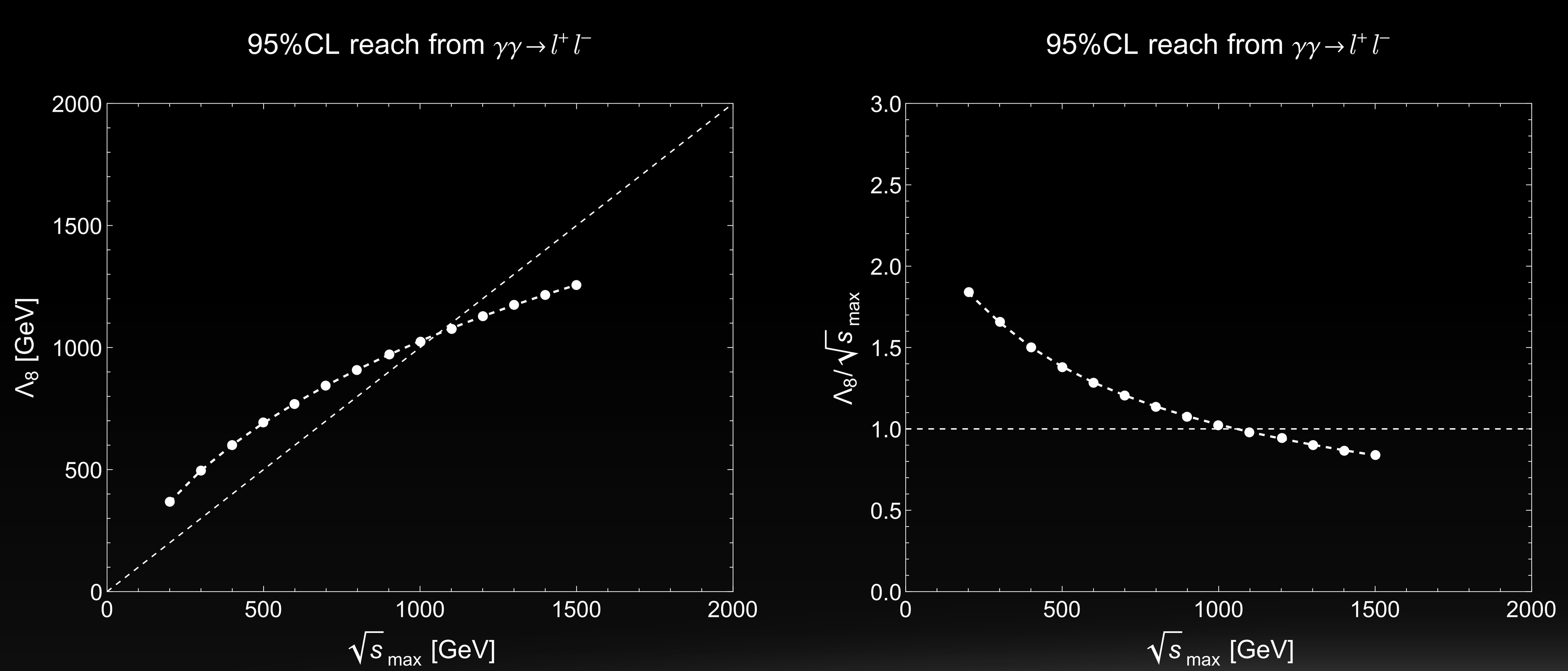
For the HL-LHC pp run of 3 ab^{-1}, we perform a binned analysis, with $m_{ll} \in [100,1500]$ GeV and a bin width of 50 GeV. The analysis on lepton colliders is reproduced from Ref. [2]. We take 240 GeV runs of CEPC and FCC-ee with luminosity 20 ab^{-1} and 5 ab^{-1} respectively, and 250 GeV run of ILC with luminosity 0.9 ab^{-1} and polarization of $(\pm 0.8, \mp 0.3)$.

This figure shows the constraint on measurements of a_L and a_R. The grey area is forbidden by positivity bounds.

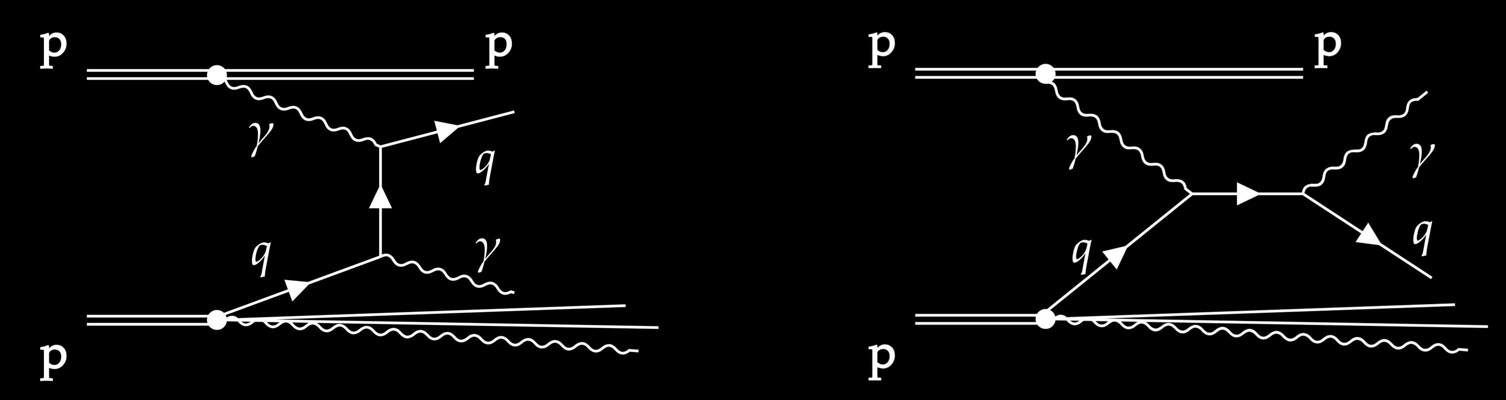




EFT Validity Test



$\gamma q \to \gamma q$ processes

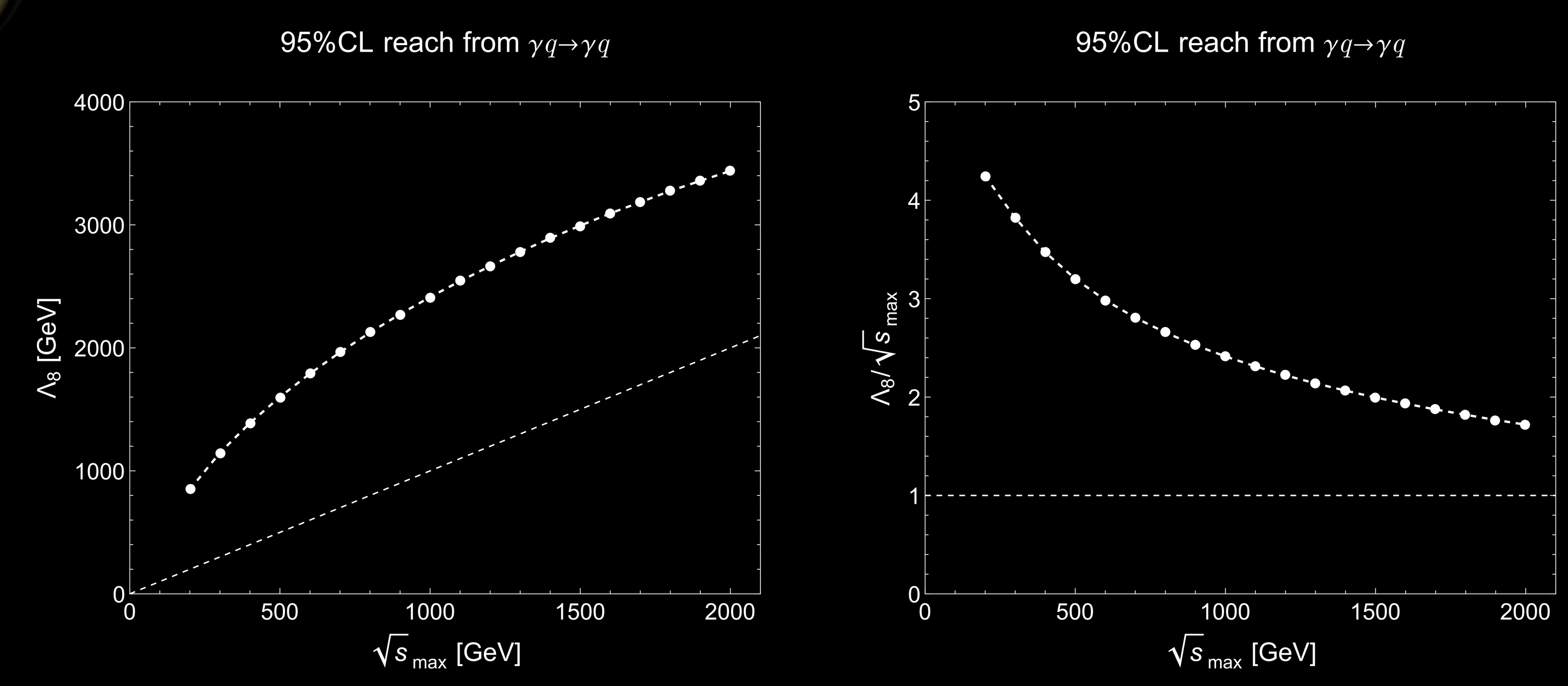


Here, we propose $\gamma q \to \gamma q$ can also be measured and is sensitive to a set of dim-8 operators involving quarks, which are subject to positivity bounds as well.

$$\frac{d\sigma\,(\gamma q\to\gamma q)}{d|\cos\theta|} = \frac{Q^4e^4}{4\pi s}\left[\frac{2}{1-c_\theta^2} - (a_L+a_R)\frac{s^2}{2Q^2e^2v^4}\right]$$

This process has two advantages: first, the final state photon could be used to reduce QCD backgrounds; second, the initial state quark has a larger PDF than photon, so the cross section of this process is larger, especially at high energies. We then convolute it with the photon PDF and the quark PDF, from MMHT PDF[3].

The reach is significantly better, with precision of $\sim 10^{-5}$ for $a_L + a_R$ (assuming the operator coefficients are universal for all quark flavors) and a reach on Λ_8 of about $2 \sim 4$ TeV. With b-tagging, one is also able to pick out and probe the b-quark related operators with a reasonable sensitivity.



Conclusion

Our analysis reveals that for dim-8 operators involved in diphoton and dilepton, the CEPC holds potential advantages over the LHC, reaching more precise results. While LHC has advantages in $\gamma q \to \gamma q$ processes, a sufficiently large ratio ($\gtrsim 2$) between the new physic scale that can be reached (assuming order one couplings) and the maximum final-state center-of-mass energy can be achieved.

Reference:
[1] JHEP. 09 (2022) 248, H.-S. Shao and D. d'Enterria.
[2] Phys. Rev. Lett. 129 (2022), no. 1 011805, Jiayin Gu, Lian-Tao Wang and Cen Zhang.
[3] Eur Phys J C 75 (2015), no. 5 204, L. A. Harland-Lang, A. Martin, P. Motylinski, and R. Thorne