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

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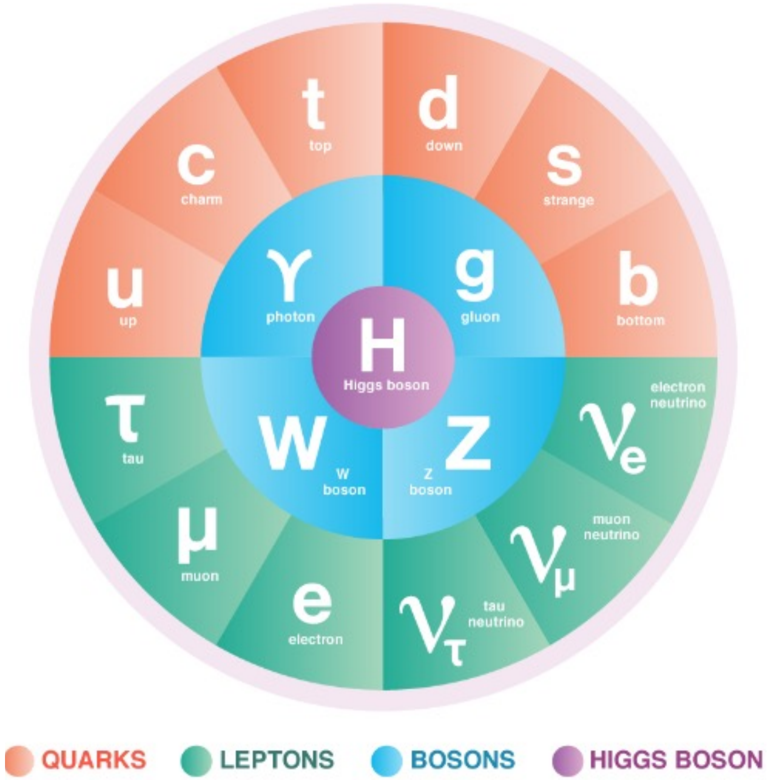
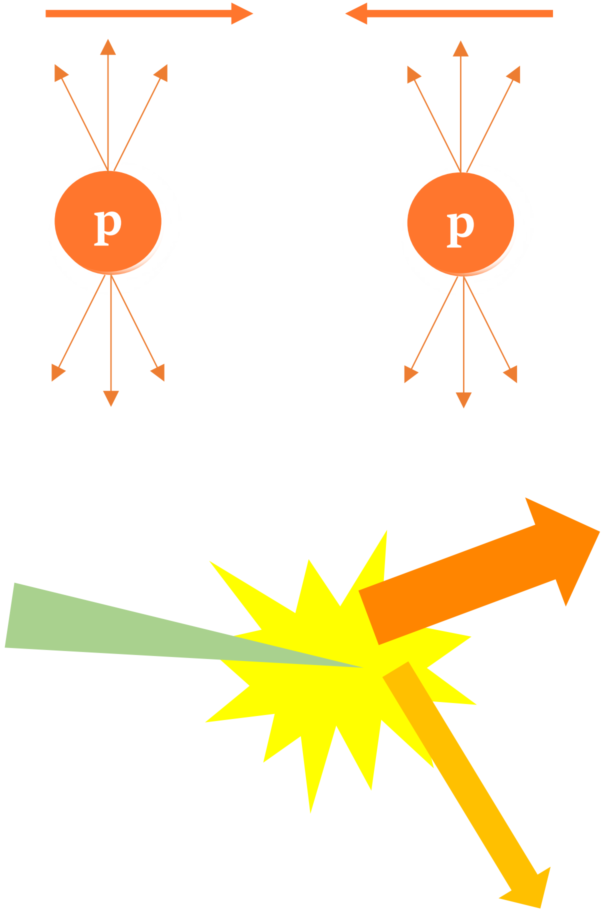
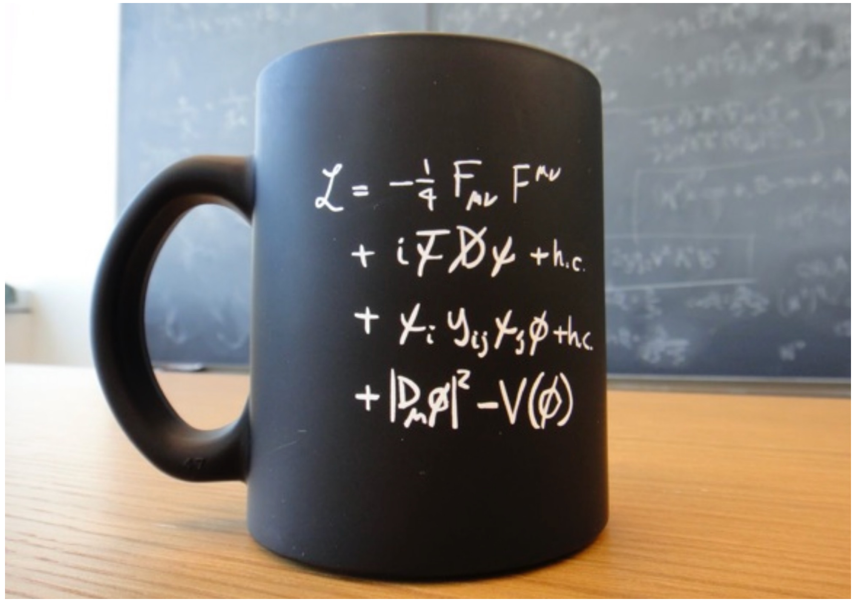
Current work with Prof. Jiayin Gu

Introduction

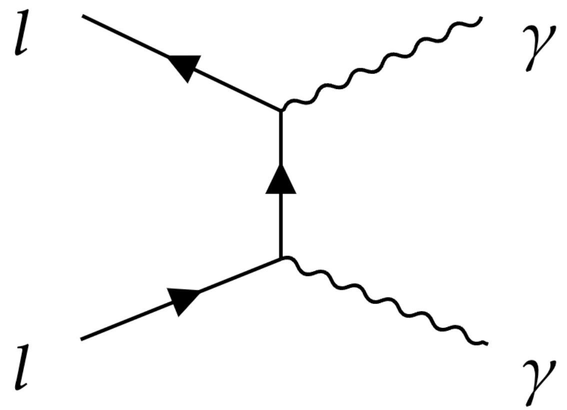




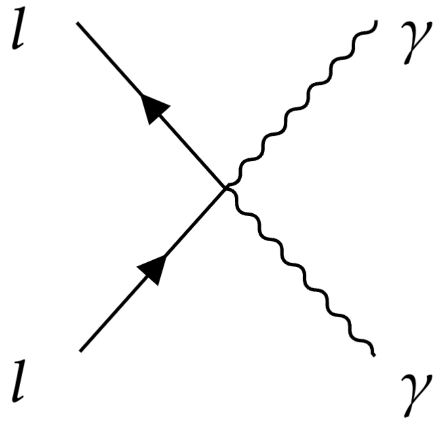


$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4} O_j^{(8)} + \ldots$$

Positivity



$$\mathcal{L}_{\text{QED}} = \mathcal{L}_{\text{Dirac}} + \mathcal{L}_{\text{Maxwell}} + \mathcal{L}_{\text{int}}$$
$$= \bar{\psi}(i\gamma^\mu \partial_\mu - m)\psi - \frac{1}{4}(F_{\mu\nu})^2 - g\bar{\psi}\gamma^\mu\psi A_\mu$$



$$Q_{l^2B^2D} = i(\bar{l}\gamma^\mu \overleftrightarrow{D}^\nu l)B_{\mu\rho}B_\nu{}^\rho\,,$$
$$Q^{(2)}_{l^2WBD} = i(\bar{l}\gamma^\mu \tau^I \overleftrightarrow{D}^\nu l)(B_{\mu\rho}W^{I\rho}_\nu + B_{\nu\rho}W^{I\rho}_\mu)\,,$$
$$Q^{(1)}_{l^2W^2D} = i(\bar{l}\gamma^\mu \overleftrightarrow{D}^\nu l)W^I_{\mu\rho}W^{I\rho}_\nu\,,$$
$$Q_{e^2B^2D} = i(\bar{e}\gamma^\mu \overleftrightarrow{D}^\nu e)B_{\mu\rho}B_\nu{}^\rho\,,$$
$$Q_{e^2W^2D} = i(\bar{e}\gamma^\mu \overleftrightarrow{D}^\nu e)W^I_{\mu\rho}W^{I\rho}_\nu\,.$$

$$a_L = -2\frac{v^4}{\Lambda^4}\left(c_W^2 c_{l^2B^2D} - 2s_W c_W c^{(2)}_{l^2WBD} + s_W^2 c^{(1)}_{l^2W^2D}\right)$$
$$a_R = -2\frac{v^4}{\Lambda^4}\left(c_W^2 c_{e^2B^2D} + s_W^2 c_{e^2W^2D}\right)$$

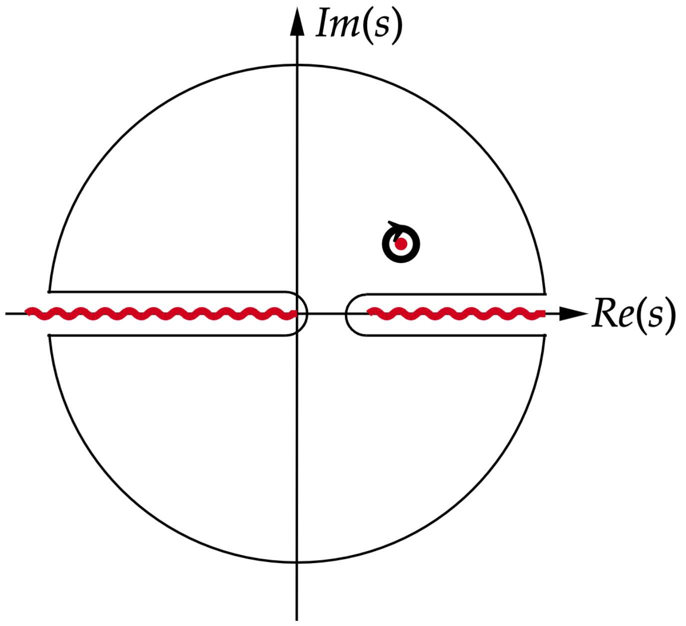
$$a_L > 0 \qquad a_R > 0$$

$$\mathcal{A}\left(l^+l^-\gamma^+\gamma^-\right)_{\text{SM+d}im-8}$$
$$= 2e^2\frac{\langle 24\rangle^2}{\langle 13\rangle\langle 23\rangle} + \frac{a}{v^4}[13][23]\langle 24\rangle^2$$
$$= 2e^2\frac{\langle 24\rangle^2}{\langle 13\rangle\langle 23\rangle}\left(1 + \frac{a}{2e^2v^4}tu\right)$$

$$\frac{d\sigma\left(l^+l^- \to \gamma\gamma\right)_{\text{SM+d}im-8}}{d|\cos\theta|}$$
$$= \frac{e^4}{8\pi s}\left(\frac{1+c_\theta^2}{1-c_\theta^2} + \frac{s^2\left(1+c_\theta^2\right)}{4e^2v^4}\frac{a_L + a_R}{2}\right)$$

PhysRevLett.129.011805 Jiayin Gu, Lian-Tao Wang and Cen Zhang

Positivity



Analyticity

- Cauchy's theorem

$$\mathcal{A}(s) = \sum_n c_n \left(s - \mu^2\right)^n$$

$$c_2 = \frac{1}{2\pi i} \oint_{s=\mu^2} ds \frac{\mathcal{A}_{ab}(s)}{\left(s-\mu^2\right)^{n+1}}$$

Locality

- poles
- branch cuts
- Froissart bound

Unitarity

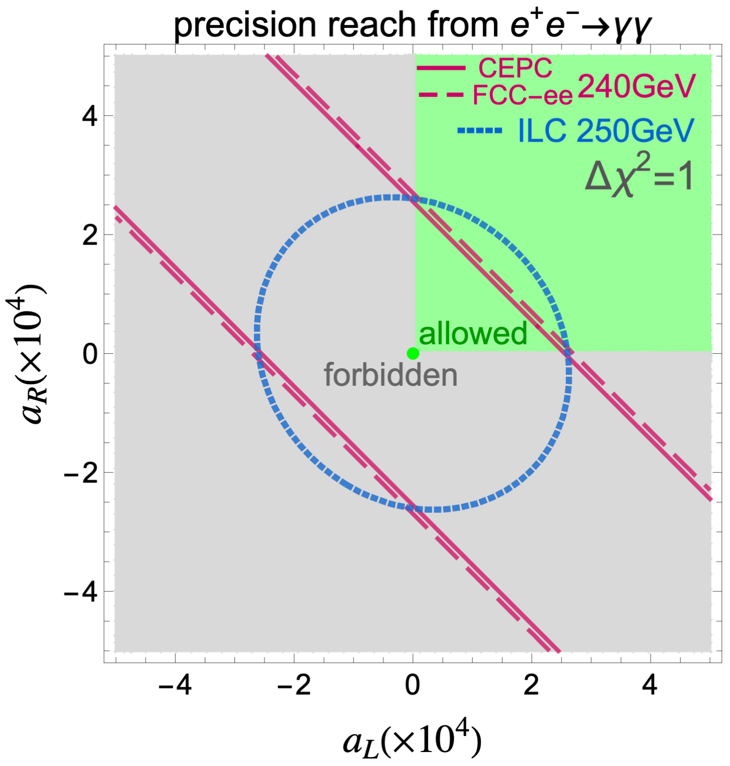
- Optical theorem

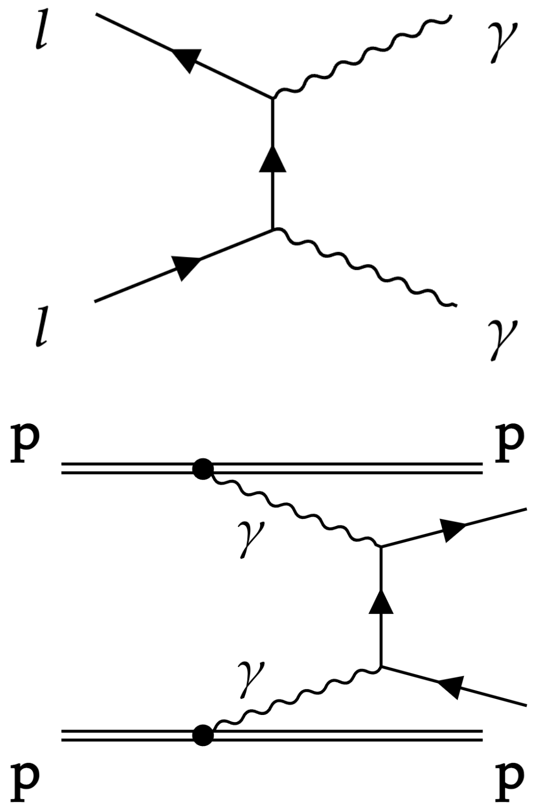
$$Im\, \mathcal{A} \propto \sigma_{tot}$$

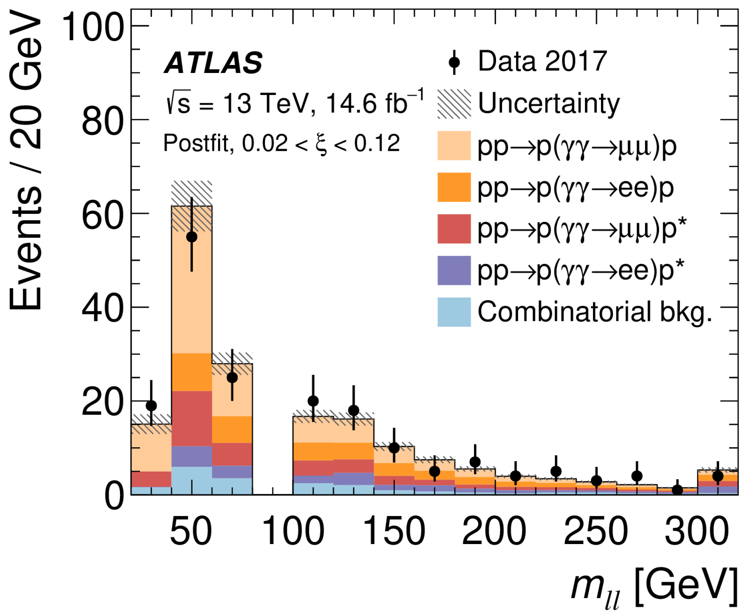
Dispersion relation

$$c_2 = \int_{4m^2}^{\infty} \frac{ds}{\pi} s \sqrt{1 - \frac{4m^2}{s}} \left(\frac{\sigma_{\text{tot}}^{ab}}{\left(s-\mu^2\right)^3} + \frac{\sigma_{\text{tot}}^{a\bar{b}}}{\left(s-4m^2+\mu^2\right)^3} \right) + c_2^{\infty}$$

$$a \propto c_2 > 0$$

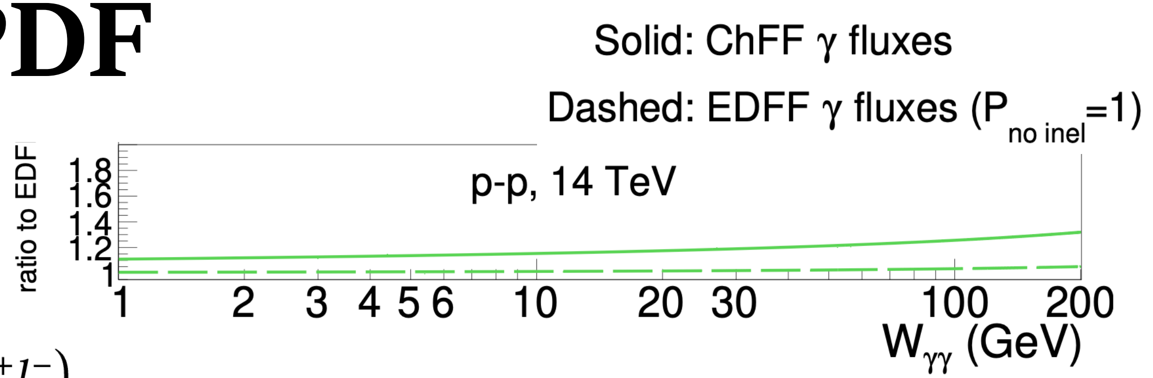




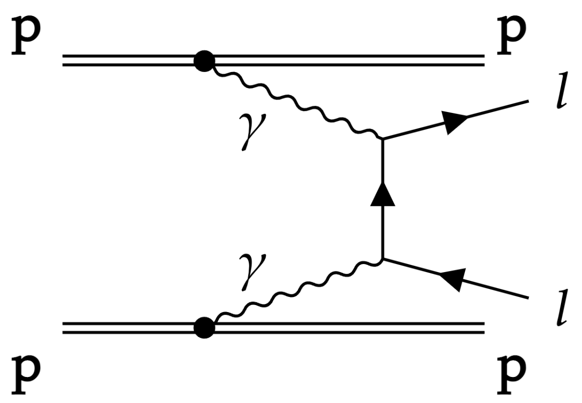


PhysRevLett.129.011805 Jiayin Gu, Lian-Tao Wang and Cen Zhang
https://cds.cern.ch/record/2754221/files/ATL-PHYS-SLIDE-2021-045.pdf

Obtain cross section by PDF



$$\frac{d\sigma(pp \to p(\gamma\gamma \to l^+l^-)p)}{d|\cos\theta|} = \int \frac{dE_{\gamma_1}}{E_{\gamma_1}} \frac{dE_{\gamma_2}}{E_{\gamma_2}} \frac{\mathrm{d}^2N^{(pp)}_{\gamma_1/\mathrm{Z}_1,\gamma_2/\mathrm{Z}_2}}{\mathrm{d}E_{\gamma_1}\mathrm{d}E_{\gamma_2}} \frac{d\sigma(\gamma\gamma \to l^+l^-)}{d|\cos\theta|}$$



$$\frac{\mathrm{d}^2N^{(pp)}_{\gamma_1/\mathrm{Z}_1,\gamma_2/\mathrm{Z}_2}}{\mathrm{d}E_{\gamma_1}\mathrm{d}E_{\gamma_2}} = \int \mathrm{d}^2b_1\mathrm{d}^2b_2 P_{\mathrm{noinel}}(|b_1 - b_2|)$$
$$N_{\gamma_1/\mathrm{Z}_1}(E_{\gamma_1}, b_1) N_{\gamma_2/\mathrm{Z}_2}(E_{\gamma_2}, b_2)$$
$$\theta(b_1 - \epsilon R_{\mathrm{A}})\theta(b_2 - \epsilon R_{\mathrm{B}})$$

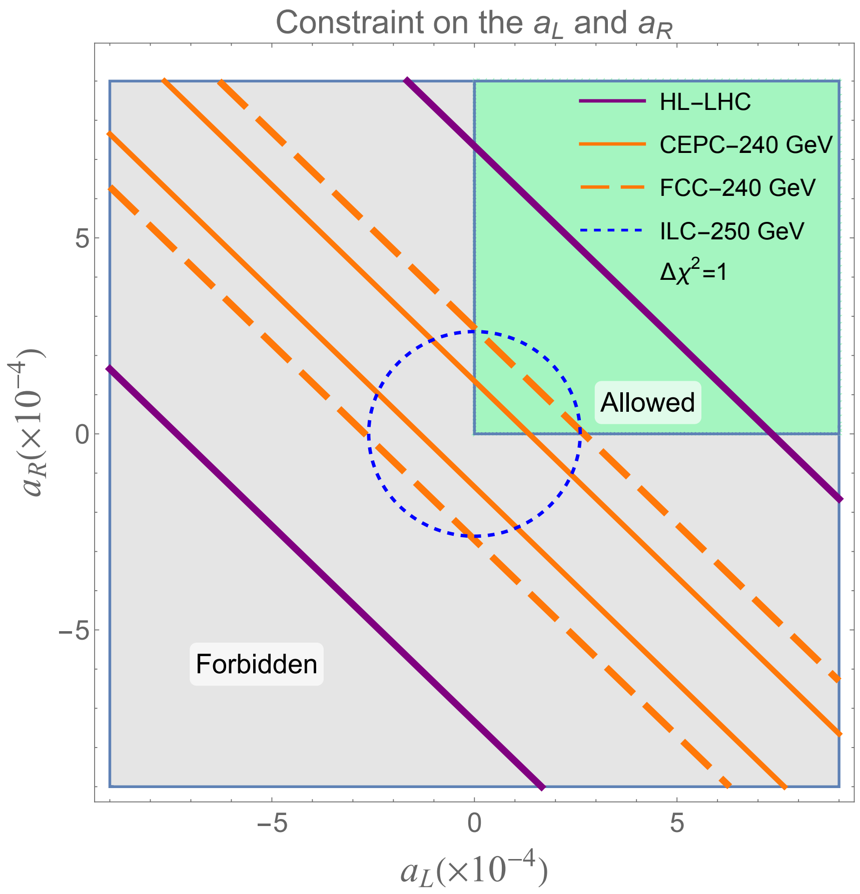
arxiv: 2207.03012 Huasheng Shao and David d’Enterria

Data analysis

chi-square analysis

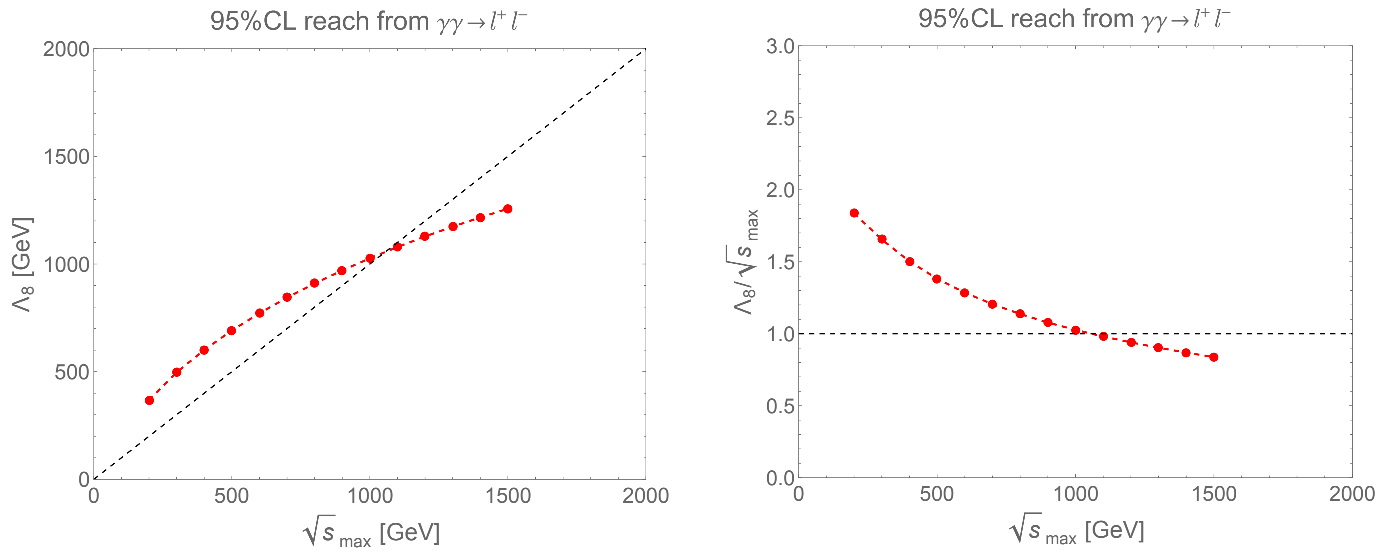
- prior hypothesis: Standard Model

$$\chi^2 = \sum \frac{(\sigma_{sm+dim8-bin} - \sigma_{sm-bin})^2 / \sigma^2_{sm-bin}}{\sqrt{\text{Events}}} \qquad \text{Events} = \text{lumi} * \sigma_{sm-bin}$$



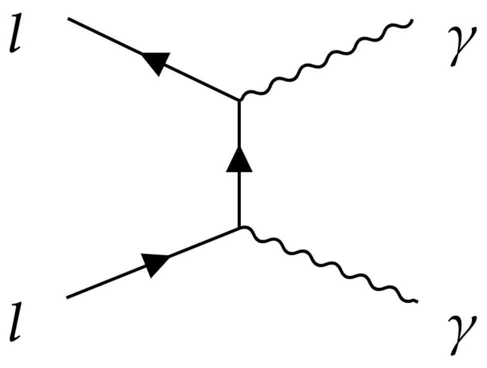
EFT validity test for the LHC

$$\Lambda_8 = \frac{v}{a^{1/4}}$$

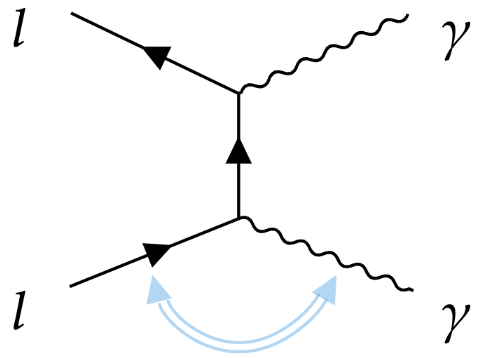


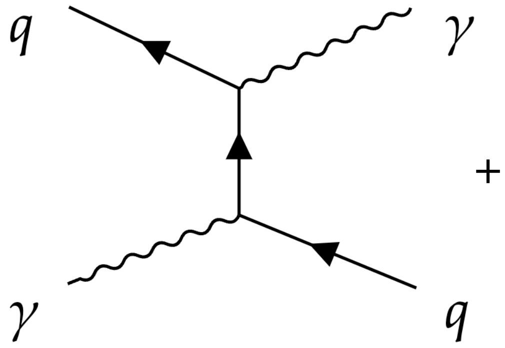
System	$\sqrt{s}$	Luminosity	Radius	1σ bound on $a_L + a_R$
Pb-Pb	14 TeV	$40\,\text{nb}^{-1}$	7.1 fm	0.26

An interesting process



$$\mathcal{A}\left(l^+l^-\gamma^+\gamma^-\right)_{\mathrm{SM+}dim\mathrm{-8}} = 2e^2\frac{\langle 24\rangle^2}{\langle 13\rangle\langle 23\rangle}\left(1+\frac{a}{2e^2v^4}tu\right)$$



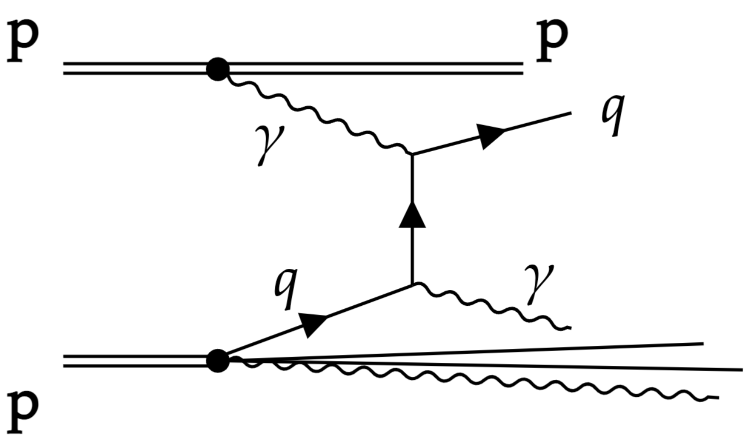


+s channel

$$\mathcal{A}\left(q^+\gamma^+q^-\gamma^-\right)_{\mathrm{SM+}dim\mathrm{-8}} = 2e^2\frac{\langle 34\rangle^2}{\langle 12\rangle\langle 32\rangle}\left(1+\frac{a'}{2e^2v^4}su\right)$$

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

The process in UPC



Detector:
- one forward proton
- one photon
- one jet

The constraint on dim-8 operators
with selection efficiency 11%
(Assuming no background)

dim-8 operators	constraint
$a_{all-quark}$	$\sim 10^{-5}$
a_b	$\sim 10^{-4}$

Conclusion

Comparative Analysis

- 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.

New process: $\gamma\, q \;\rightarrow \gamma\, q$ process

- There are positivity bounds between $\gamma\, q \;\rightarrow \gamma\, q$ process in UPC. The final state photon could be used to reduce QCD backgrounds and the initial state quark has a larger PDF than photon.
- The LHC can make constrain on dim-8 operators for quark, presenting an innovative approach for probing these physics beyond the SM.

Reference

[1] Gu, Jiayin, Lian-Tao Wang, and Cen Zhang. "Unambiguously testing positivity at lepton colliders." *Physical Review Letters* 129.1 (2022): 011805.
[2] Shao, Hua-Sheng, and David d'Enterria. "gamma-UPC: automated generation of exclusive photon-photon processes in ultraperipheral proton and nuclear collisions with varying form factors." *Journal of High Energy Physics* 2022.9 (2022): 1-43.
[3] Aad, Georges, et al. "Observation and measurement of forward proton scattering in association with lepton pairs produced via the photon fusion mechanism at ATLAS." *Physical review letters* 125.26 (2020): 261801.
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