Probing positivity with UPC

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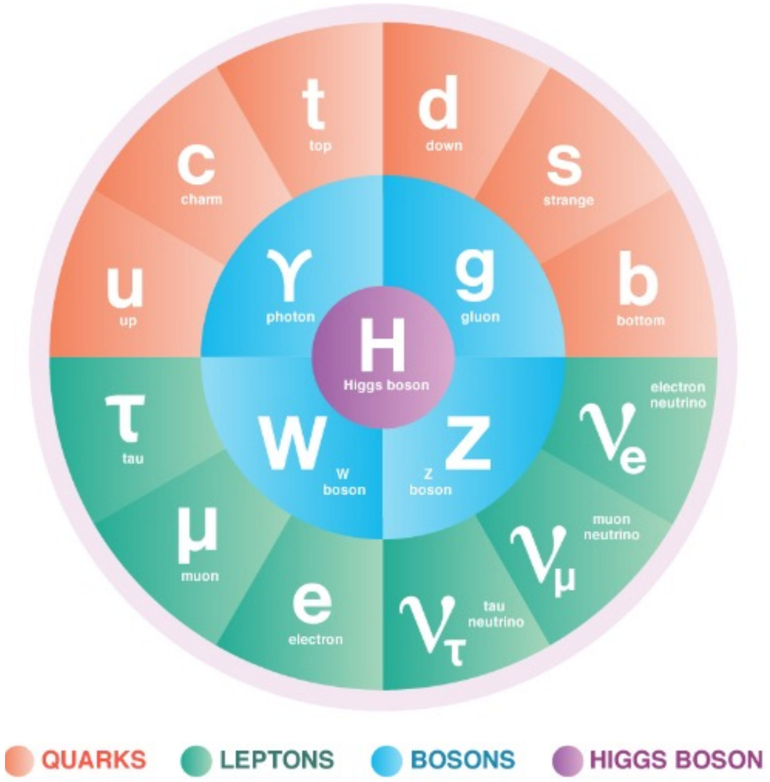
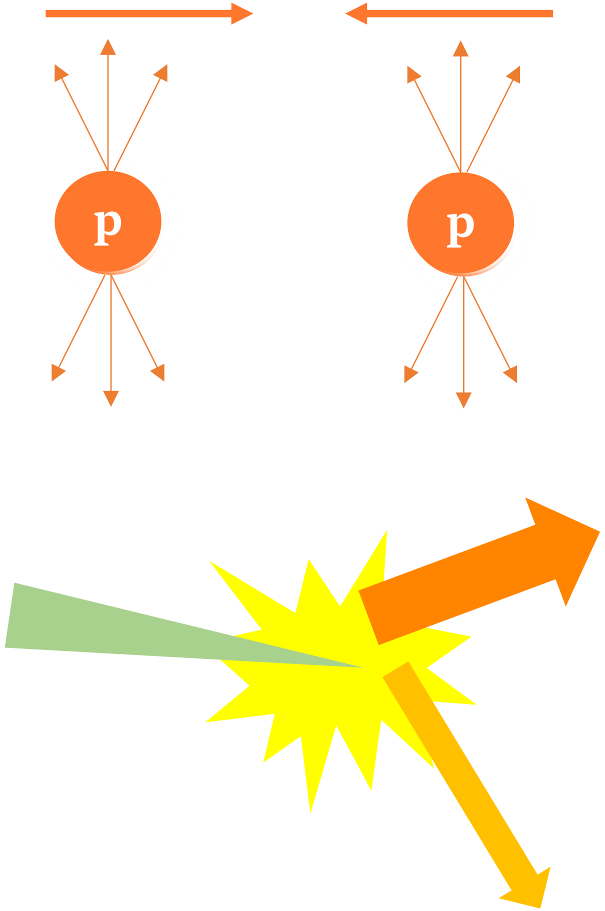
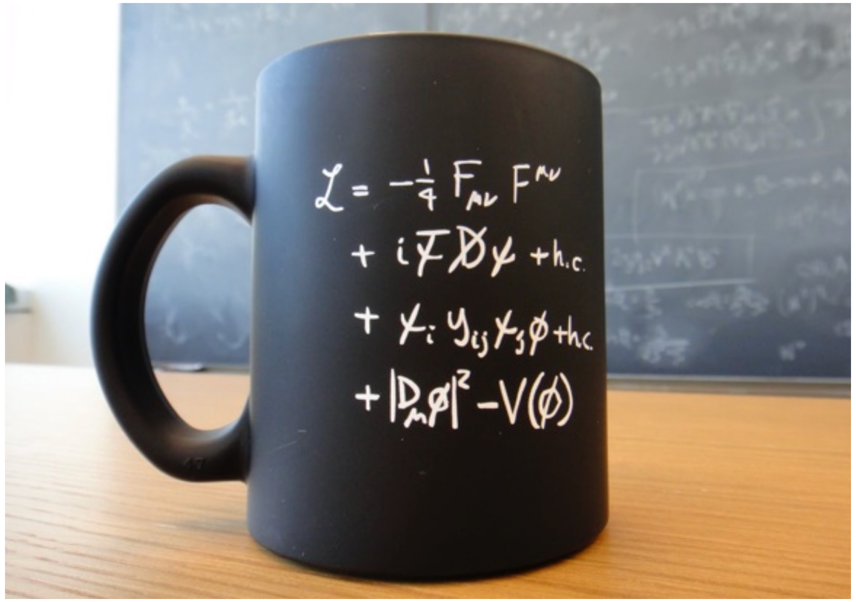
Current work with Prof. Jiayin Gu

Introduction

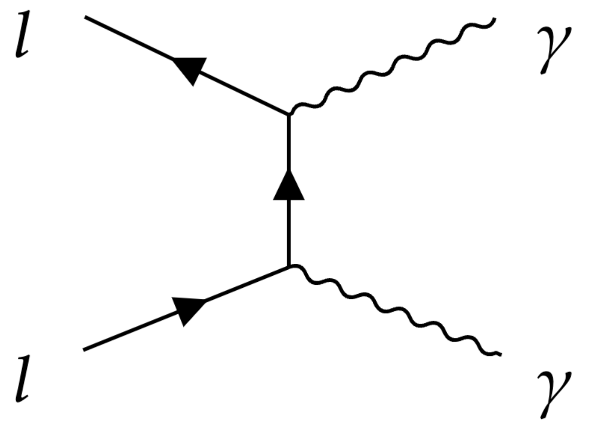




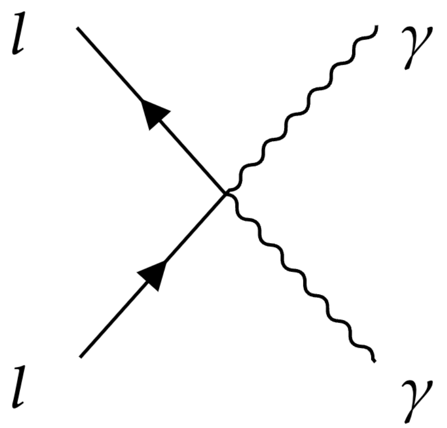


$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4} O_j^{(8)} + \dots$$

Positivity



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



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

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

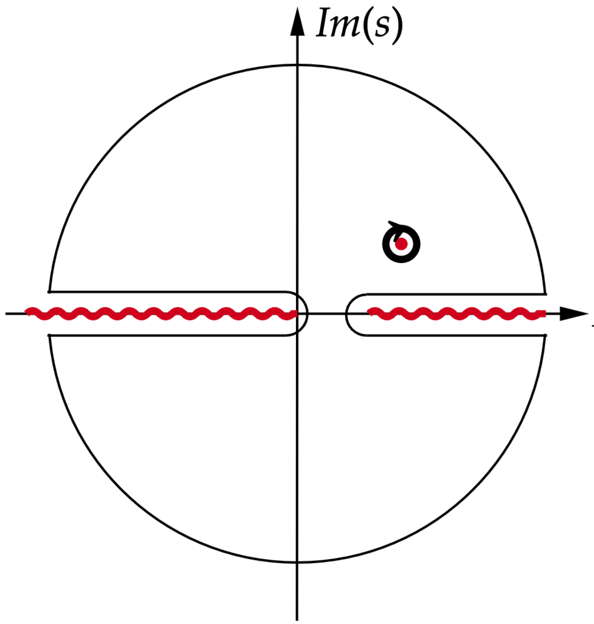
$$a_R = -2\frac{v^4}{\Lambda^4}\left(c_W^2 c_{e^2B^2D} + s_W^2 c_{e^2W^2D}\right)$$

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

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

PhysRevLett.129.011805 Jiayin Gu, Liantao 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

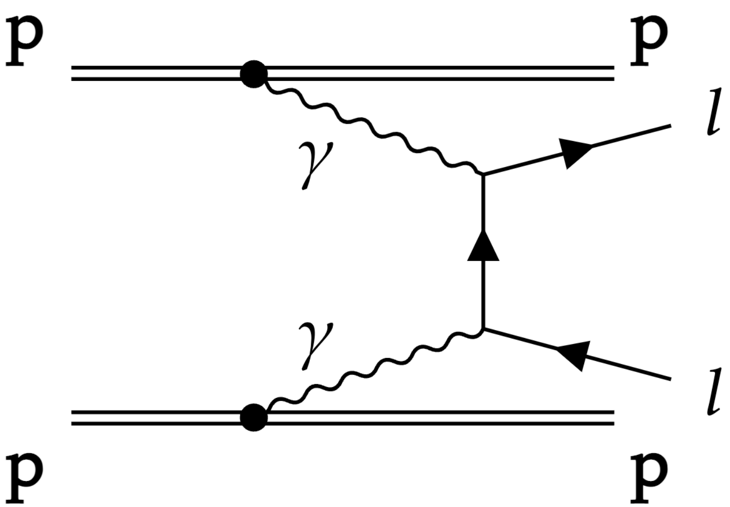
$$Im\, \mathcal{A} \propto \sigma_{tot}$$

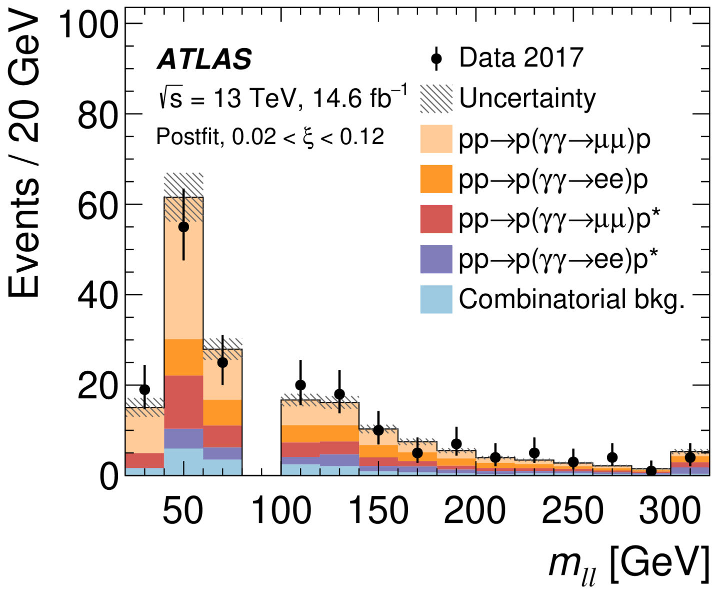
Dispersion relation

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

$$a \propto c_2 > 0$$

Ultraperipheral Collision





https://cds.cern.ch/record/2754221/files/ATL-PHYS-SLIDE-2021-045.pdf

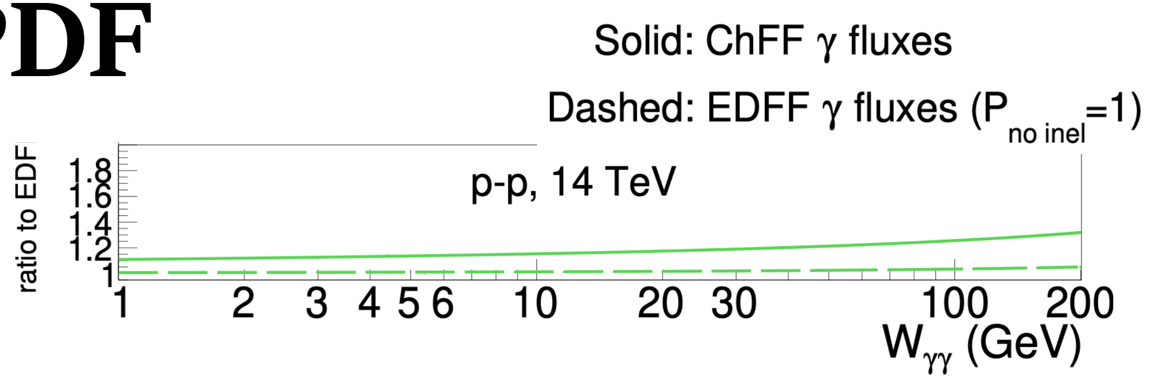
Obtain cross section by PDF

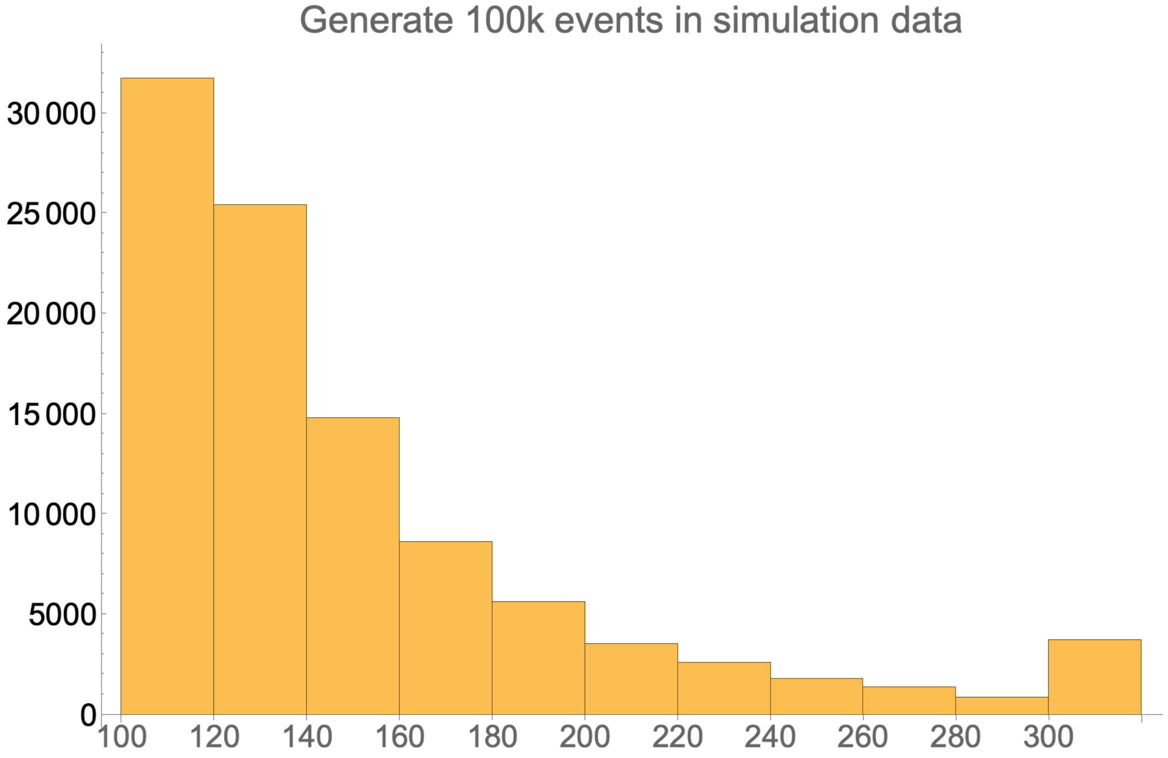
$$\frac{d\sigma(pp \to p(\gamma\gamma \to l^+l^-)p)}{d|\cos\theta|} = \int \frac{dE_{\gamma_1}}{E_{\gamma_1}} \frac{dE_{\gamma_2}}{E_{\gamma_2}} \frac{\mathrm{d}^2 N^{(pp)}_{\gamma_1/Z_1,\gamma_2/Z_2}}{\mathrm{d}E_{\gamma_1}\mathrm{d}E_{\gamma_2}} \frac{d\sigma(\gamma\gamma \to l^+l^-)}{d|\cos\theta|}$$

$$\frac{\mathrm{d}^2 N^{(pp)}_{\gamma_1/Z_1,\gamma_2/Z_2}}{\mathrm{d}E_{\gamma_1}\mathrm{d}E_{\gamma_2}} = \int \mathrm{d}^2 b_1 \mathrm{d}^2 b_2 P_{\mathrm{noinel}}(|b_1 - b_2|) N_{\gamma_1/Z_1}(E_{\gamma_1}, b_1) N_{\gamma_2/Z_2}(E_{\gamma_2}, b_2) \theta(b_1 - \epsilon R_{\mathrm{A}})\theta(b_2 - \epsilon R_{\mathrm{B}})$$

Take the approximation

$$P_{noinel}(\mathbf{b}) = 1$$





arxiv: 2207.03012 Huasheng Shao and David d'Enterria

Data analysis

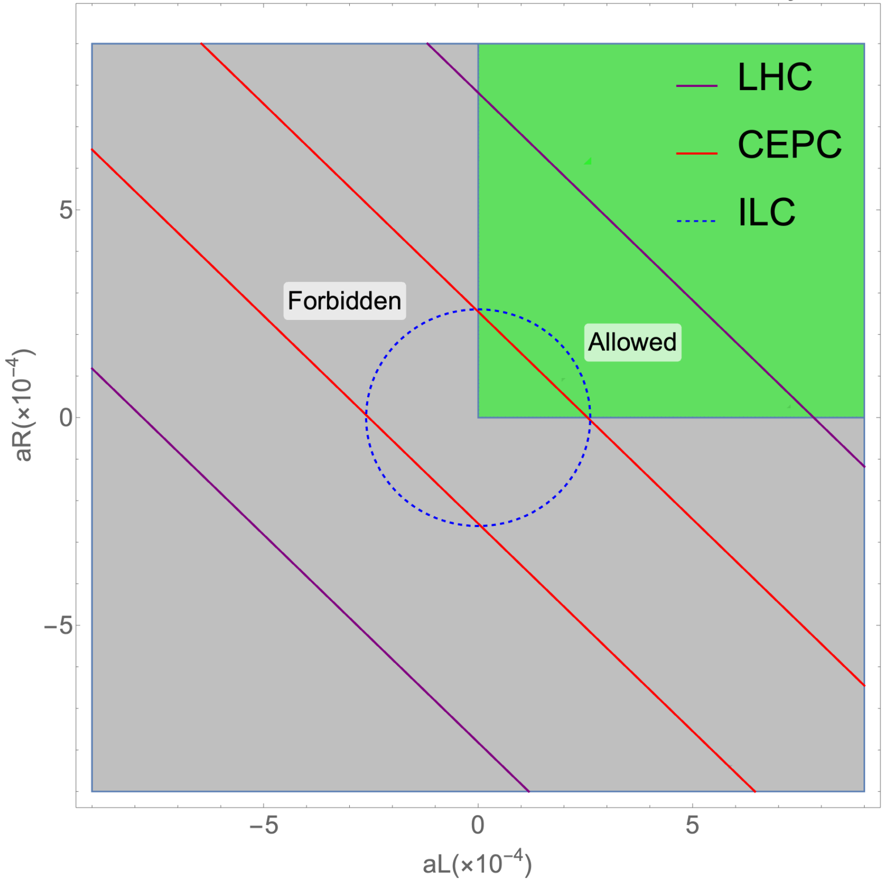
chi-square analysis

- prior hypothesis: Standard Model

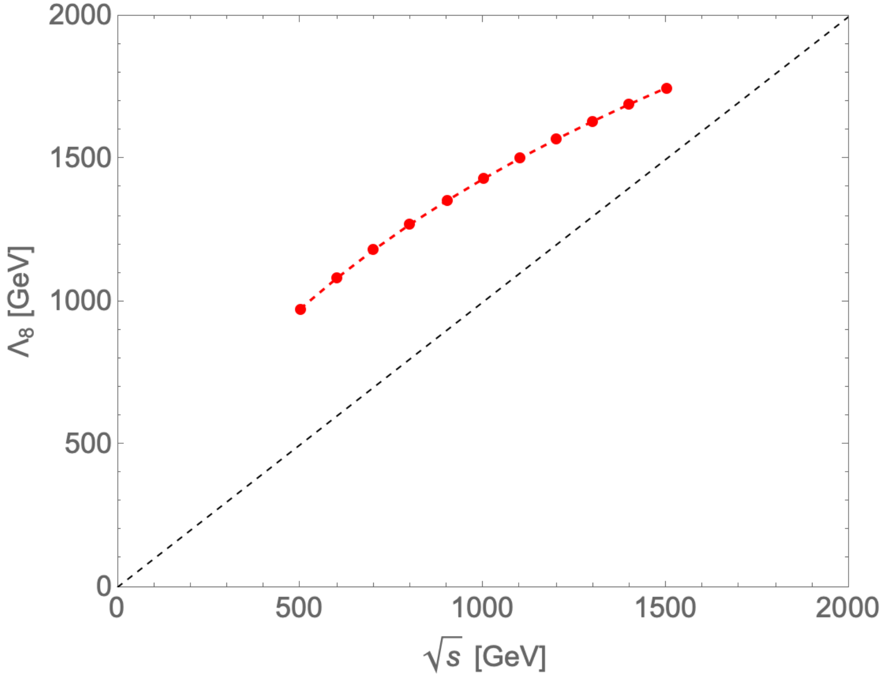
$$\chi^2 = \sum \frac{(\sigma_{sm+dim8-bin} - \sigma_{sm-bin})^2 / \sigma_{sm-bin}^2}{\sqrt{\text{Events}}} \qquad \text{Events} = \text{lumi} * \sigma_{sm-bin}$$

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

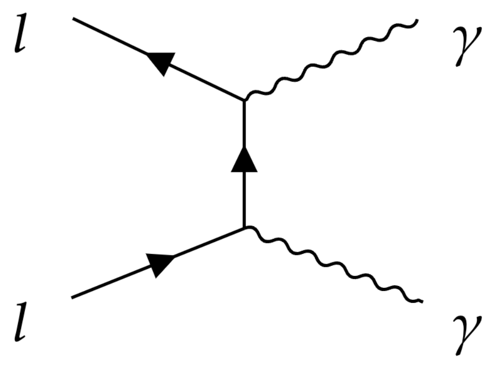
Constraint on the aL and aR with selection effeciency 25%



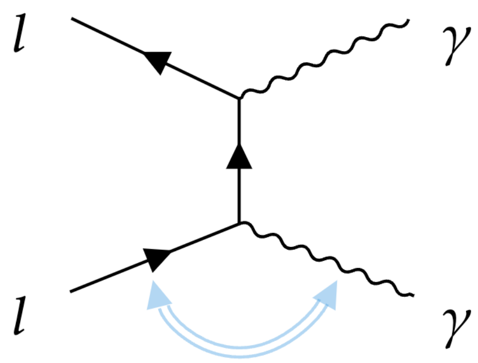
The reach on the scale of the dim−8 operators

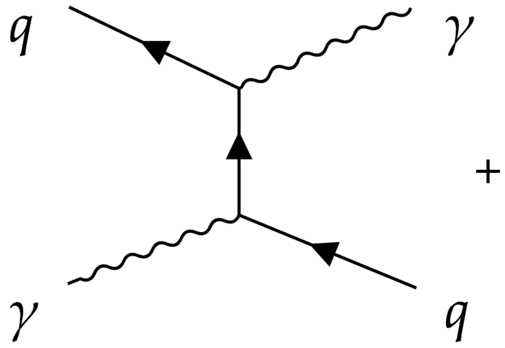


An interesting process



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



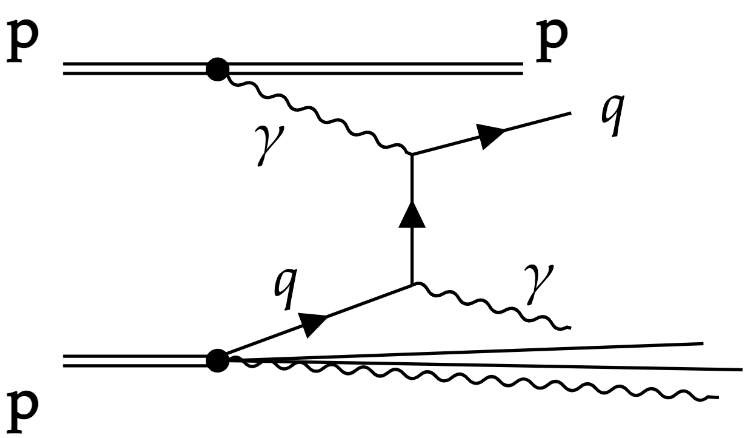


+s channel

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

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

The process in UPC



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

The constraint on dim-8 operators
with selection efficiency 15%
(Assuming no background)

dim-8 operators	constraint
$a_{all-quark}$	2.38×10^{-5}
a_b	1.49×10^{-4}

Conclusion

$\gamma\gamma \to l^+ l^-$ process

- The ATLAS has observed $\gamma\gamma \to l^+ l^-$ process at LHC.
- As the LHC continues to operate at high luminosity, the resulting experimental data promises to open new avenues for testing the SM and QFT.
- The constraint on dim-8 operators from LHC and CEPC is in the same order.

New process: $\gamma q \to \gamma q$ process

- There are positivity bounds between $\gamma q \to \gamma q$ process in UPC.
- 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.
[4] Alwall, Johan, et al. "The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations." *Journal of High Energy Physics* 2014.7 (2014): 1-157.
[5] Liu, Jesse. *Photon-induced dilepton production with forward proton tag at ATLAS*. No. ATL-PHYS-SLIDE-2021-045. ATL-COM-PHYS-2021-055, 2021.