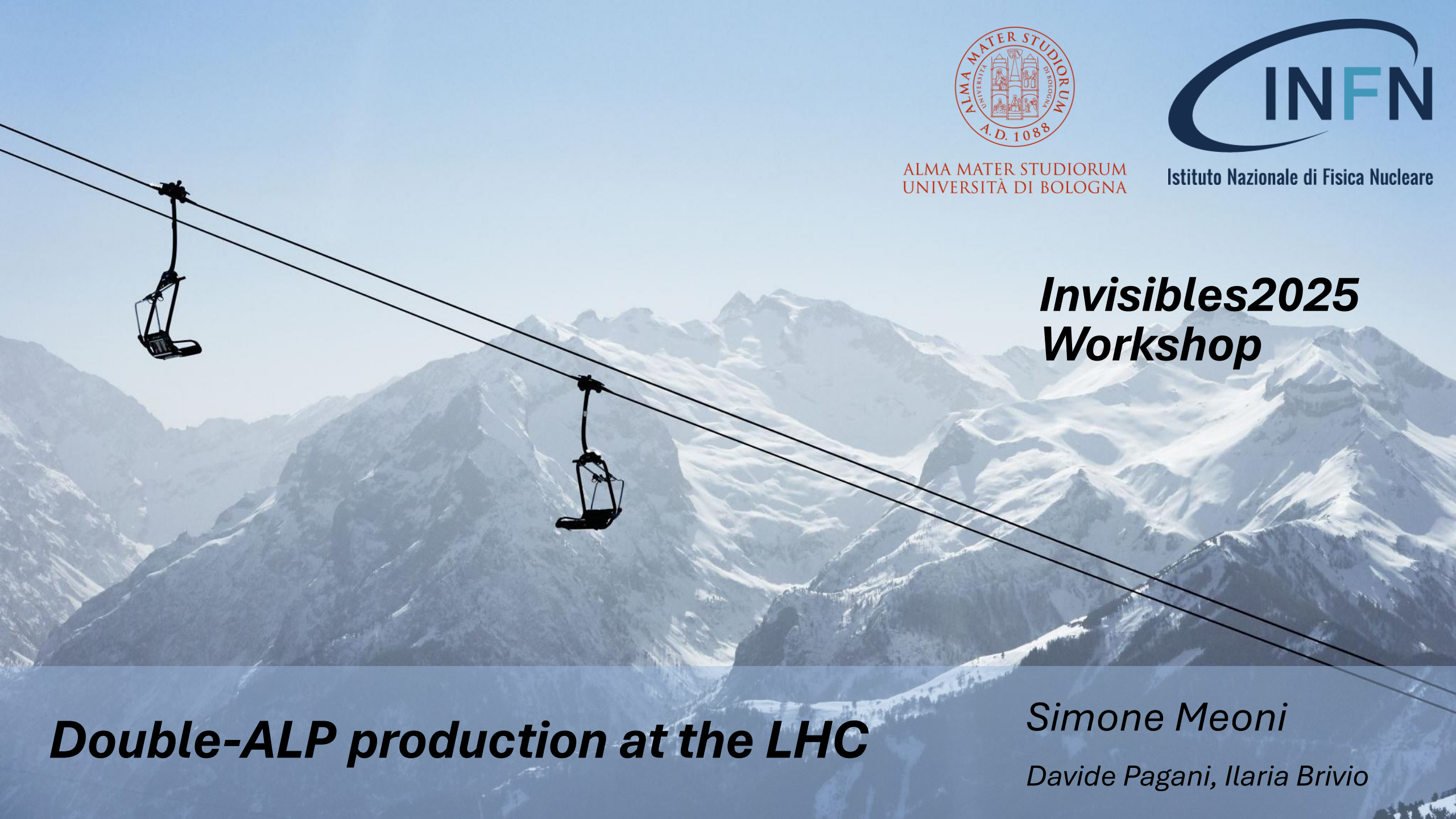


ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Istituto Nazionale di Fisica Nucleare

Invisibles2025 Workshop

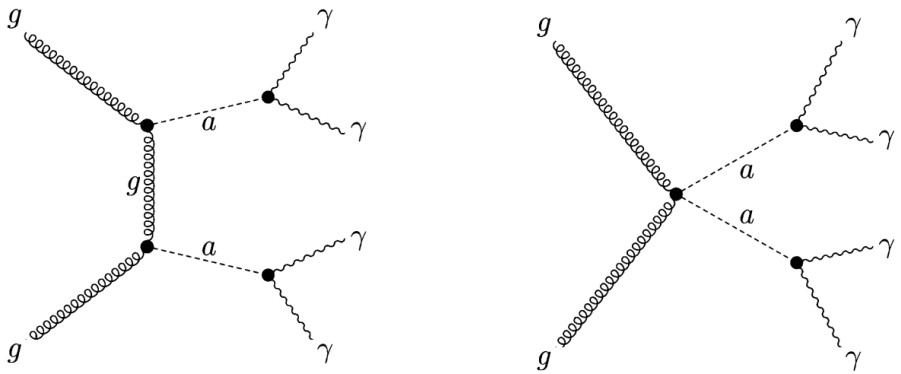
Double-ALP production at the LHC

Simone Meoni

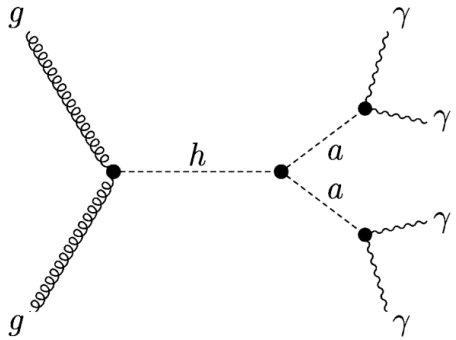
Davide Pagani, Ilaria Brivio

Introduction & Motivations

$$pp \to aa \to 4\gamma$$



Non-resonant



Resonant

- ***First*** study of non-resonant ***double-ALP*** production
- Natural inclusion of ***dimension-six*** operators (usual analyses include only dimension-five)
- ***Clear signature*** & ***small background***
- Possibility to probe the interplay between the ***ALP-photon*** and **ALP-gluon *coupling***

Signal Parametrization

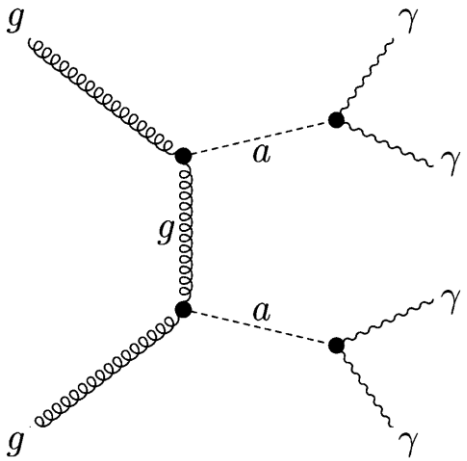
Dimension-five operators

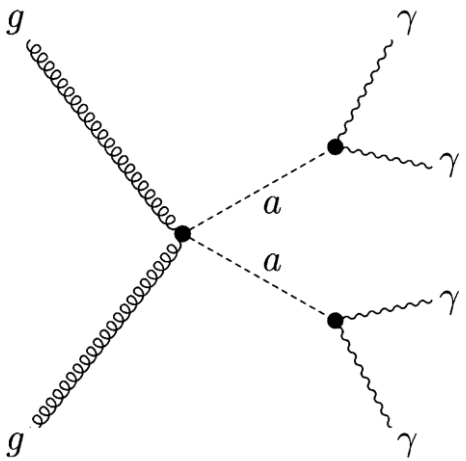
- $\widetilde{\mathcal{O}}_{G1} = \widetilde{C}_{G1}\frac{a}{\Lambda_a}G^a_{\mu\nu}\widetilde{G}^{a,\mu\nu}$
- $\mathcal{O}_{\gamma\gamma} = C_{\gamma\gamma}\frac{a}{\Lambda_a}F_{\mu\nu}\widetilde{F}^{\mu\nu}$

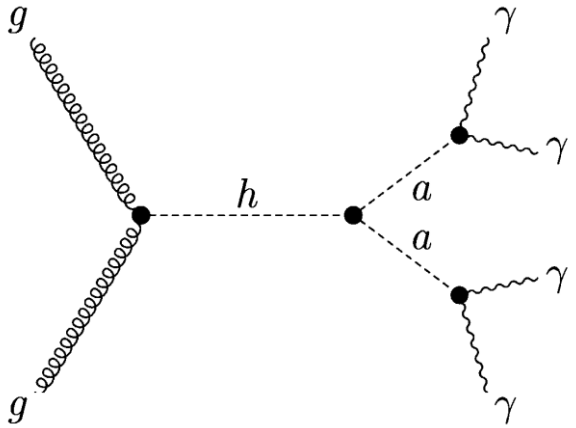
Dimension-six operators

- $\mathcal{O}_{ah} = C_{ah}\frac{\partial_\mu a\,\partial^\mu a}{\Lambda_a^2}\Phi^\dagger\Phi$
- $\mathcal{O}_{G2} = C_{G2}\frac{a^2}{\Lambda_a^2}G^a_{\mu\nu}G^{a,\mu\nu}$

- *CP-Even interactions*
- *No Fermionic ALP-interactions*







$$\mathcal{M}_{\text{prod}} \sim \Lambda_a^{-2}$$

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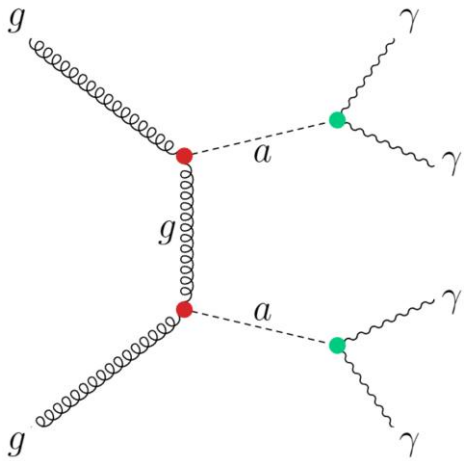

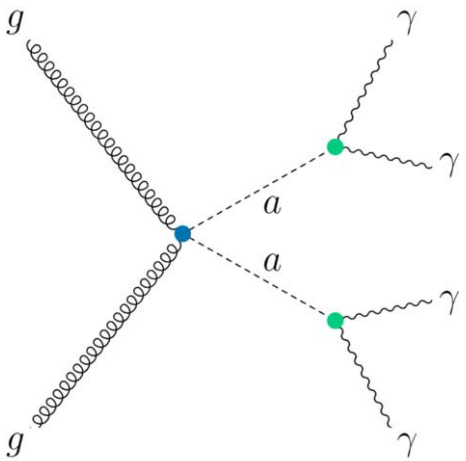

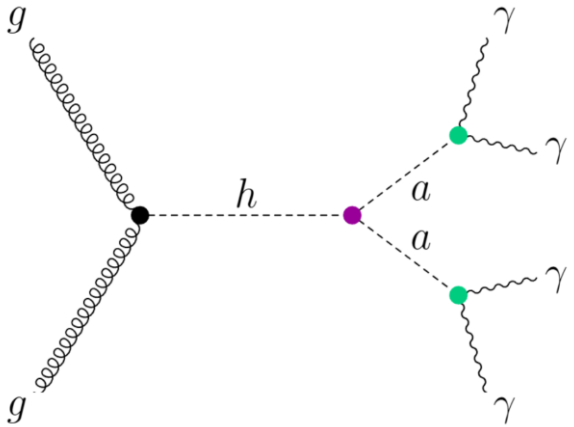

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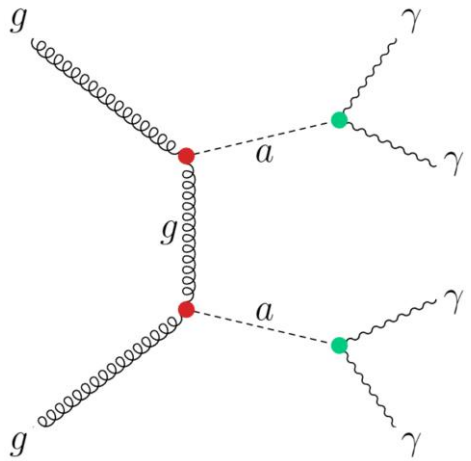
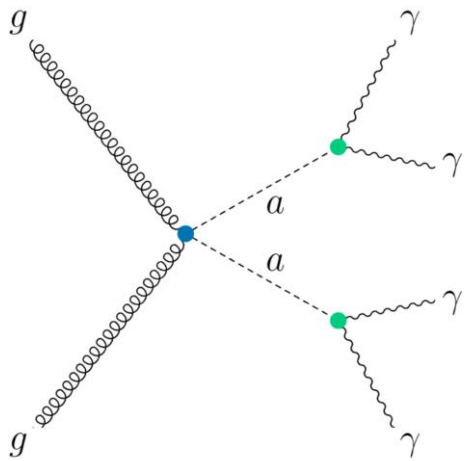
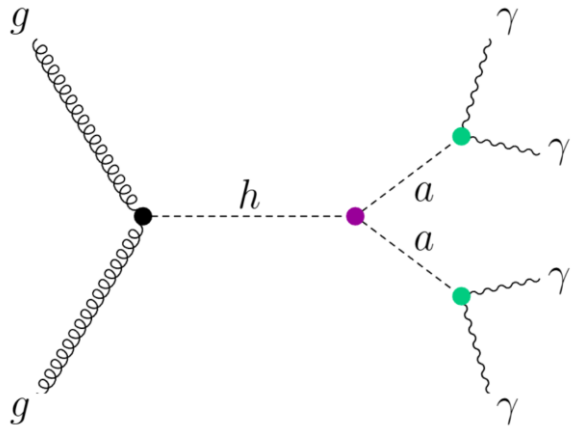




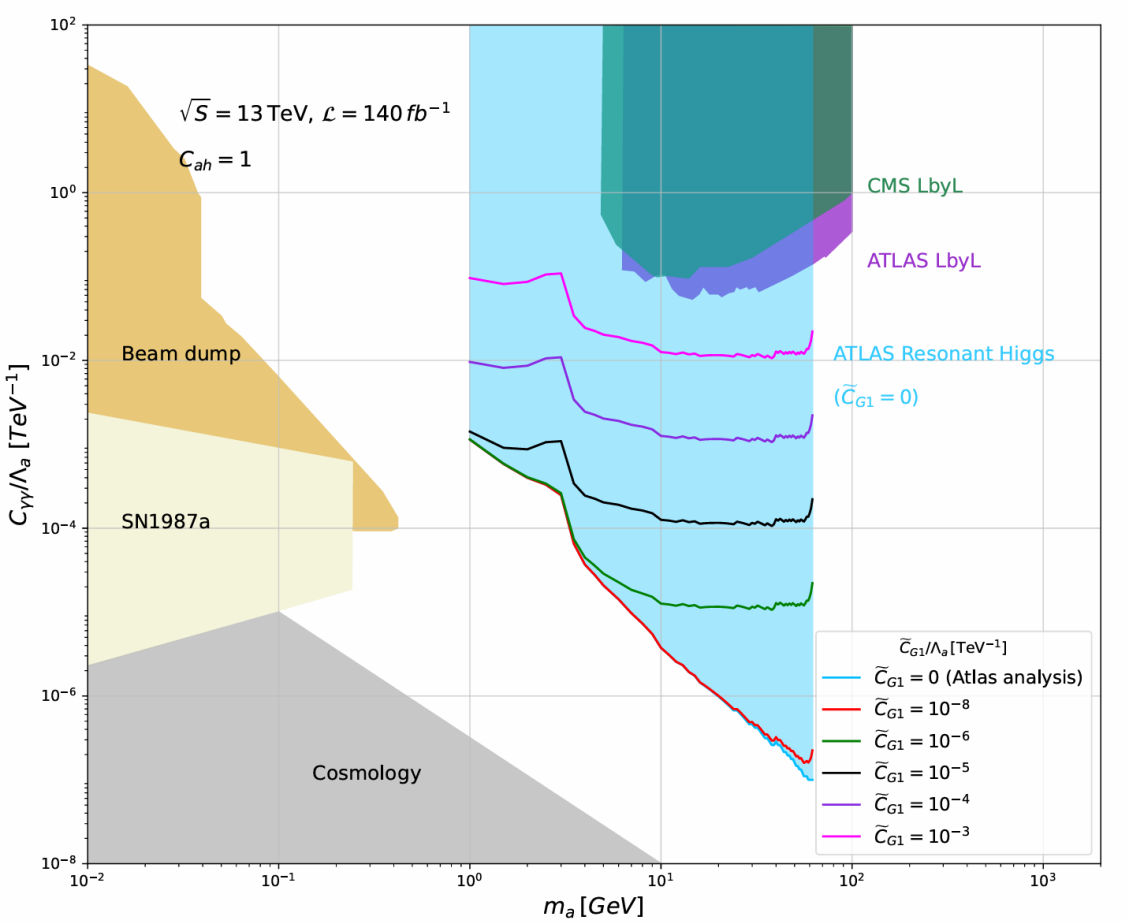


$$\mathcal{M}_{\text{prod}} \sim \Lambda_a^{-2}$$

$$\mathcal{N} = \mathcal{L}\,\epsilon^{\text{reco}}\,\epsilon^{\text{cuts}}\,\sigma_{pp\to aa}(m_a, \widetilde{C}_{G1}, C_{G2})\,\text{Br}^2_{a\to\gamma\gamma}(m_a, C_{\gamma\gamma}, \widetilde{C}_{G1})$$

$$\mathcal{N} = \mathcal{L}\,\epsilon^{\text{reco}}\,\epsilon^{\text{cuts}}\,\sigma_{pp\to h}\,\text{Br}_{h\to aa}(m_a, C_{ah})\text{Br}^2_{a\to\gamma\gamma}(m_a, C_{\gamma\gamma}, \widetilde{C}_{G1})$$

Results from resonant ALP production analysis



Colored regions → ***Forbidden regions***

$gg \to h \to aa \to 4\gamma$ *(arXiv:2312.03306)*

$$\mathcal{N} = \mathcal{L}\,\epsilon^{\text{reco}}\,\epsilon^{\text{cuts}}\,\sigma_{pp\to h}\,\text{Br}_{h\to aa}(m_a, C_{ah})\text{Br}^2_{a\to\gamma\gamma}(m_a, C_{\gamma\gamma}, \widetilde{C}_{G1})$$

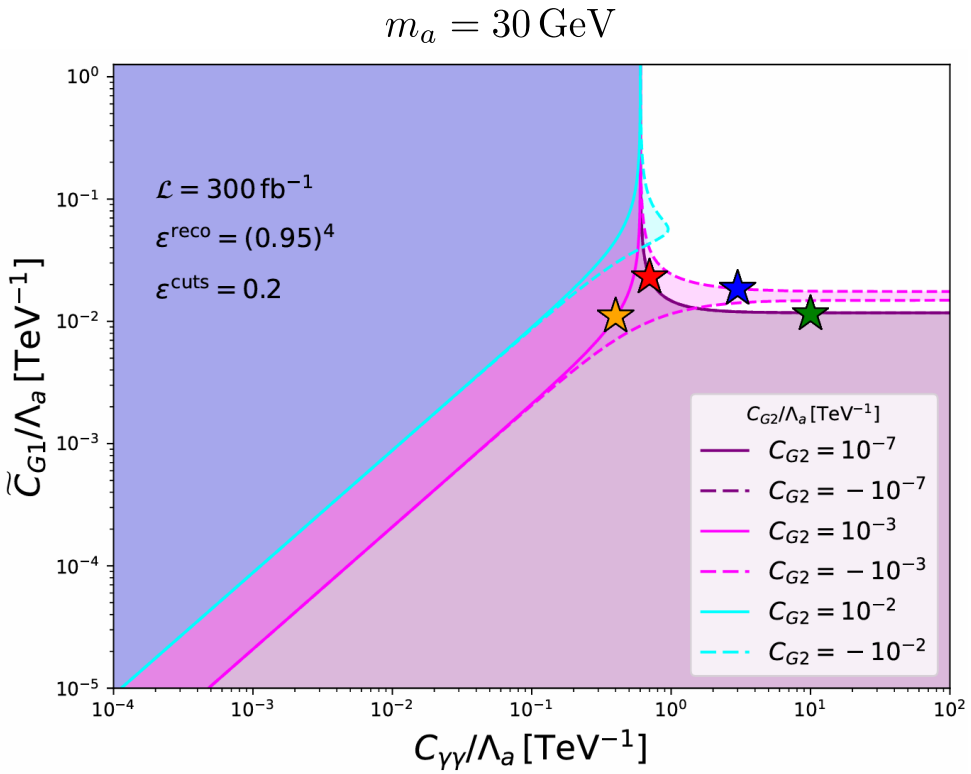
- ***Baseline (ATLAS):*** $\text{Br}(a \to \gamma\gamma) = 1$
- ***Our extension:*** allowing $a \to gg$ (non-zero gluonic coupling $\widetilde{C}_{G1}$)

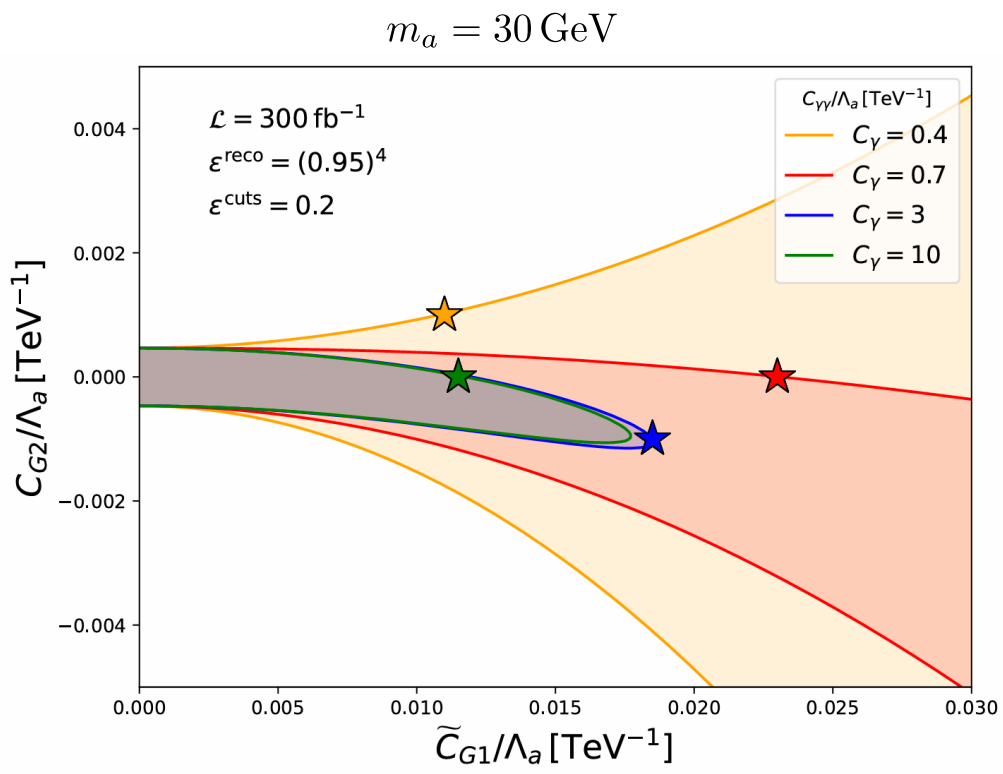
  → $\text{Br}(a \to \gamma\gamma) \neq 1$
- ***Results:*** Weakening existing upper limits on $C_{\gamma\gamma}$
- **Limitations:** $m_a < \dfrac{m_h}{2}$

Results from non-resonant ALP production analysis

$gg \to aa \to 4\gamma$

- Allowed regions at 95% -CL are defined requiring $\mathcal{N} \leq 3$, since SM-background is negligible





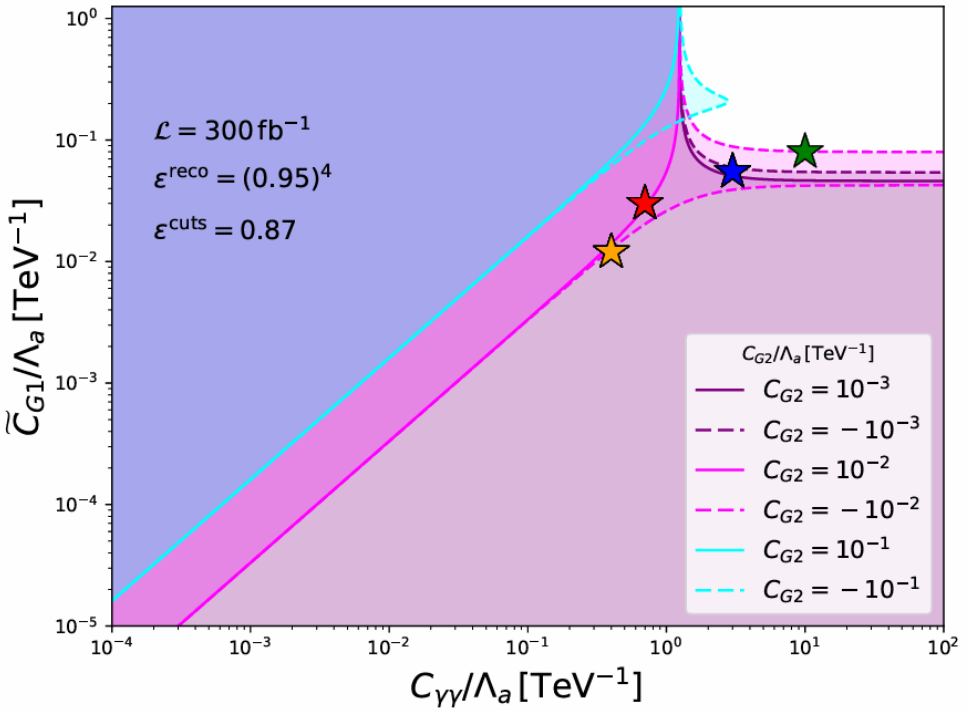
Colored regions → ***Allowed regions***

Upper limits from non-resonant ALP analysis

$gg \to aa \to 4\gamma$

- Allowed regions at 95% are defined requiring $\mathcal{N} \leq 3$, since SM-background is negligible

$m_a = 1000\,\mathrm{GeV}$



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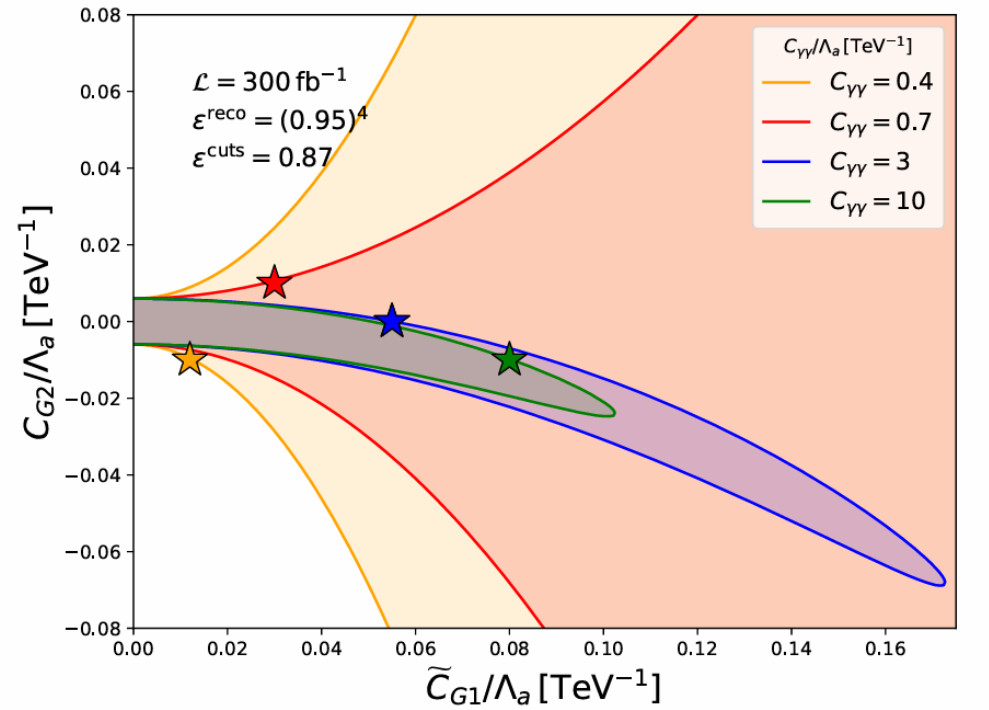

Colored regions → ***Allowed regions***

Outlooks and conclusion

- We focused on the ***double ALP production*** at the ***LHC*** specifically on: $gg \to aa \to 4\gamma$
- ***Relevant couplings*** for this process have been tested for m_a up to ***1 TeV mass scales***
- We have investigated how the insertion of a **non-zero** $\tilde{C}_{G1}$ **impacts** the existing bounds (arXiv:2312.03306)
- We derived upper bound on the: $(\tilde{C}_{G1}, C_{G2})$-plane with fixed mass:

  → The ***best bounds*** on C_{G2} are of the ***order of*** $\sim 10^{-3}$ with fixed C_γ

  → A ***3-parameter fit*** of this process ***doesn't find a finite allowed region***

- Improvements: ***tailored cut-strategy*** & study of ***kinematics distributions*** (as the photon invariant mass)

Thank you for your attention