Constraints on Physics Beyond the Standard Model using the LHC - Axion Like Particles

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Axion Like Particles

Pseudo scalar particles - weakly interacting

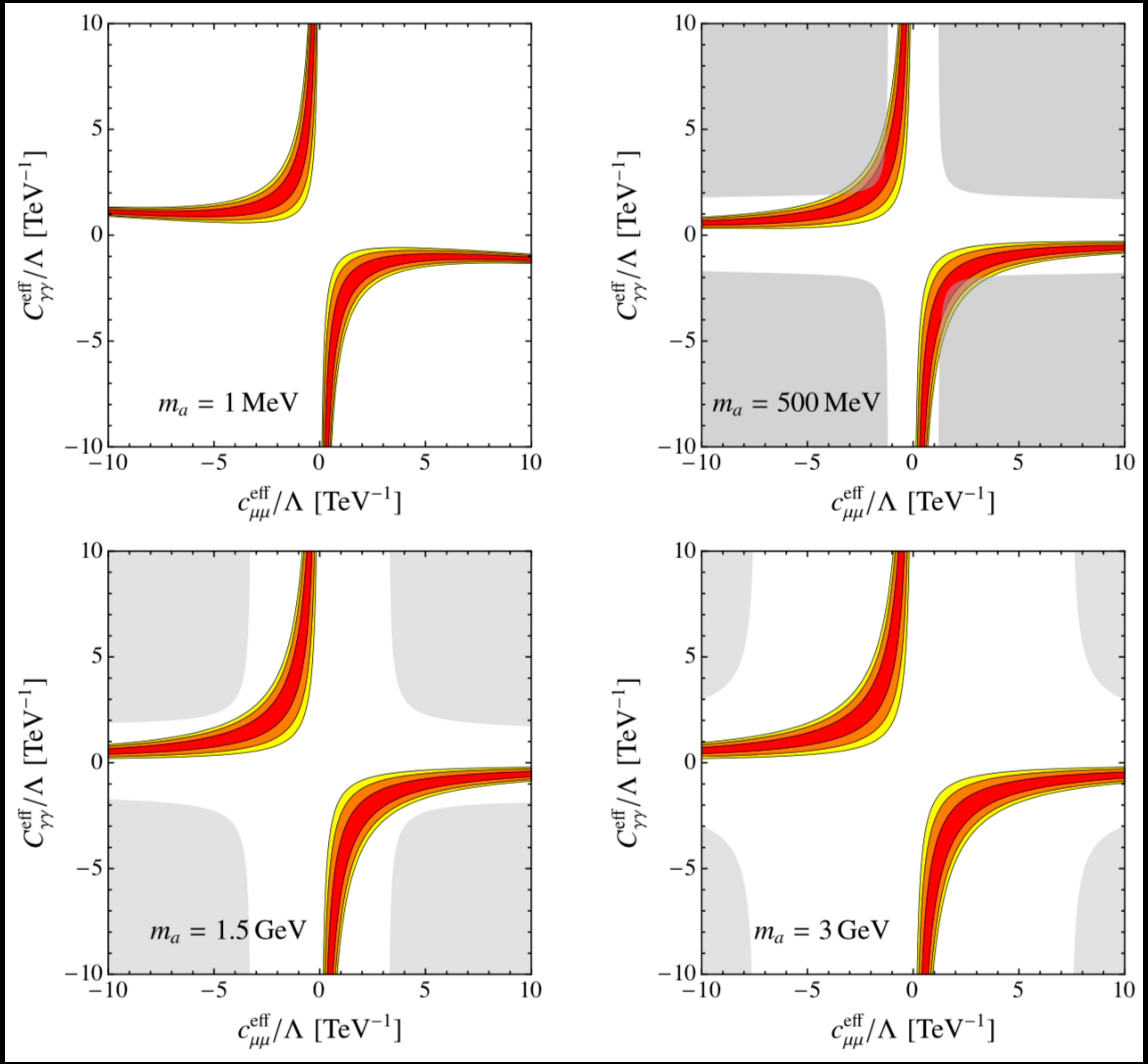
Resolve:

- Strong CP problem
- Cold Dark Matter
- Anomalous Magnetic moment of the muon
  - Experimental value differs from the Standard model value
  - $a_\mu^{exp} - a_\mu^{SM} = (29.3 \pm 7.6) \bullet 10^{-10}$

General ALP model

- Defines the ALP-SM interactions.
- Gives us an equation that solves the magnetic moment of muon discrepancy. Which has been obtained from arXiv:1708.00443.

$$\delta a_\mu = \frac{m_\mu^2}{\Lambda^2}\left\{K_{a_\mu}(\mu) - \frac{(c_{\mu\mu})^2}{16\pi^2} h_1\left(\frac{m_a^2}{m_\mu^2}\right) - \frac{2\alpha}{\pi} c_{\mu\mu} C_{\gamma\gamma}\left[\ln\frac{\mu^2}{m_\mu^2} + \delta_2 + 3 - h_2\left(\frac{m_a^2}{m_\mu^2}\right)\right] - \frac{\alpha}{2\pi}\frac{1-4s_w^2}{s_w c_w} c_{\mu\mu} C_{\gamma Z}\left(\ln\frac{\mu^2}{m_Z^2} + \delta_2 + \frac{3}{2}\right)\right\}$$



From arXiv:1708.00443

Research Framework - CONTUR

UFO
- Takes a Lagrangian and generates matrix elements
- Allows event generator to choose which vertices to work with

HERWIG
- Monte-Carlo event generator
- Simulates proton-proton collision LHC events

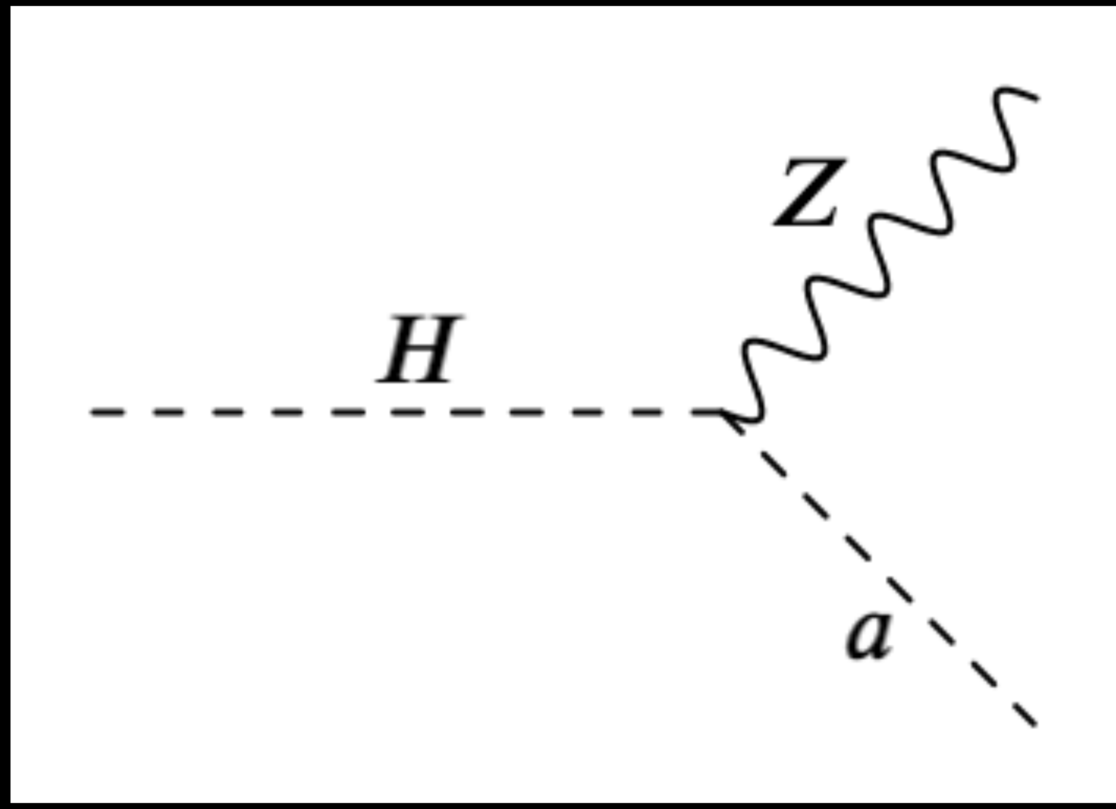
RIVET
- Library of routines (contains particle cross-section data)

- Generates histograms
- Compiles the exclusion from the individual histograms into a grid

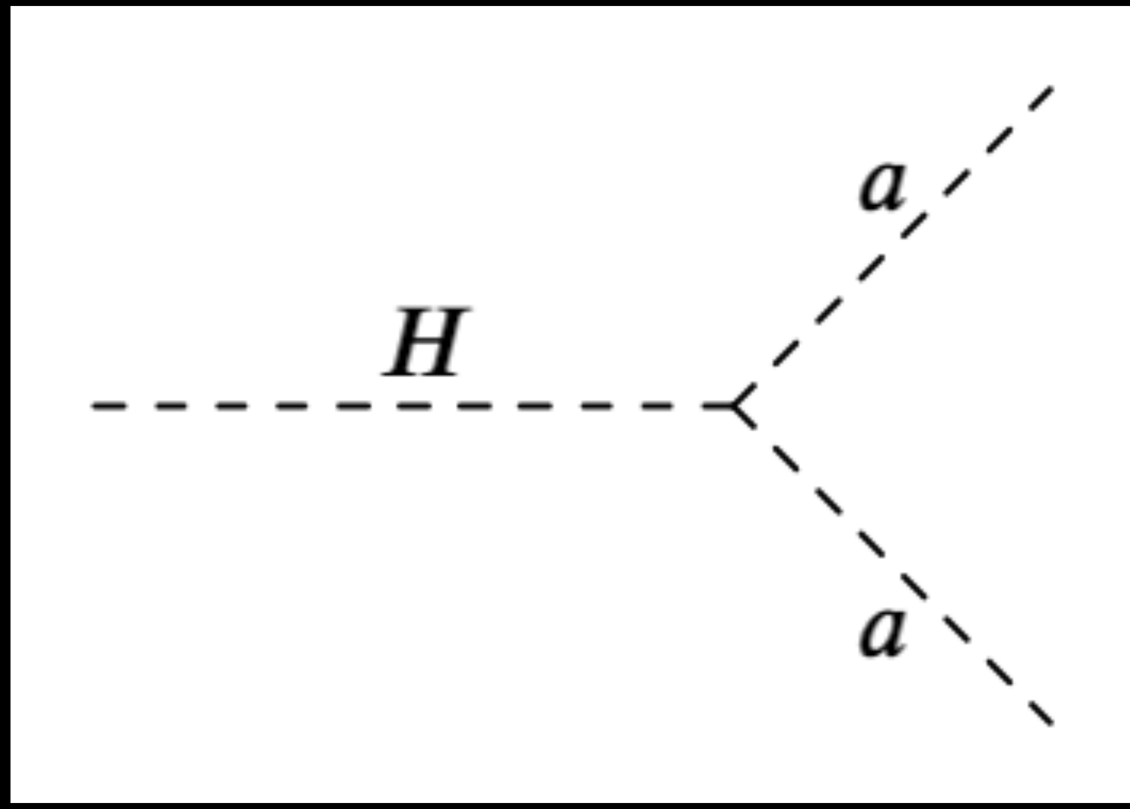
Couplings

- gPu, gPd (=0): universal couplings of ALP to up and down quarks, respectively
- cGG(=0): coupling of ALP to gluons
- cZA(=0): coupling of ALP to one Z boson and one photon
- cAA: coupling of ALP to photons
- gPl: universal coupling of ALP to leptons

- Scenario 1: cah=cZh5=0
- Scenario 2: cah=cZh5=1
- Scenario 3: cah=1, cZh5=0

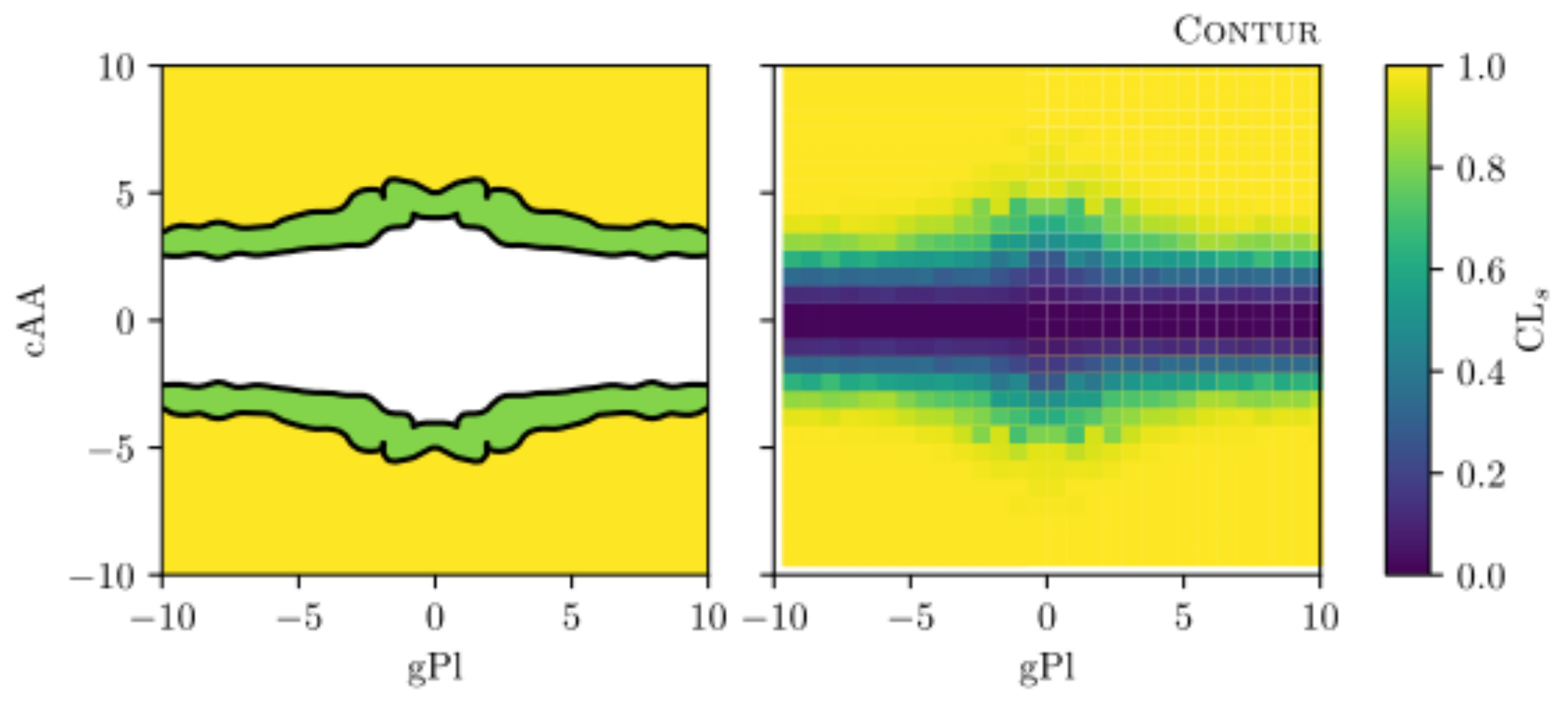


cZh5

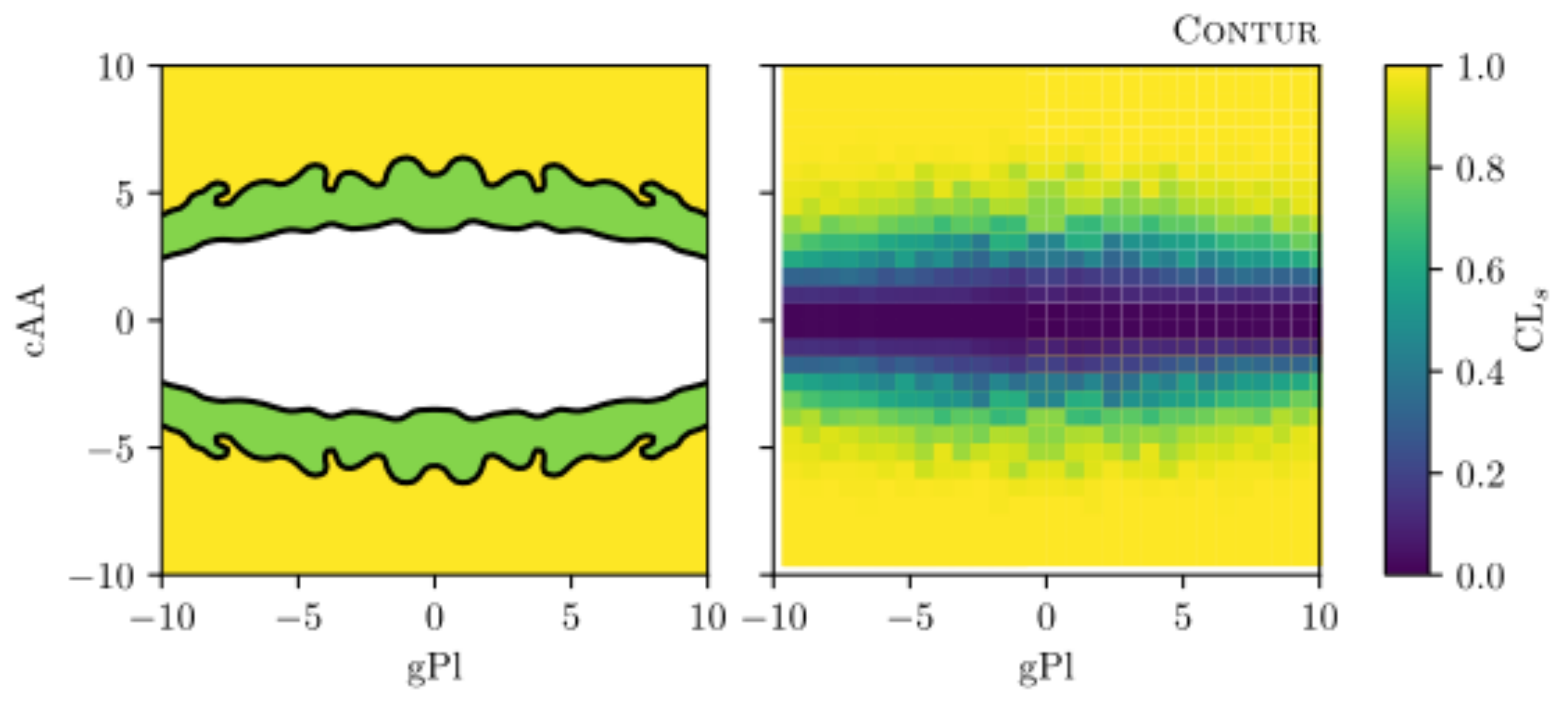


cah

Scenario 1: cah=cZh5=0 (Low mass)

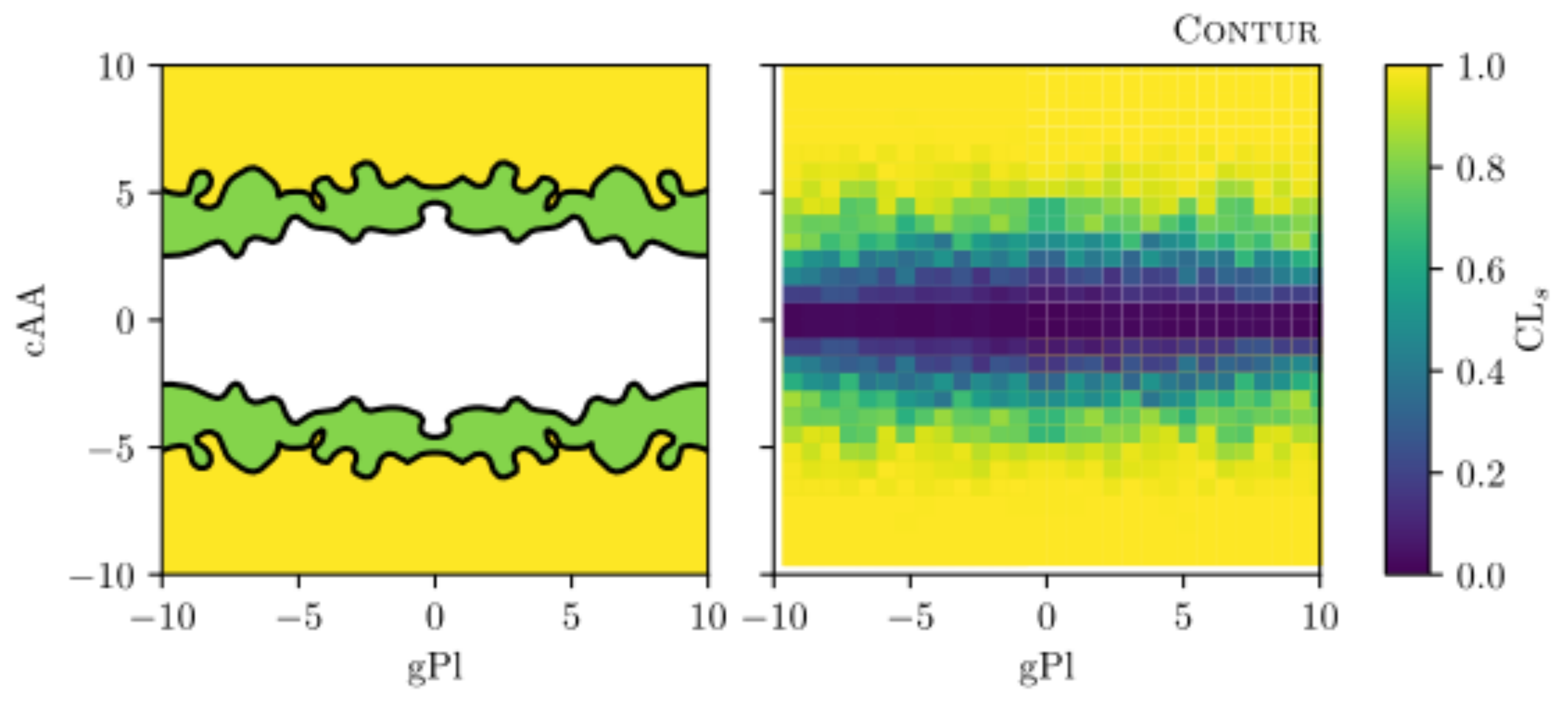


0.5 GeV

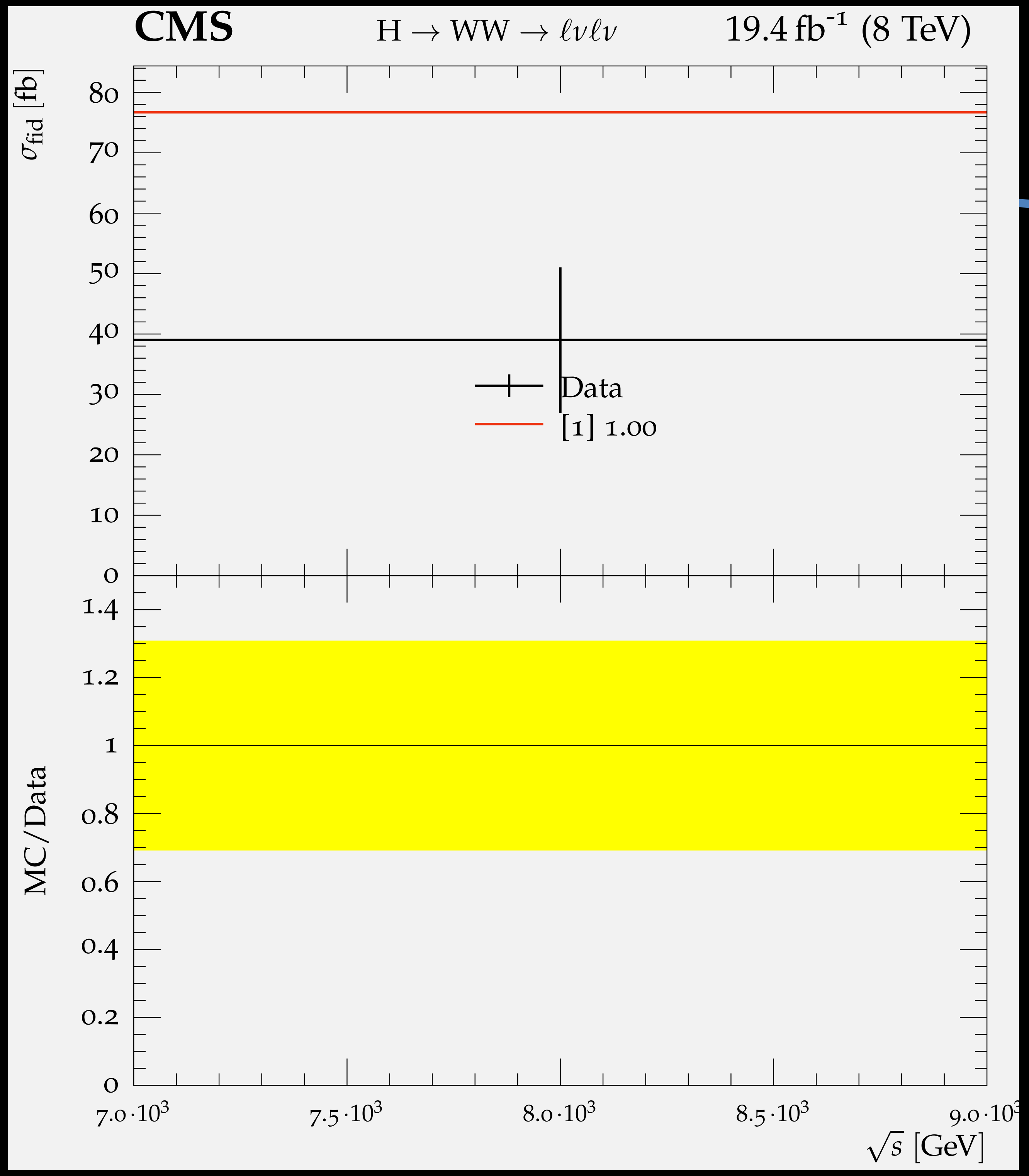


1.5 GeV

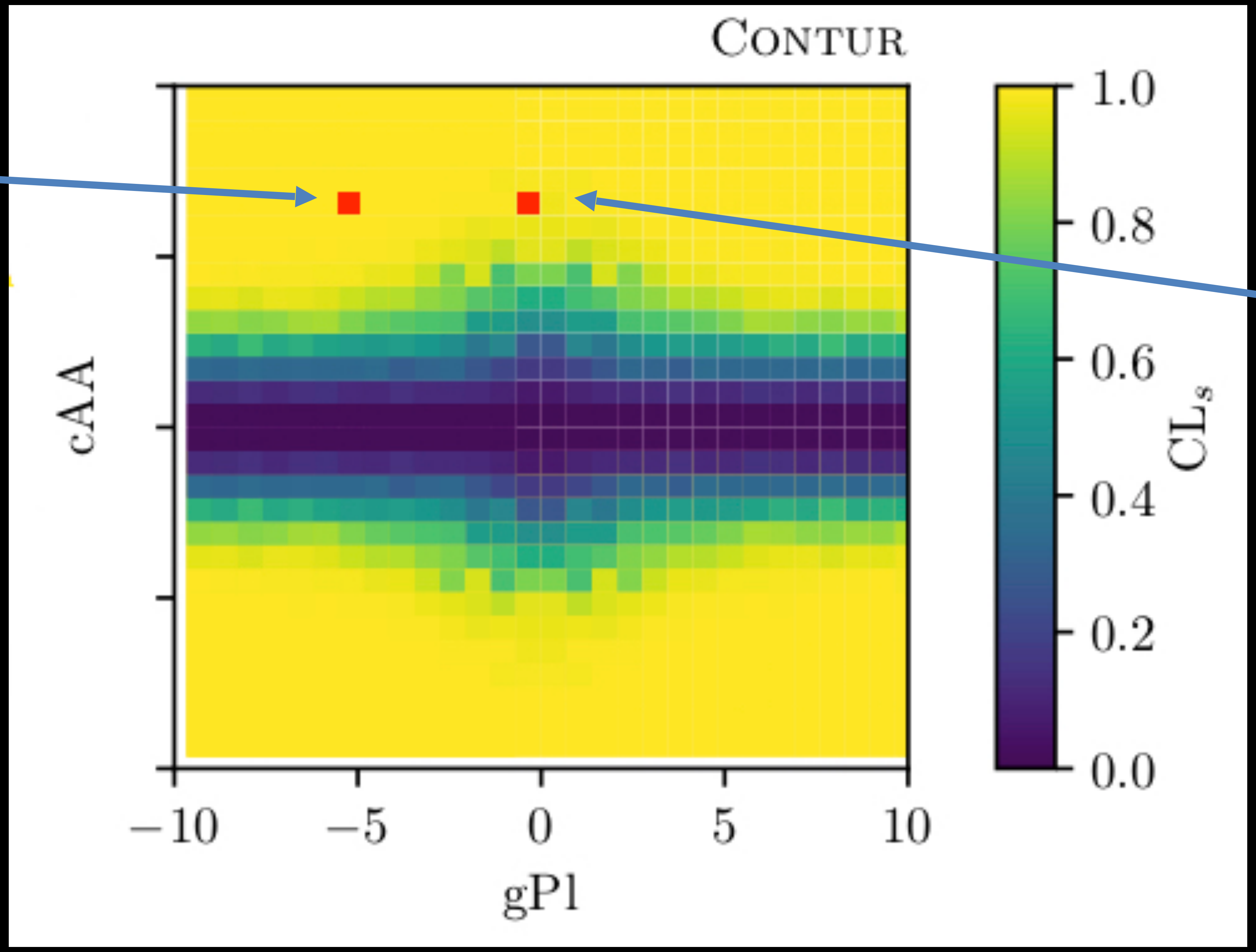
3 GeV



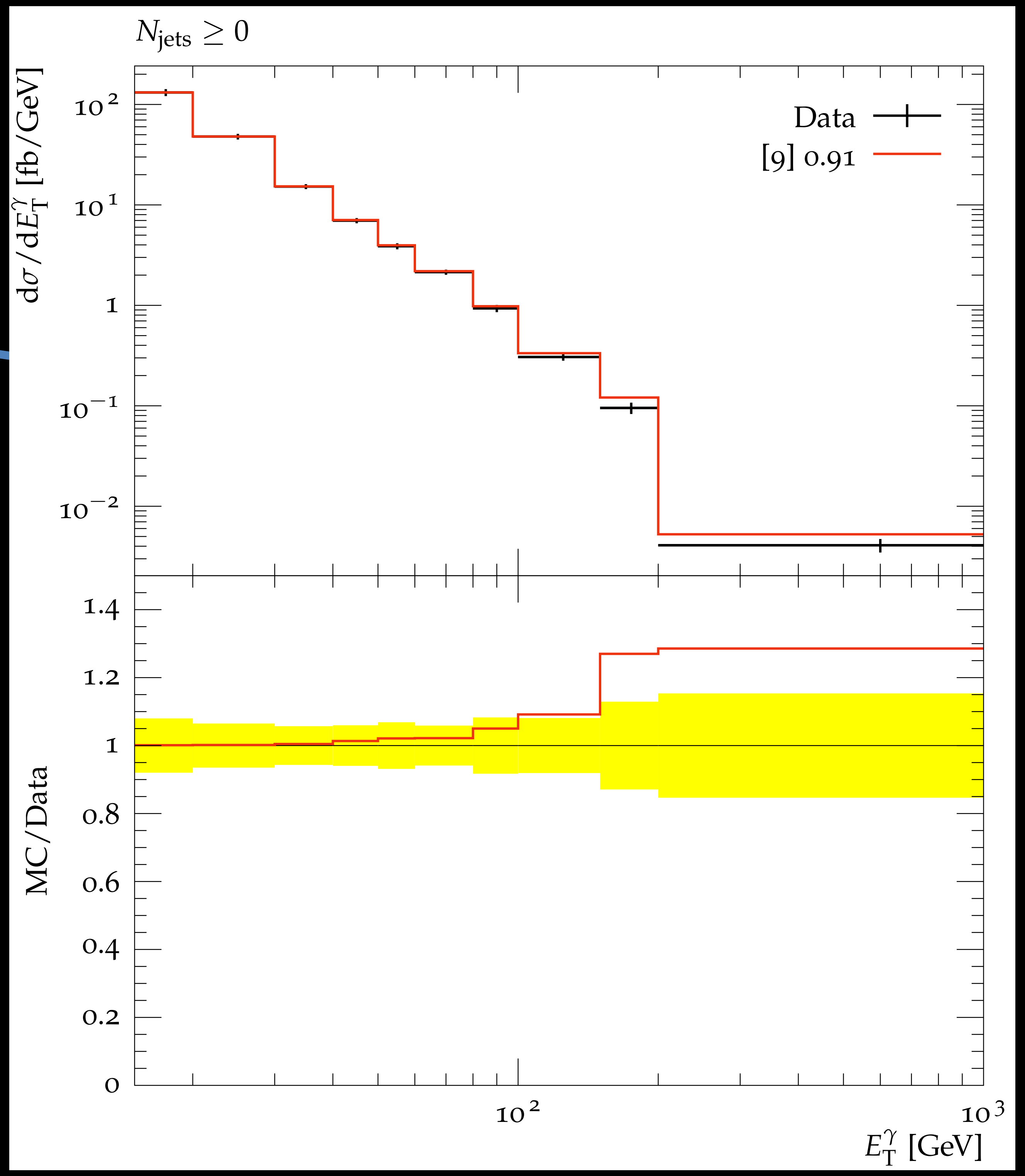
Scenario 1: cah=cZh5=0 (0.5 GeV)



CMS_8_WW
(reference point 0727)



CONTUR heatmap



ATLAS_8_MM_GAMMA
(reference point 0734)

Decay rate mass dependence

$$\Gamma(a \to \gamma\gamma) = \frac{4\pi\alpha^2 m_a^3}{\Lambda^2}\left|C_{\gamma\gamma}^{\rm eff}\right|^2 \qquad \propto m_a^3$$

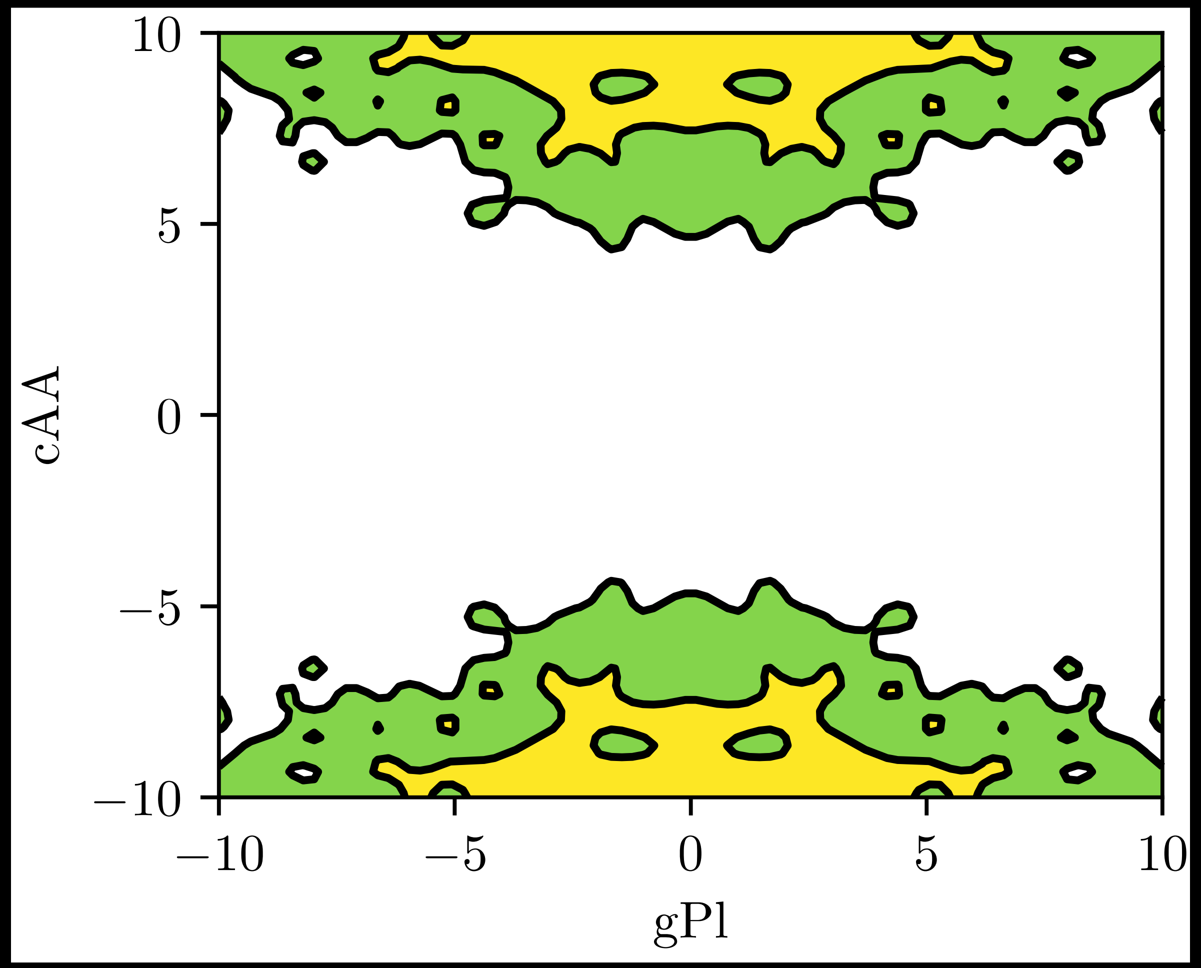
and

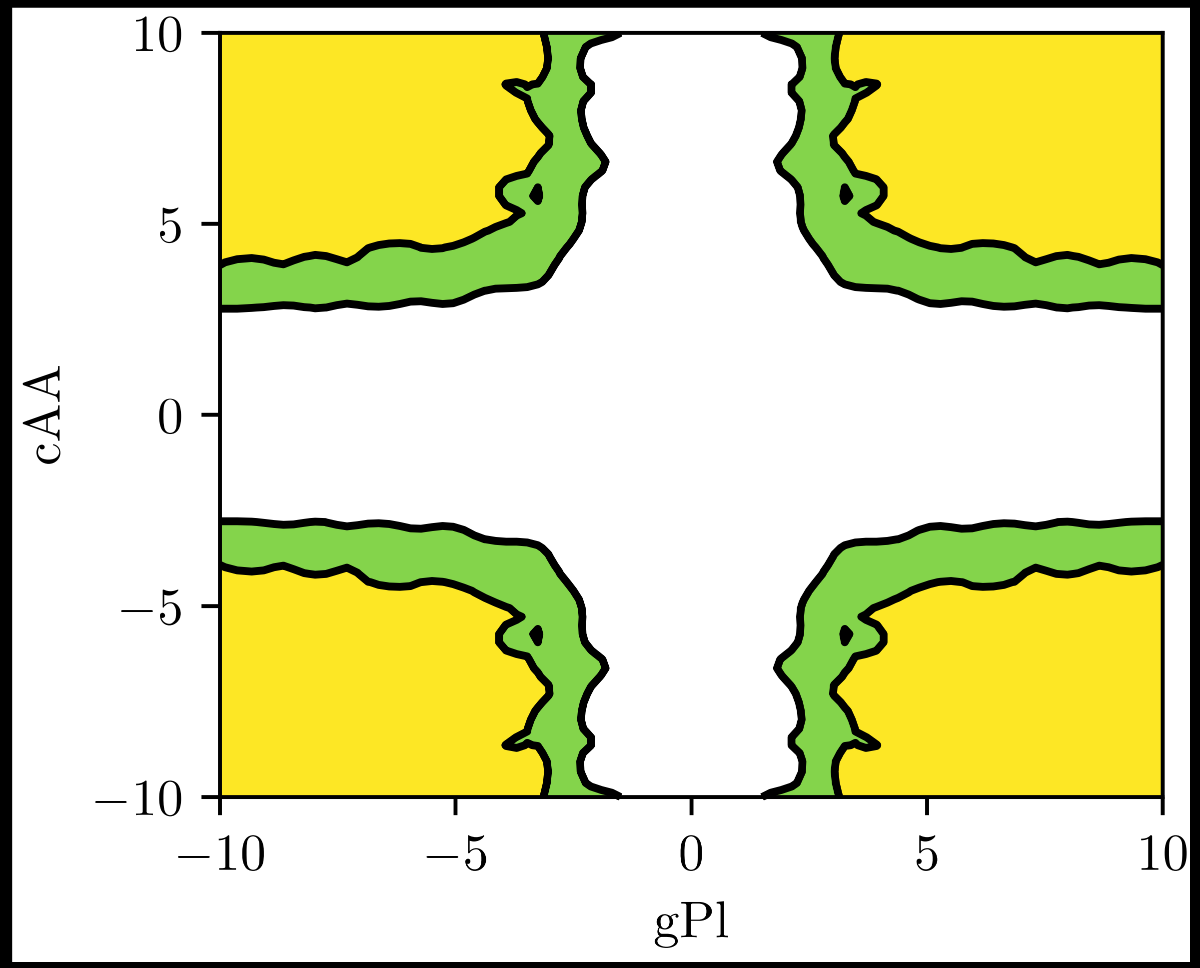
$$\Gamma(a \to \ell^+\ell^-) = \frac{m_a m_\ell^2}{8\pi\Lambda^2}\left|c_{\ell\ell}^{\rm eff}\right|^2\sqrt{1-\frac{4m_\ell^2}{m_a^2}} \qquad \propto m_a$$

0.5 GeV

ATLAS_8_MM_GAMMA

Consists of cross-sections of Zɣ and Zɣɣ

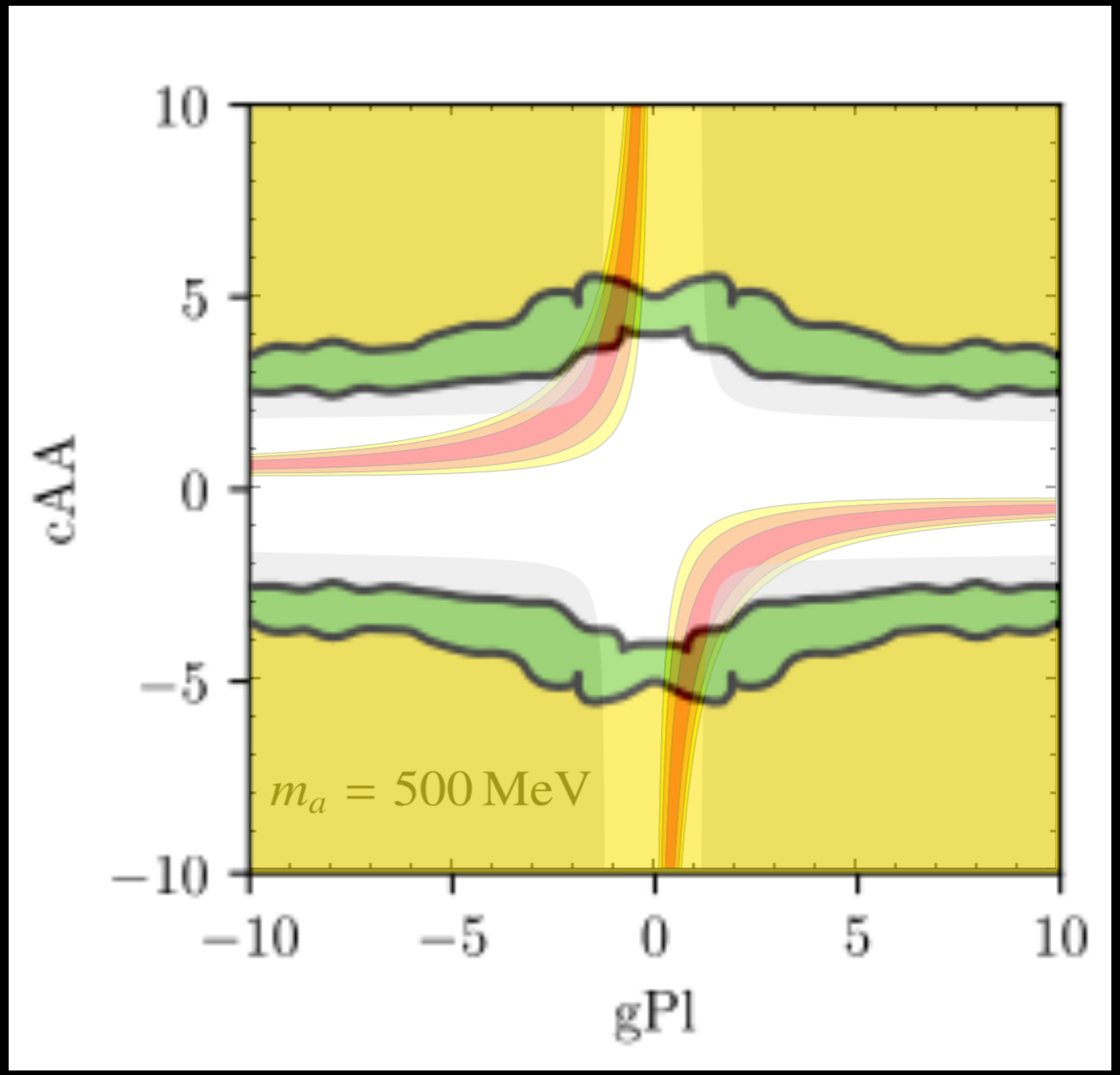




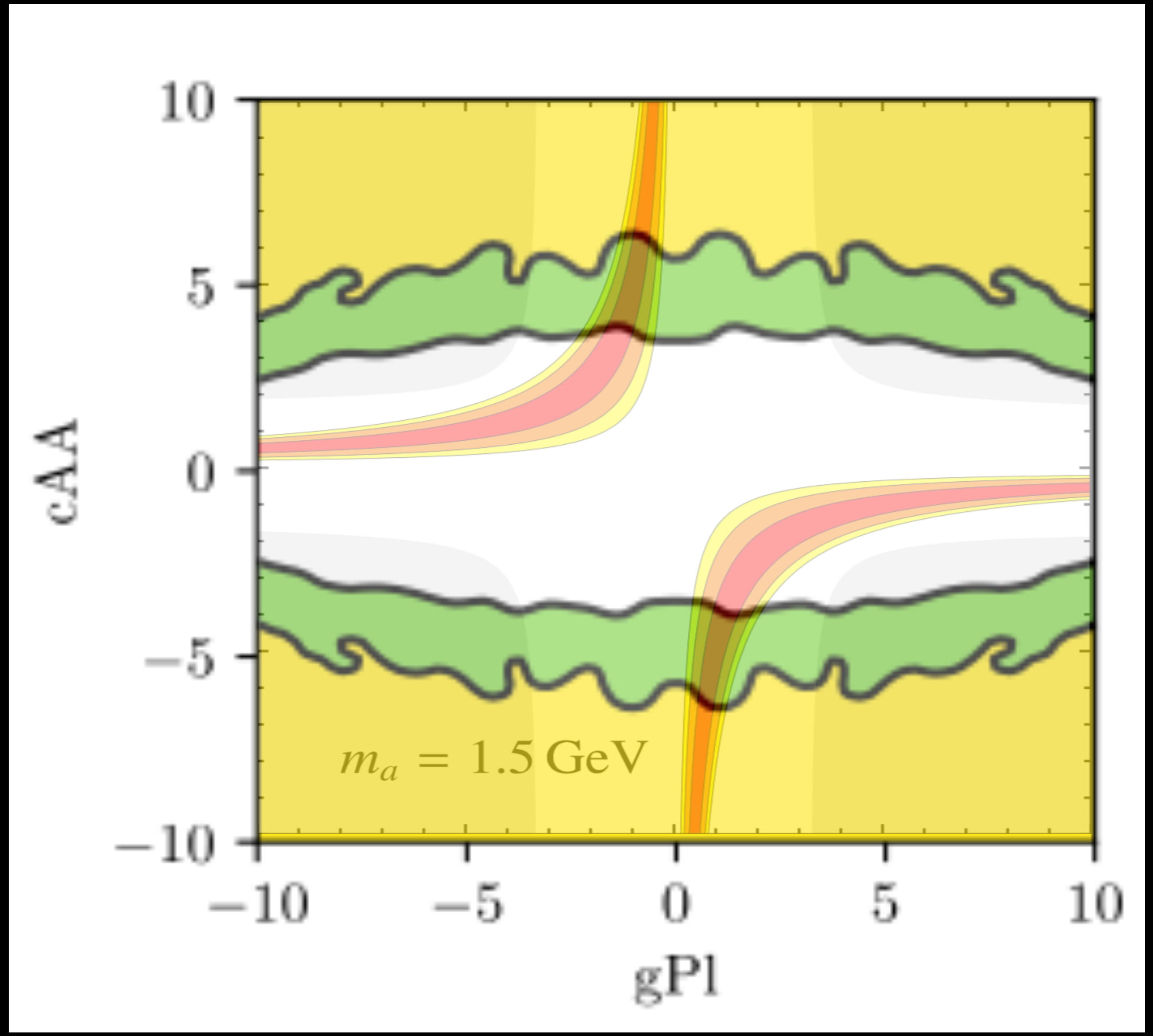
CMS_8_WW

Consists of cross-sections of W-boson productions via Higgs decays

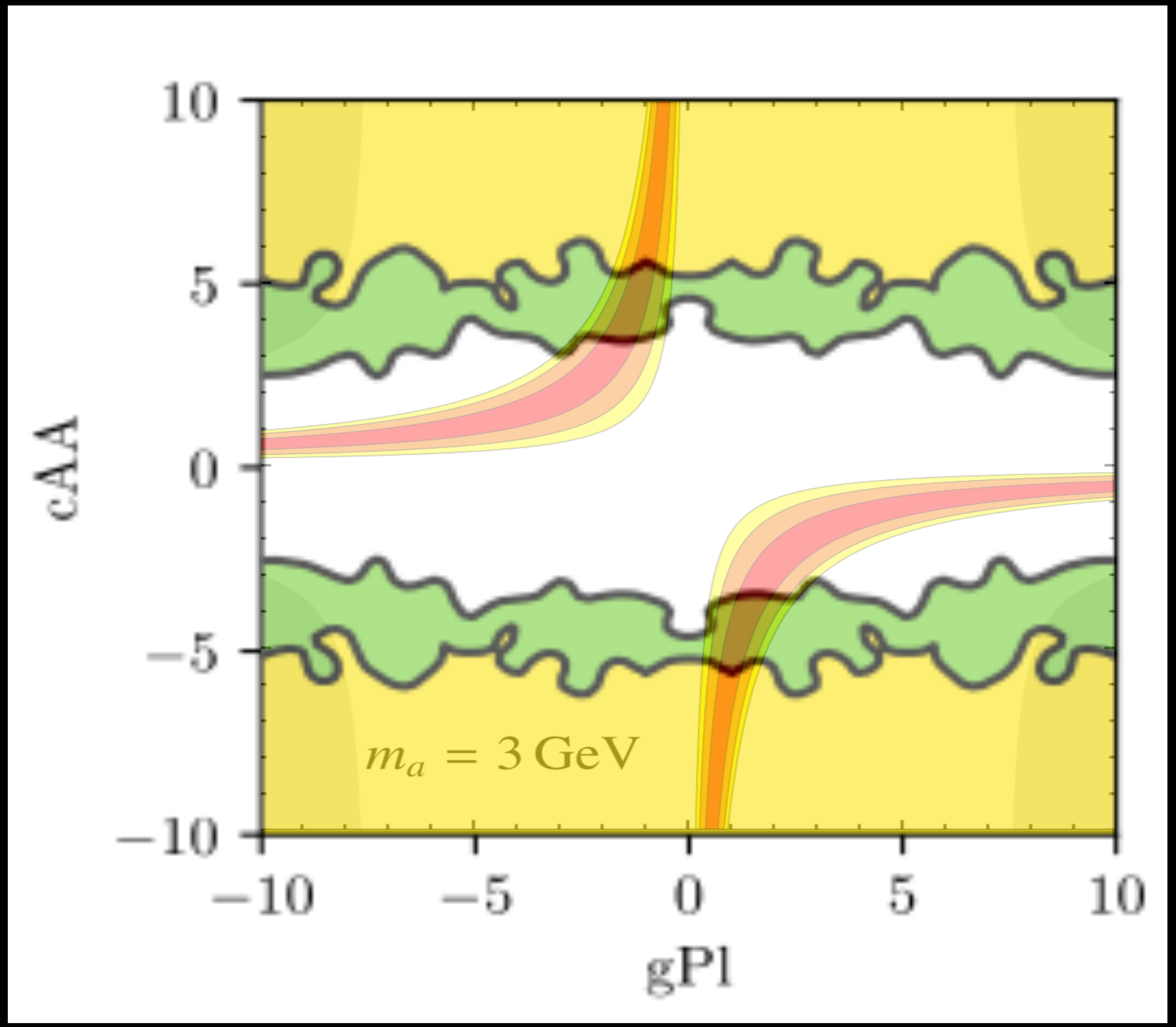
Anomalous magnetic moment of muon



0.5 GeV

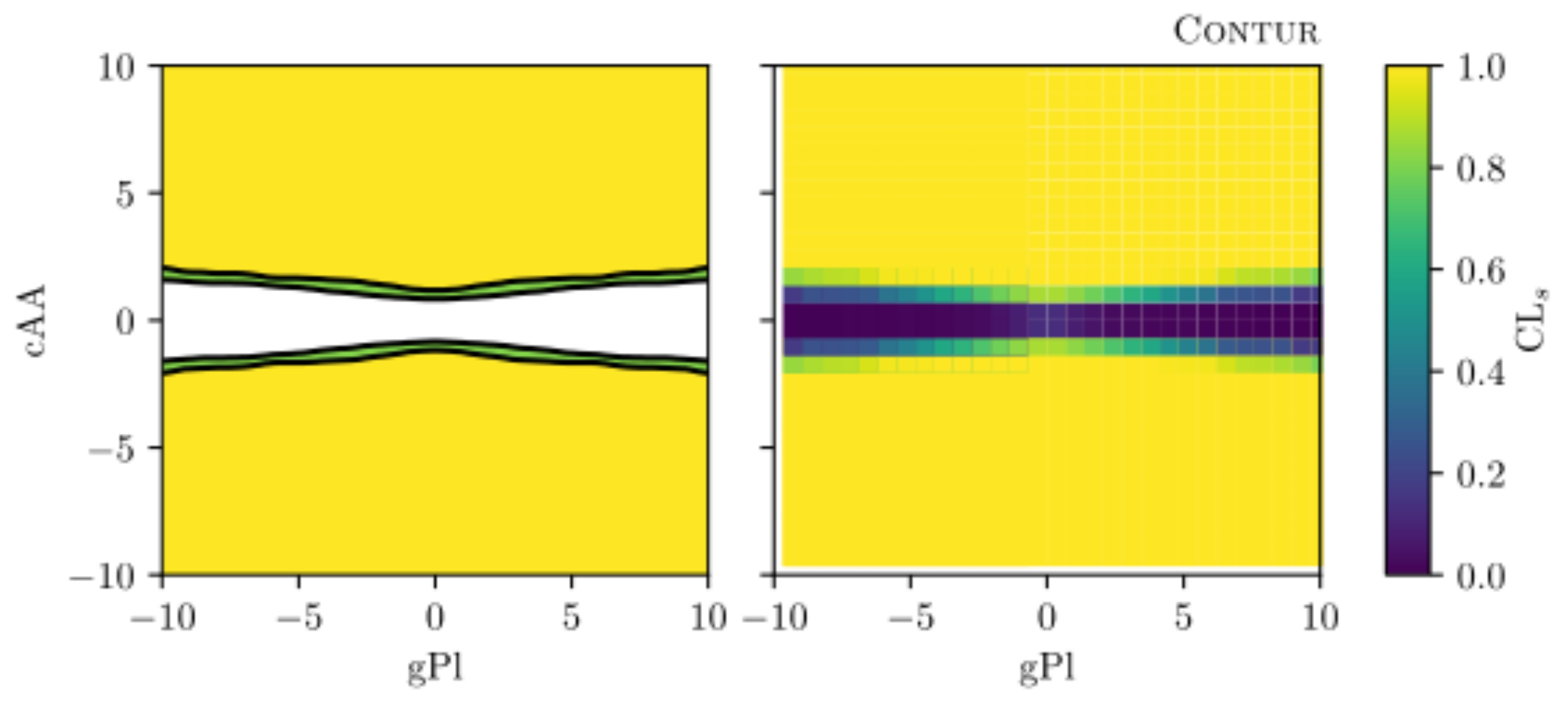


1.5 GeV

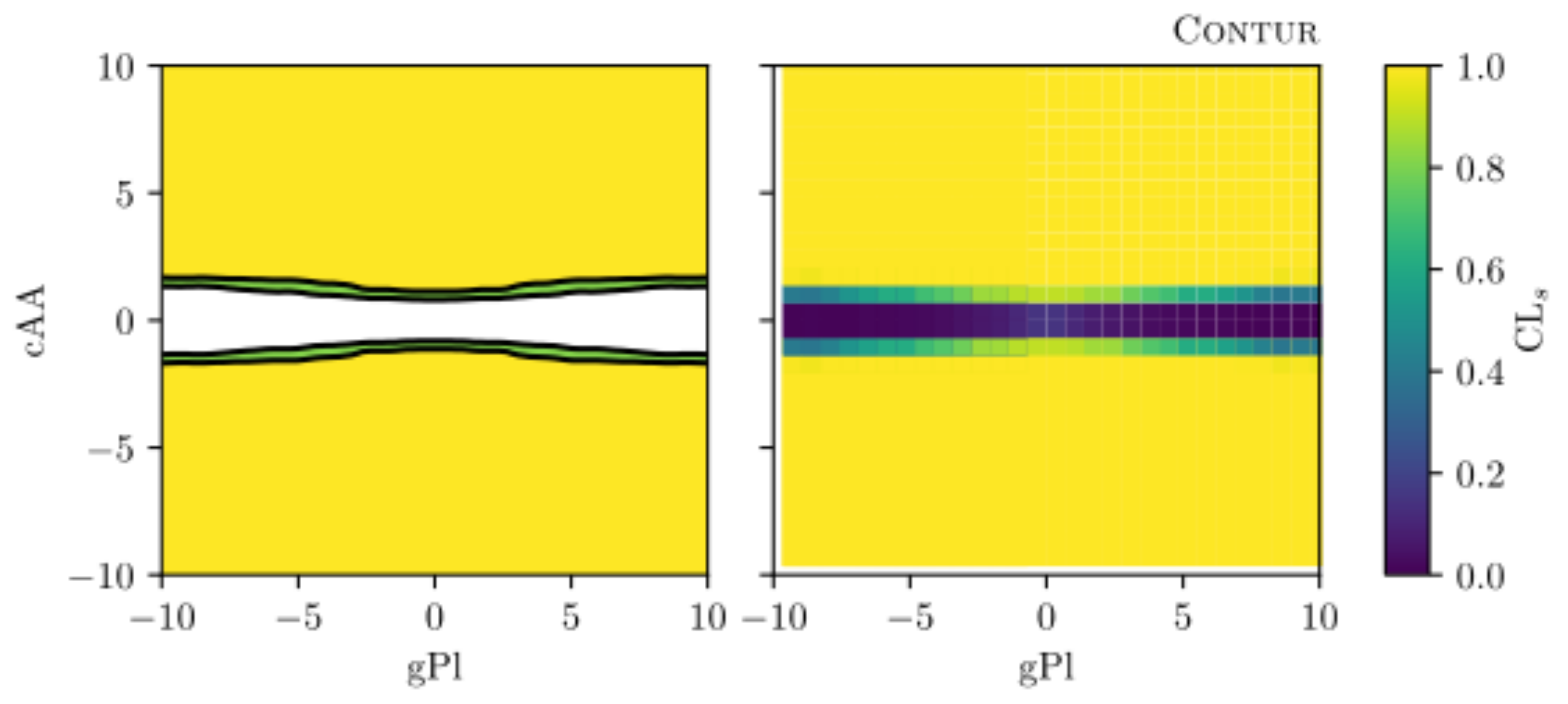


3 GeV

Scenario 1: cah=cZh5=0 (High mass)

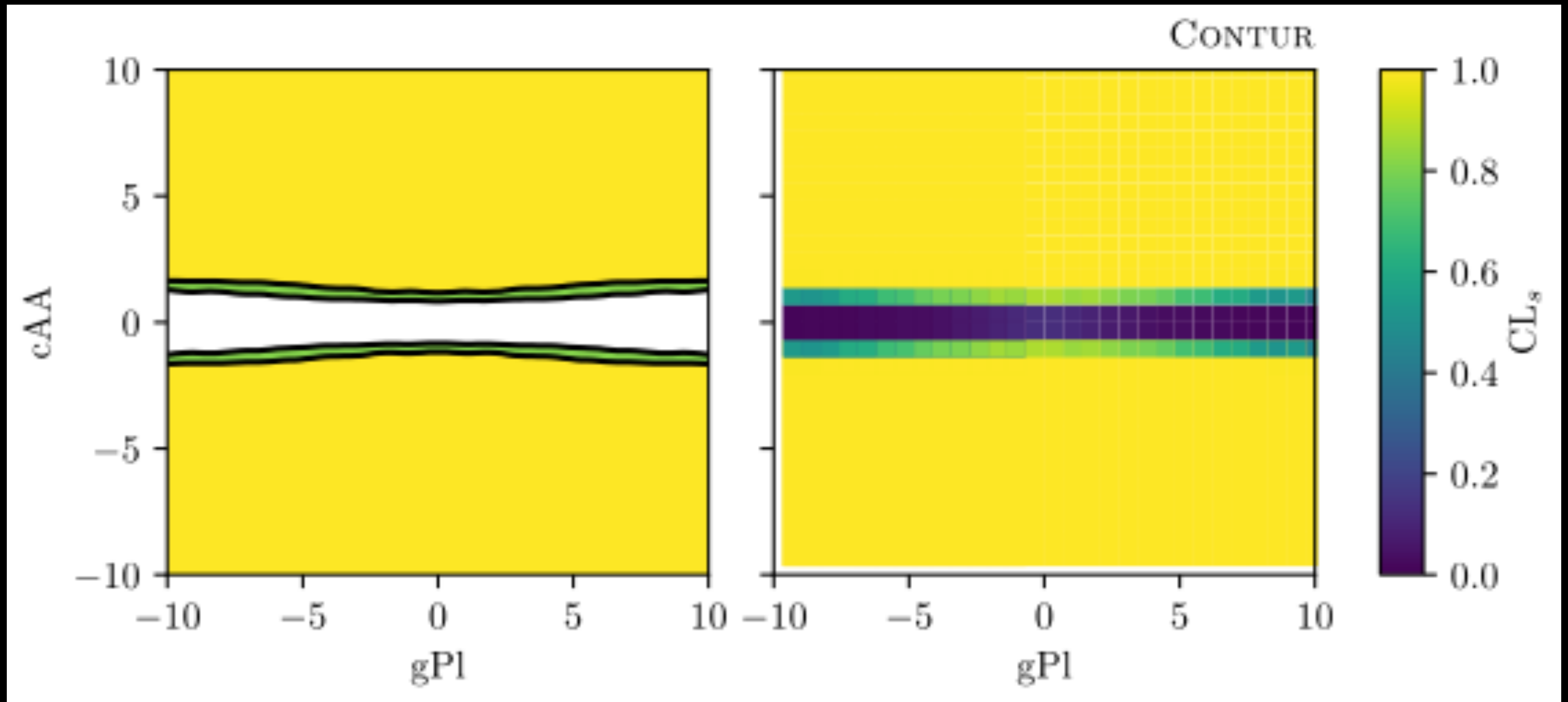


50 GeV

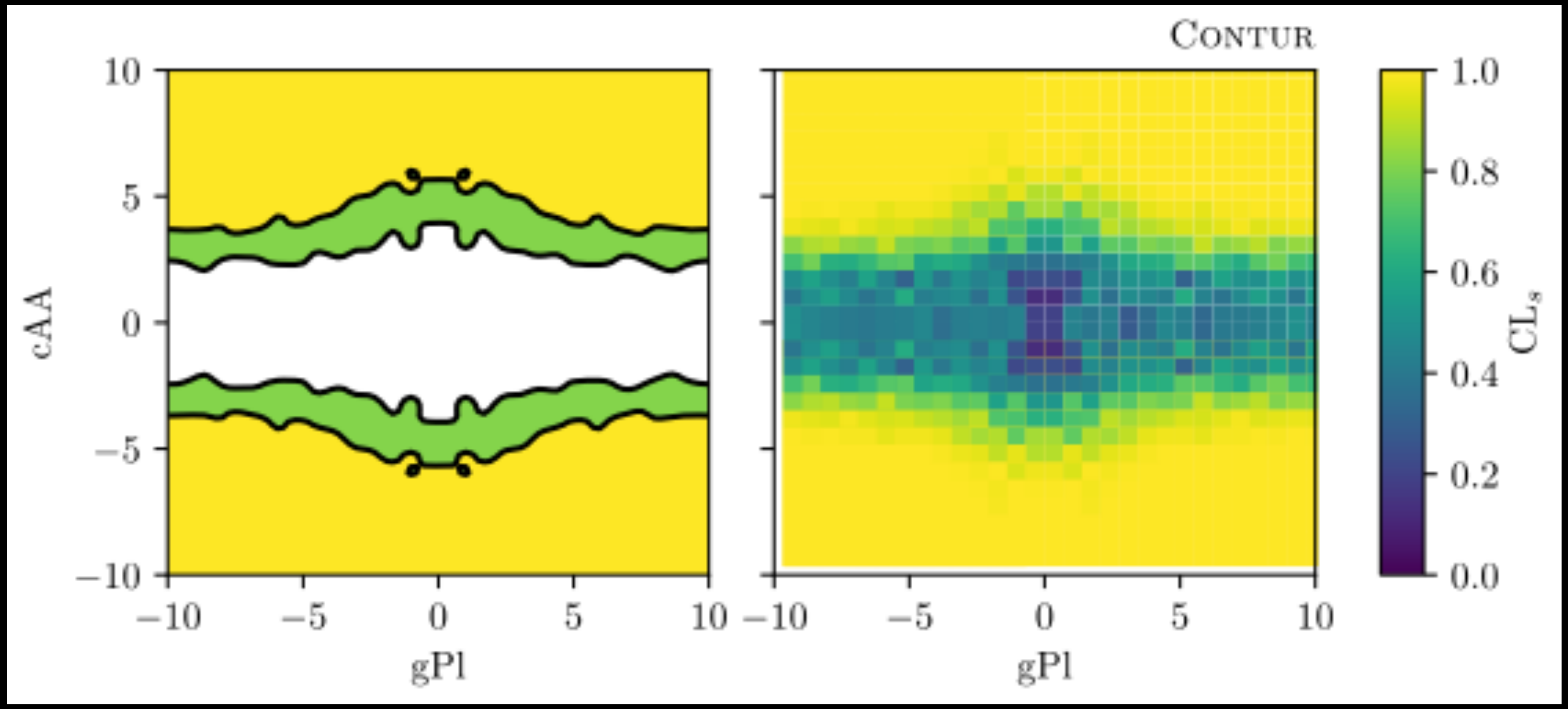


75 GeV

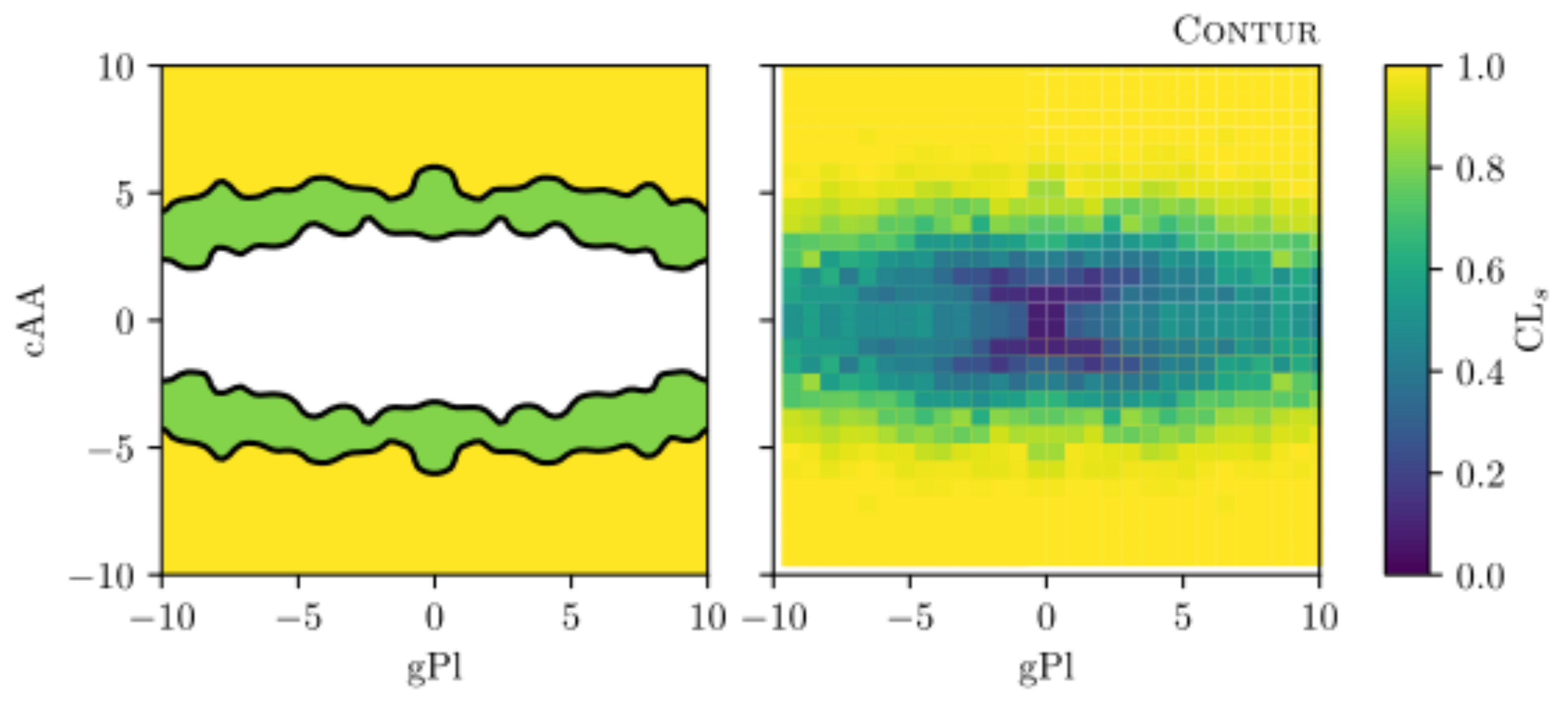
100 GeV



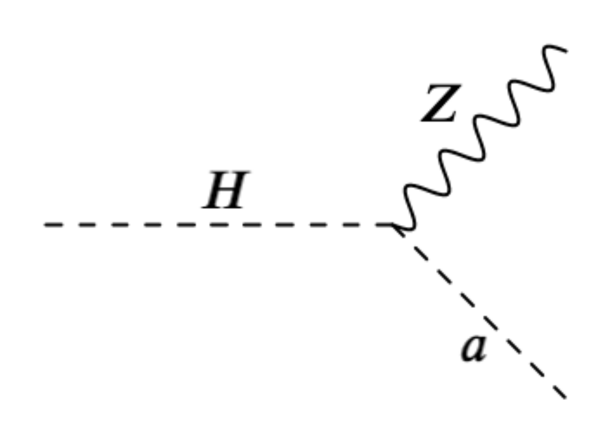
Scenario 2: cah=cZh5=1 (Low mass)

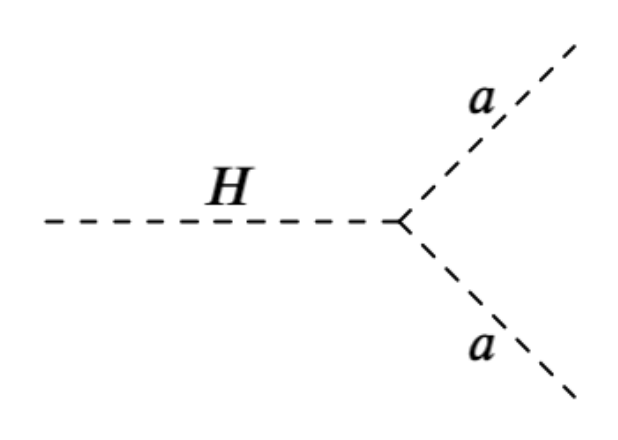


0.5 GeV



1.5 GeV





<u>At 0.5 GeV</u>

Case 2:

σ(H→Za) = 0.982802

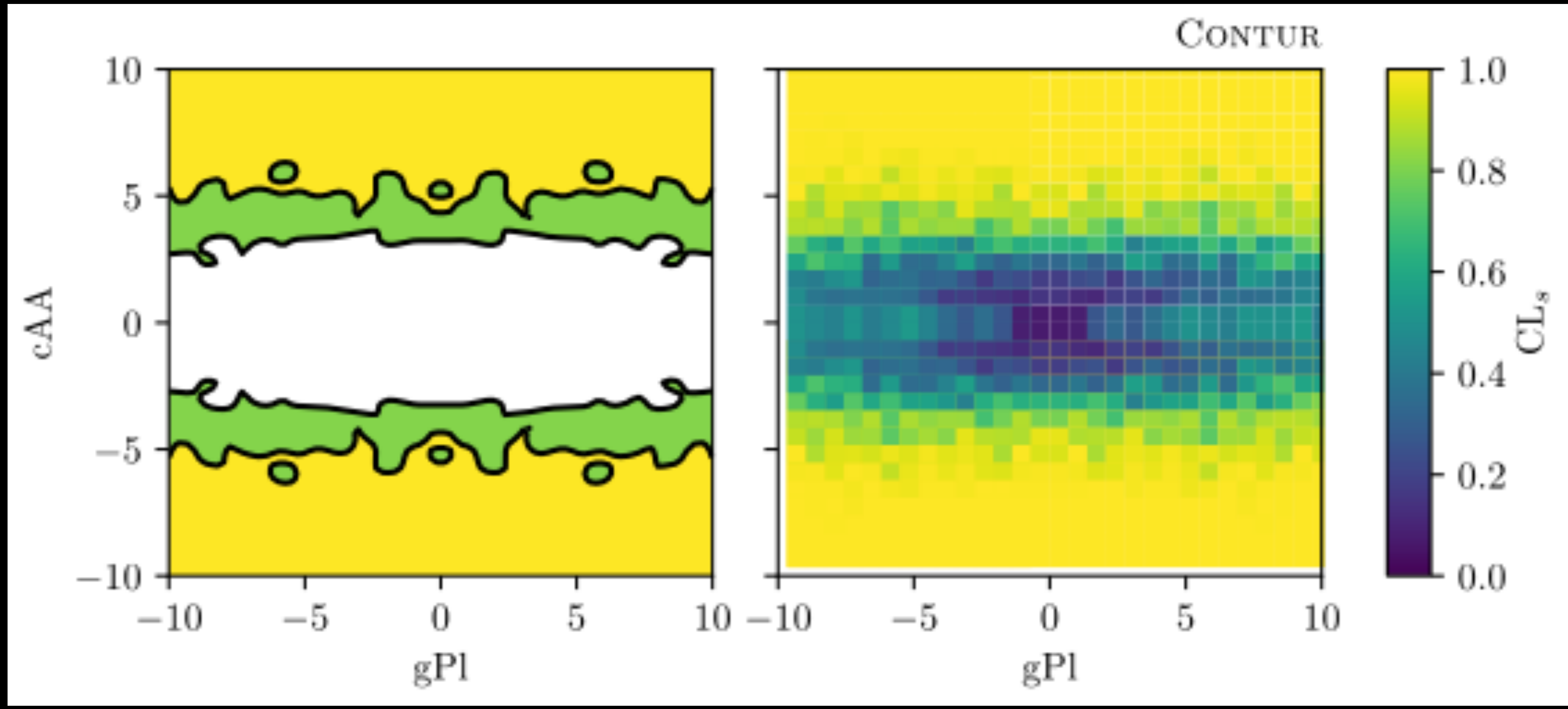
σ(H→aa) = 0.00241992

Case1:

σ(H→Za) = 0.985186

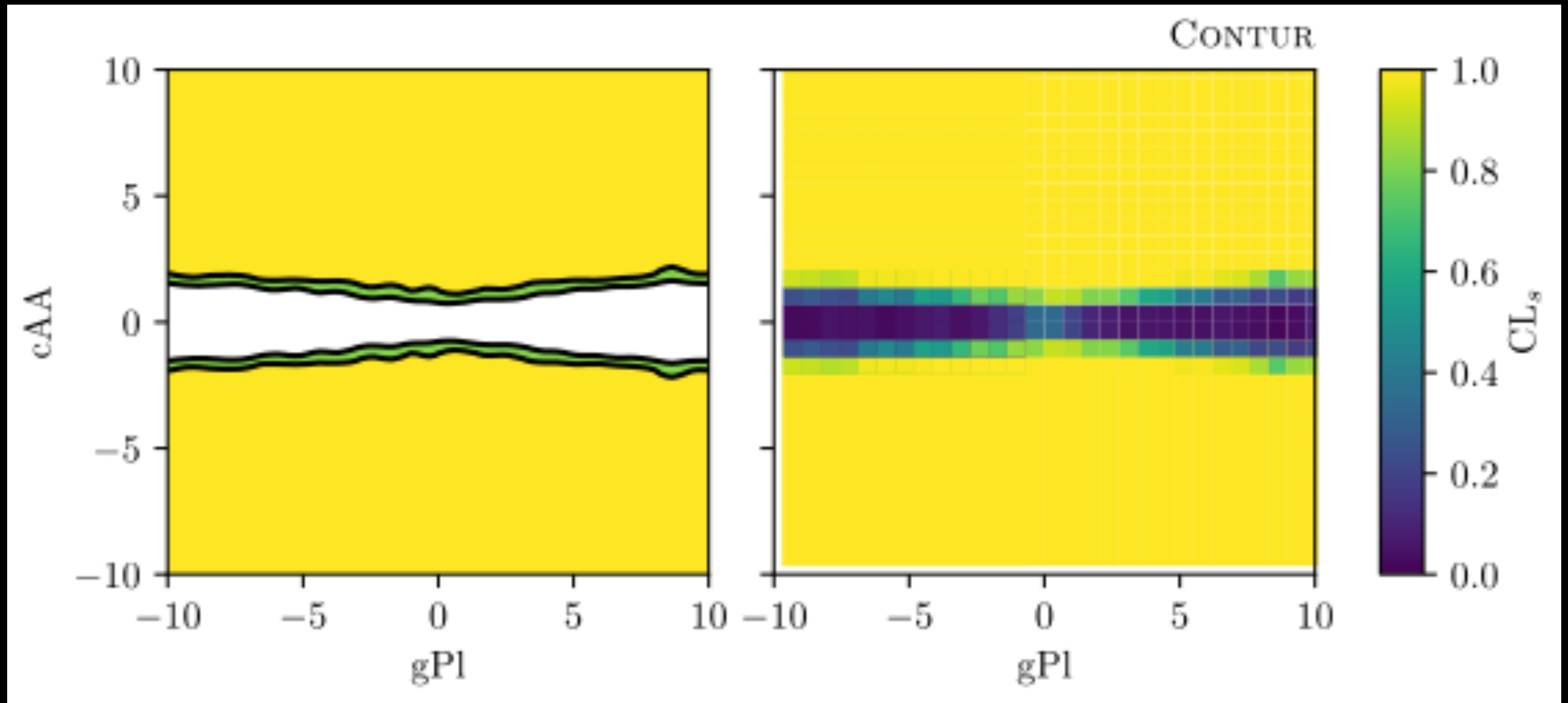
σ(H→aa) = 0

3 GeV



Scenario 2: cah=cZh5=1 (High mass)

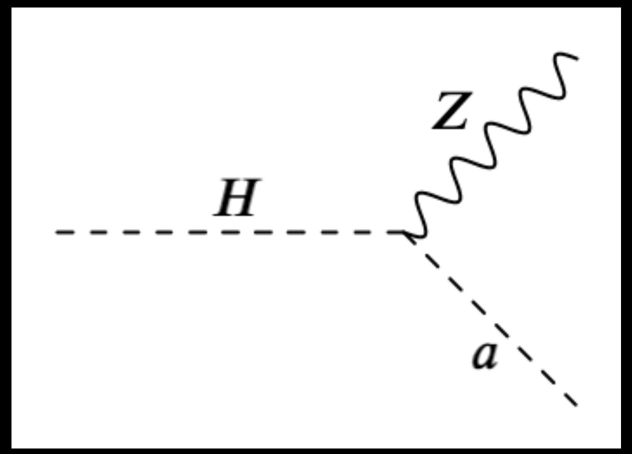
- No visible impact as no change to the decay modes as at high mass only the a→ɣɣ is the dominant decay mode.

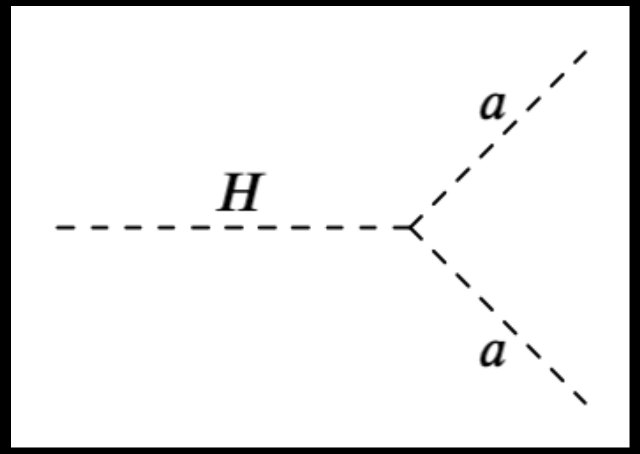


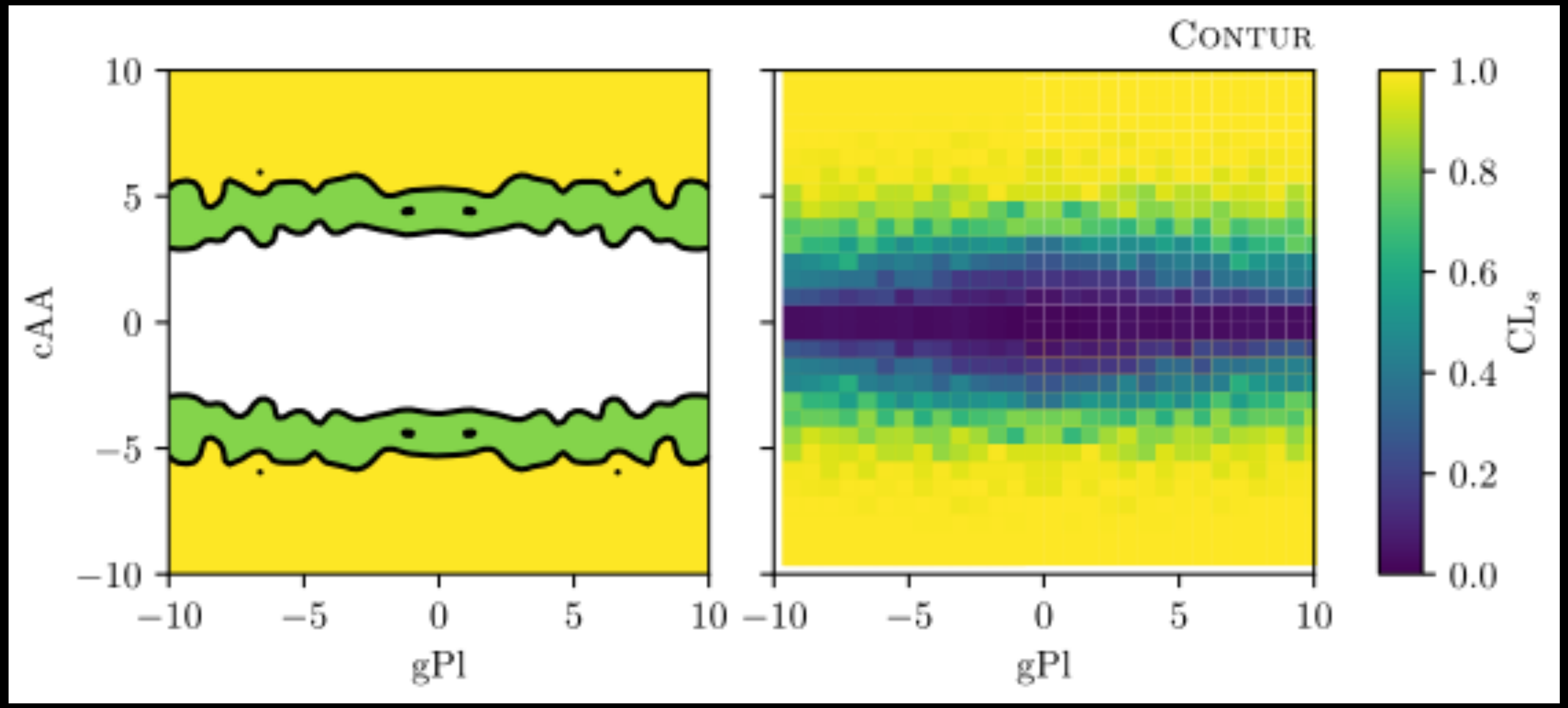
50 GeV

Scenario 3: cah=1 and cZh5=0

- Same exclusion as Scenario 2 cah=cZh5=1
- Same cross-sections for Higgs to ALP decay too
- Hinting at cZh5 coupling turned on in UFO file or some underlying loop process taking place giving this contribution.







3 GeV

Conclusion

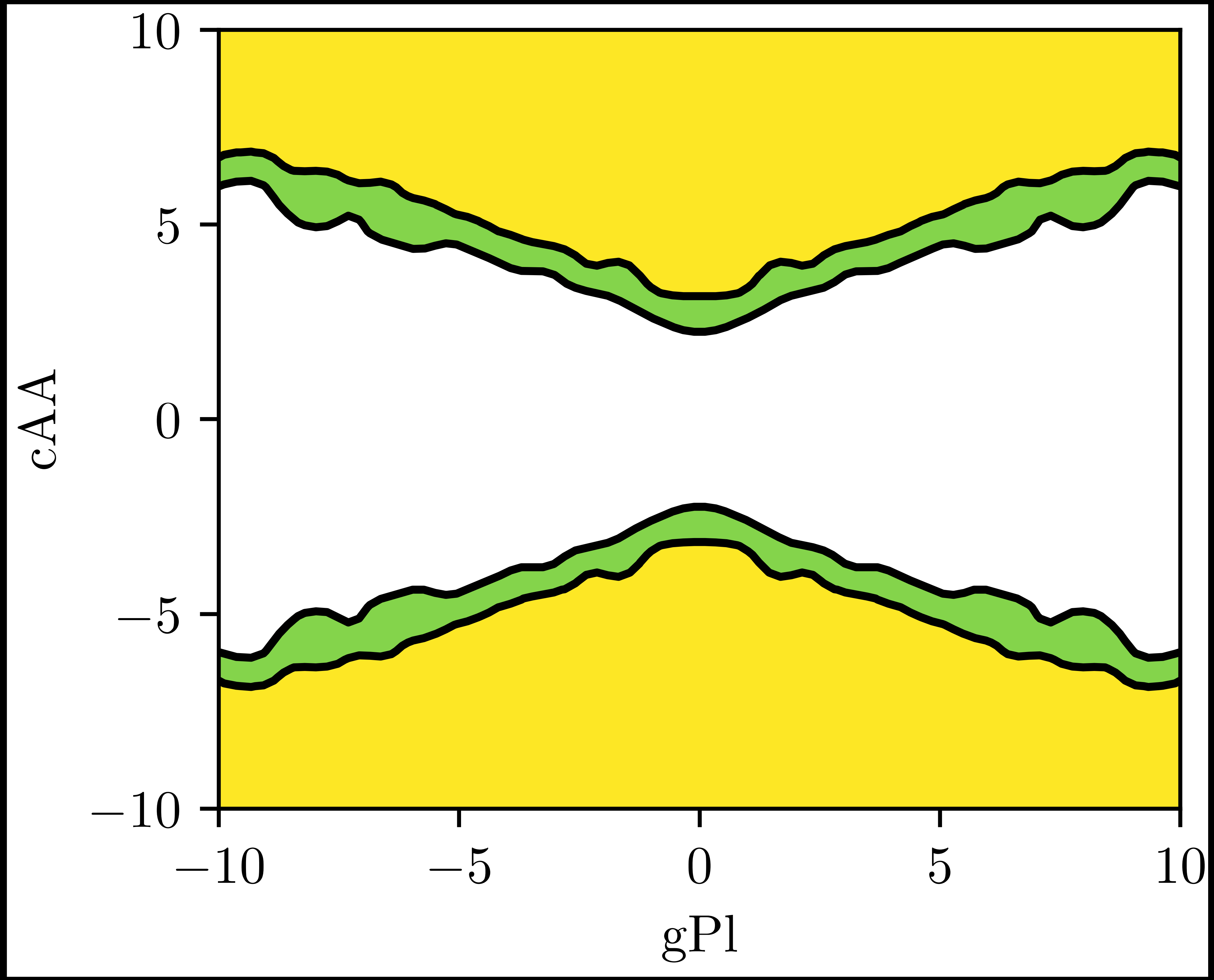
- Axion Like Particles cannot be fully ruled out
- Explains various unresolved phenomena
- Using CONTUR we narrowed down parameter space where ALP model explains region anomalous magnetic moment of the muon
- High pressure on the ALP-lepton coupling value and we see that we have excluded most of the ALP-photon coupling space
- Even for high mass cases there is a region which cannot be fully excluded hinting that this model should be probed further and it makes for a viable BSM candidate
- Scans at other CoM energy levels should also be run in order to compare our results with tau – anti tau lepton measurements
- Scans can also be run for more events to see smoother exclusions.

Backup

Scenario 1 3 GeV (bump origin)

ATLAS_8_GAMMA

Consists of cross-sections of H→ɣɣ



Strong CP problem

- Evidence of Charge Parity symmetry violation in Electroweak interactions
- Charge Parity symmetry theoretically allowed to be broken in Strong interactions
- Charge Parity symmetry not observed to be broken in Strong interactions
- New global symmetry introduced which helps explain this situation
- This symmetry when undergoes through Spontaneous symmetry breaking it creates pseudo-scalar particles such the as ALP.

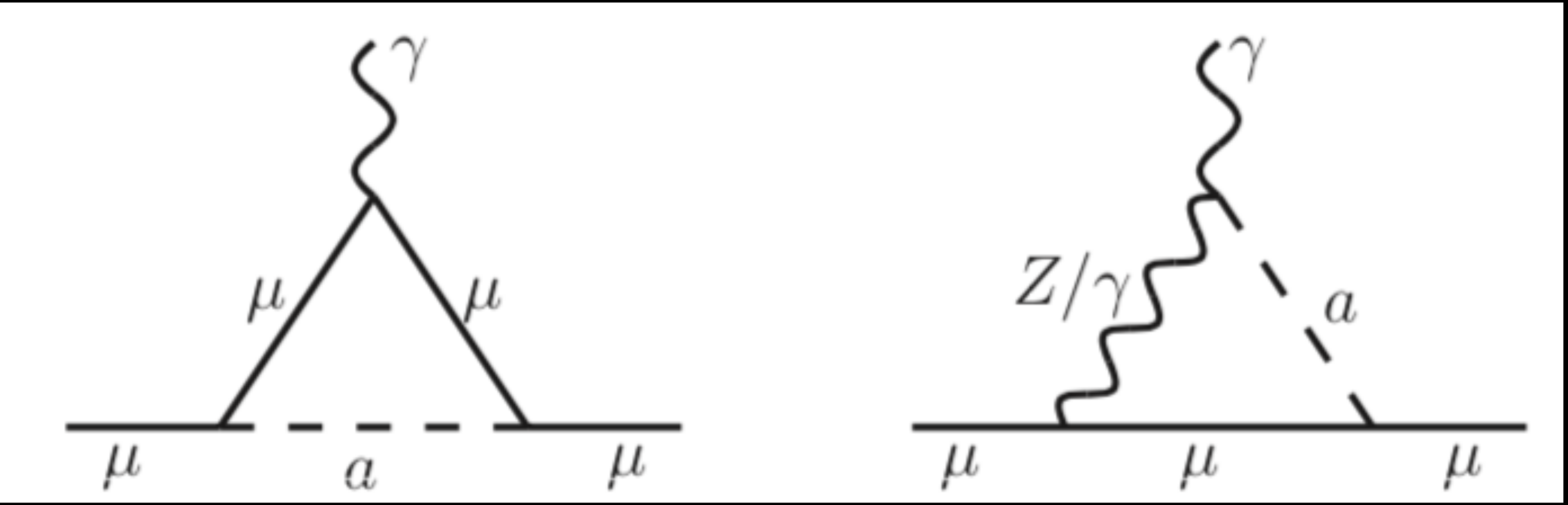
Functions

The loop functions read $\left(\text{ with } x = m_a^2/m_\mu^2 + i0\right)$

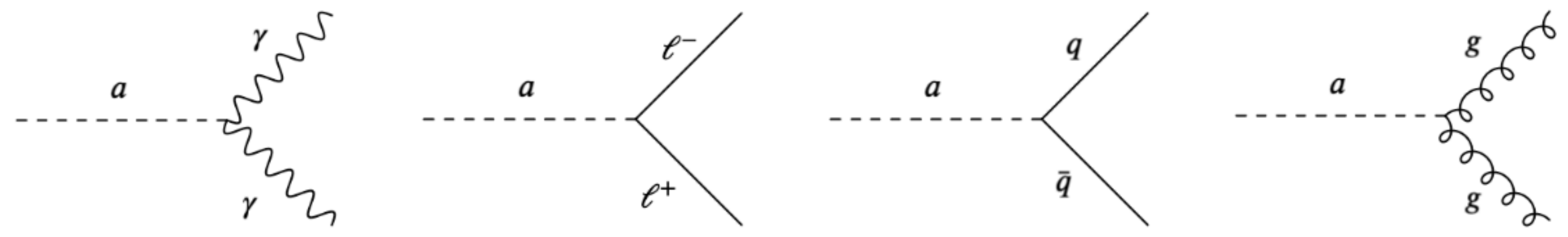
$$h_1(x) = 1 + 2x + x(1-x)\ln x - 2x(3-x)\sqrt{\frac{x}{4-x}}\arccos\frac{\sqrt{x}}{2}$$

$$h_2(x) = 1 - \frac{x}{3} + \frac{x^2}{6}\ln x + \frac{2+x}{3}\sqrt{x(4-x)}\arccos\frac{\sqrt{x}}{2}$$

One-loop diagrams contributing to the anomalous magnetic moment of the muon.



ALP Feynman diagrams



(a) (b) (c) (d)

(e) (f)

(g) (h) (i)