Nonresonant Searches for Axion-Like Particles in Vector Boson Scattering Processes at the LHC

Jonathan Machado Rodríguez

Universidad Autónoma de Madrid - Instituto de Física Teórica

Based on: J. Bonilla , I. Brivio, J. Machado-Rodríguez, J. F. de Trocóniz [2202.03450]

UAM UNIVERSIDAD AUTONOMA DE MADRID

ift

Invisibles'22 Workshop, 20th-24th June 2022

Axion-Like Particles

- Axion-Like Particles (or ALPs) are neutral pseudo scalars with shift-invariant and/or anomalous couplings

- Effective Field Theory (EFT) consistent with SM gauge and CP symmetries

- **ALP interactions with SM particles have a derivative character**: they grow with momentum

$$\mathscr{L}_{ALP} \supset -c_{\tilde{B}} \frac{a}{f_a} B_{\mu\nu} \tilde{B}^{\mu\nu} - c_{\tilde{W}} \frac{a}{f_a} W^i_{\mu\nu} \tilde{W}^{i\mu\nu} - c_{\tilde{G}} \frac{a}{f_a} G^A_{\mu\nu} \tilde{G}^{A\mu\nu} .$$

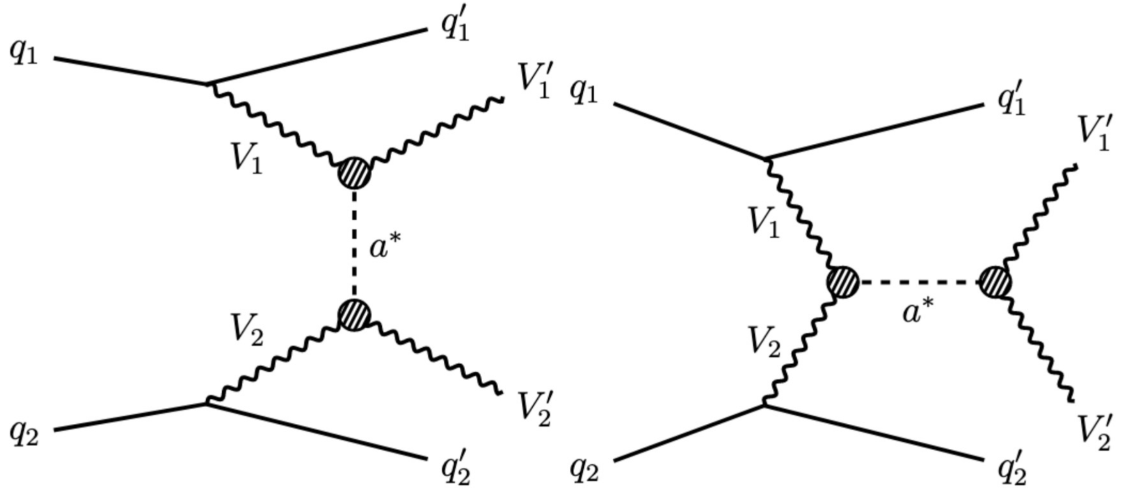
- LHC sensitive to NP scale f_a ~ TeV

- ALP couplings to EWK bosons: ZZ, WW and Wγ → (@LO) $c_{\tilde{B}}$ $c_{\tilde{W}}$

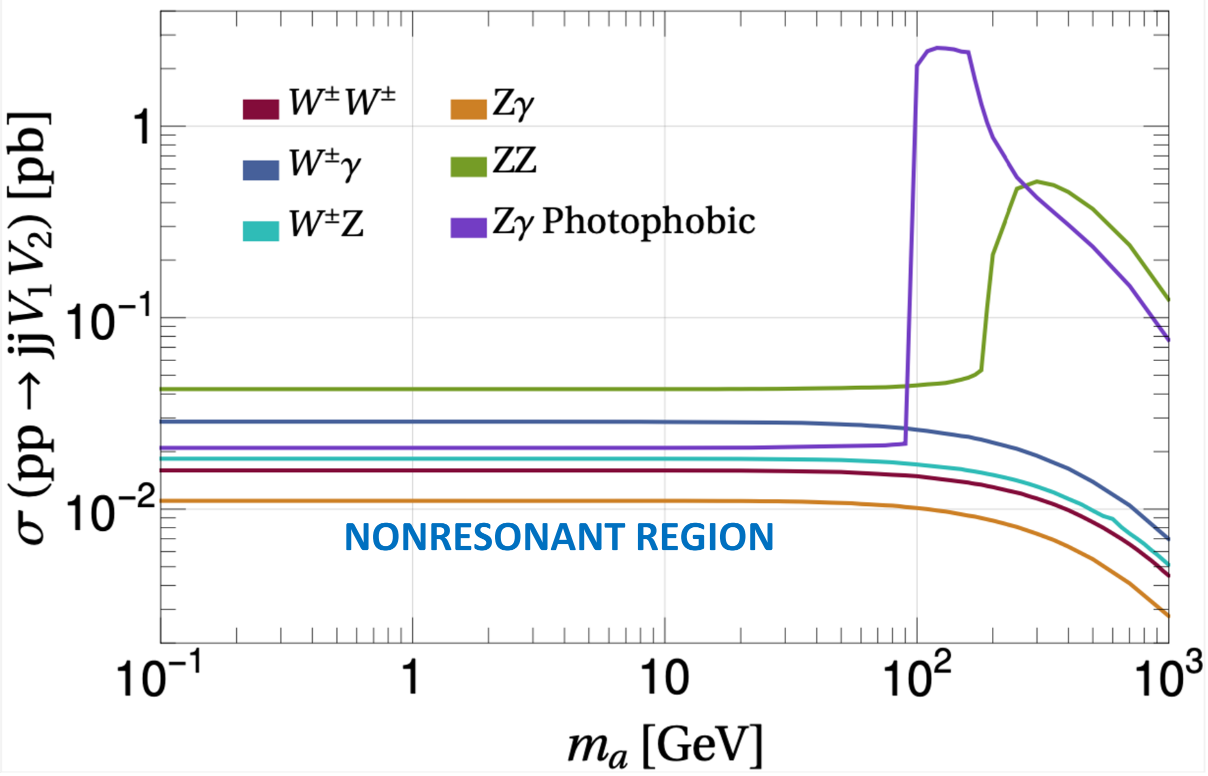
A Novel Approach:
Nonresonant ALPS in VBS

- Vector Boson Scattering (VBS)
- Nonresonant ALP searches proposed by M.B. Gavela, J.M. No, V. Sanz and **J.F. de Trocóniz** [1905.12953]
- ALP acts as a very off-shell mediator of the process $m_a^2 \ll \hat{s}$
- Signals **independent of ALP mass m_a and its decay width up to $m_a \lesssim 100$ GeV**
- **VBS limits on ALP couplings to vector boson independently of the gluon coupling**

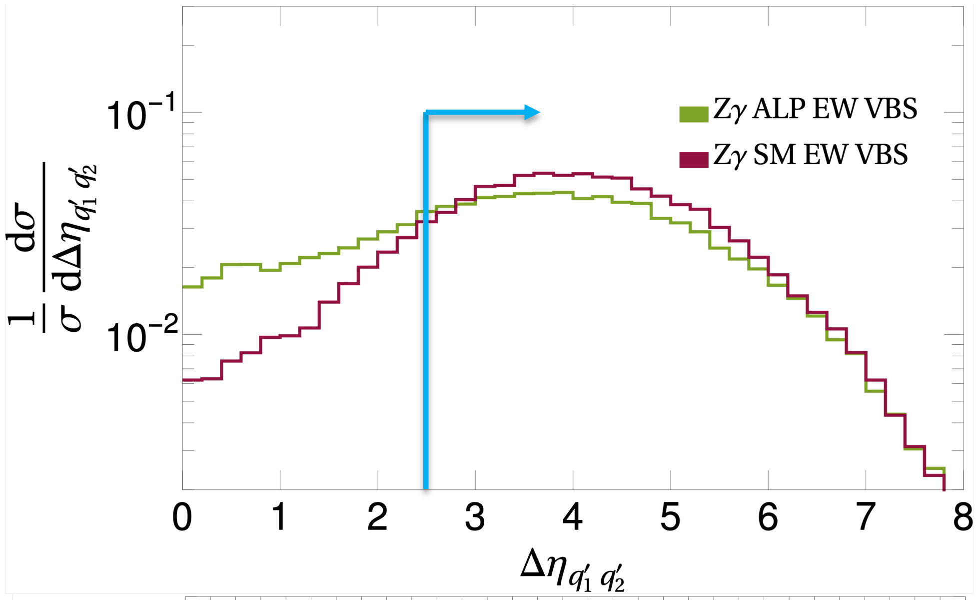
→ $c_{\tilde{B}}$ $c_{\tilde{W}}$ ~~$c_{\tilde{G}}$~~

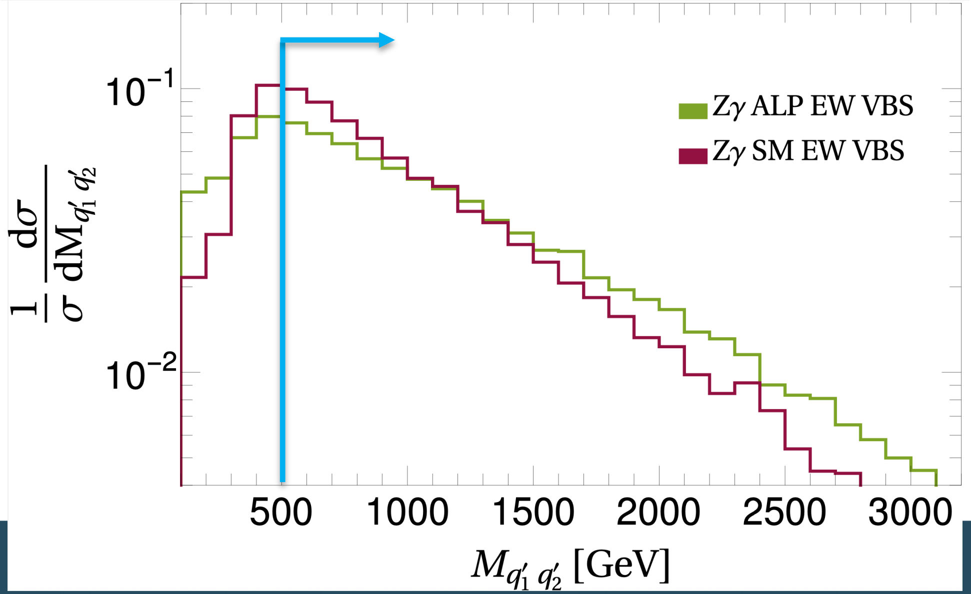


VBS $pp \to V_1V_2jj$ LO diagrams.



A Novel Approach:
Nonresonant ALPS in VBS



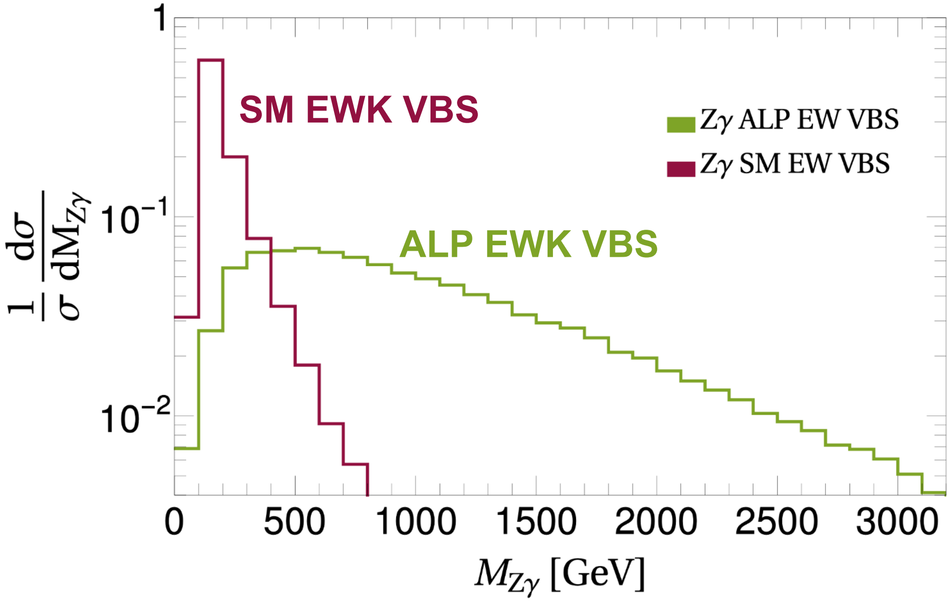


Wide rapidity separation

VBS characteristic observables

Large dijet mass

Diboson Mass



- Derivative nature of ALP interactions: **deviations in the tail of the diboson mass with respect to the SM**

ALP Diboson Mass in CMS Leptonic Analyses

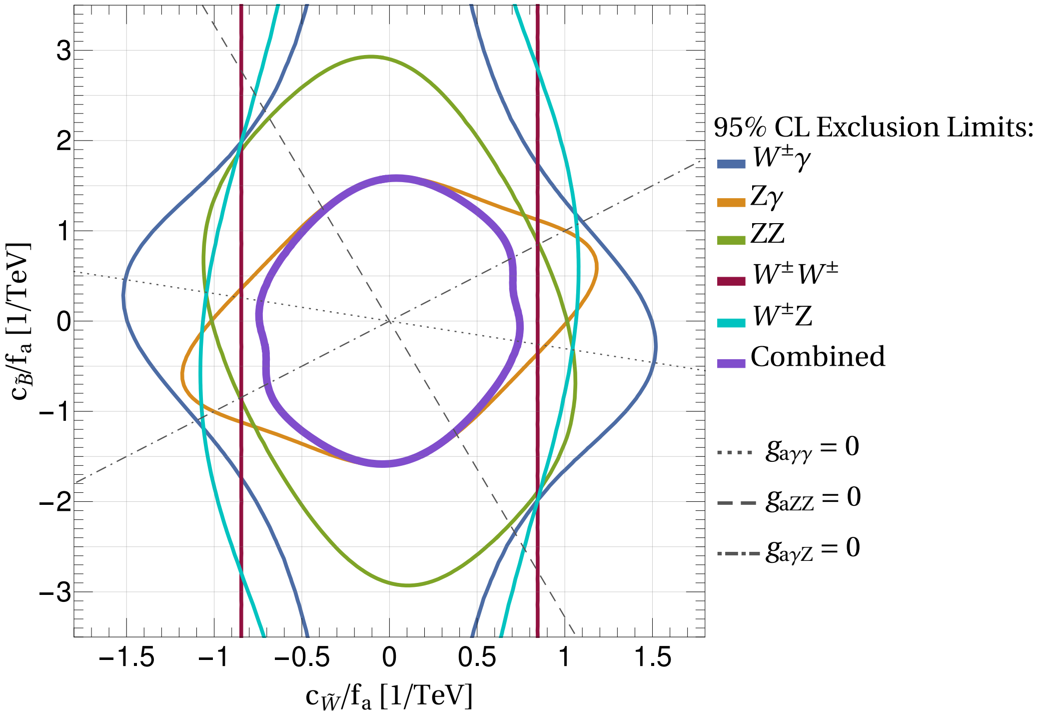
- ATLAS/CMS Run 2 measurements.
- **Reinterpretation of five CMS VBS analyses** with lepton/photon final states:
  - ZZ: CMS-SMP-20-01
  - Same-sign WW and WZ: CMS-SMP-19-012
  - $Z\gamma$: CMS-SMP-20-016
  - $W\gamma$: CMS-SMP-19-008
- Look at high energy deviations in the tail of the transverse momentum/mass spectra
- Selections cuts and integrated luminosities in the CMS papers
- Calibrate our Delphes detector simulation for the ALP-mediated VBS using the SM EWK channel

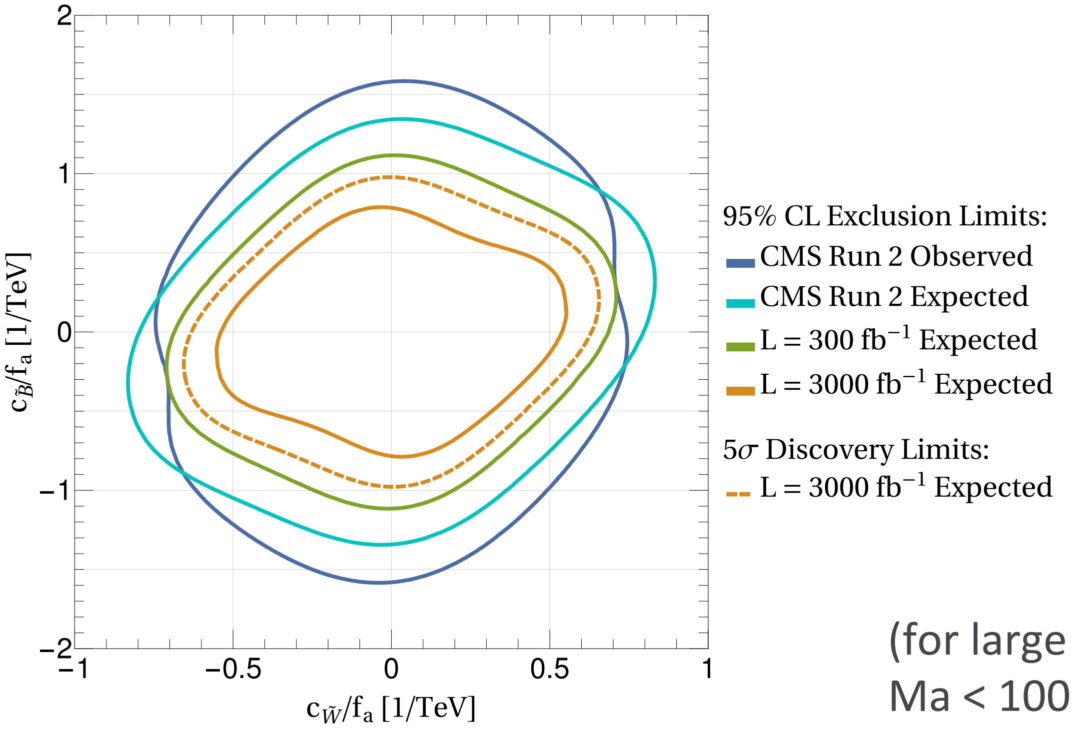
ALP Diboson Mass in CMS Leptonic Analyses

	$c_{\tilde{W}} = c_{\tilde{B}}$ signal / interf. [fb]	**Photophobic** signal / interf. [fb]	**Expected Lepton Events**	**Int. lum.** [fb^{-1}]
ZZ	42.4 / -13.5	18.5 / -9.3	9.3 / -3.2	137
WZ	18.4 / 1.7	23.9 / -0.14	4.2 / 0.05	137
$W^{\pm}W^{\pm}$	16.0 / -4.0	16.0 / -4.0	18 / -5.5	137
$W\gamma$	28.7 / 4.3	5.4 / 1.7	3.6 / -0.04	35.9
$Z\gamma$	11.1 / 0.3	20.9 / -9.1	15.1 / 0.07	137

Results

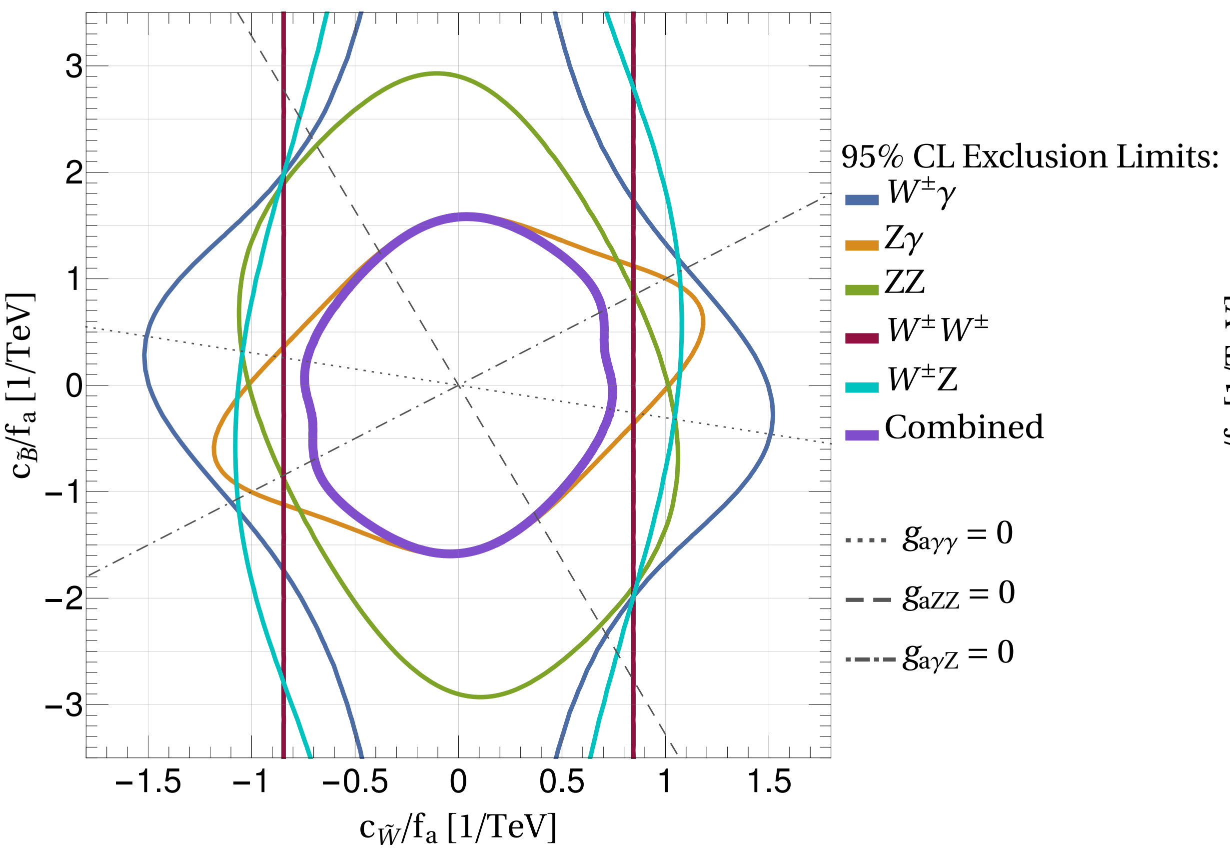
- No excess found
- **Current limits** with CMS Run 2 data and **projected limits** at Run 3 and HL-LHC in the ALP $(c_{\widetilde{W}}, c_{\widetilde{B}})$ parameter space
- Expected diff. cross sections parameterized in $(c_{\widetilde{W}}/f_a, c_{\widetilde{B}}/f_a)$ plane with 4th -2nd degree polynomials for pure ALP signal / interference

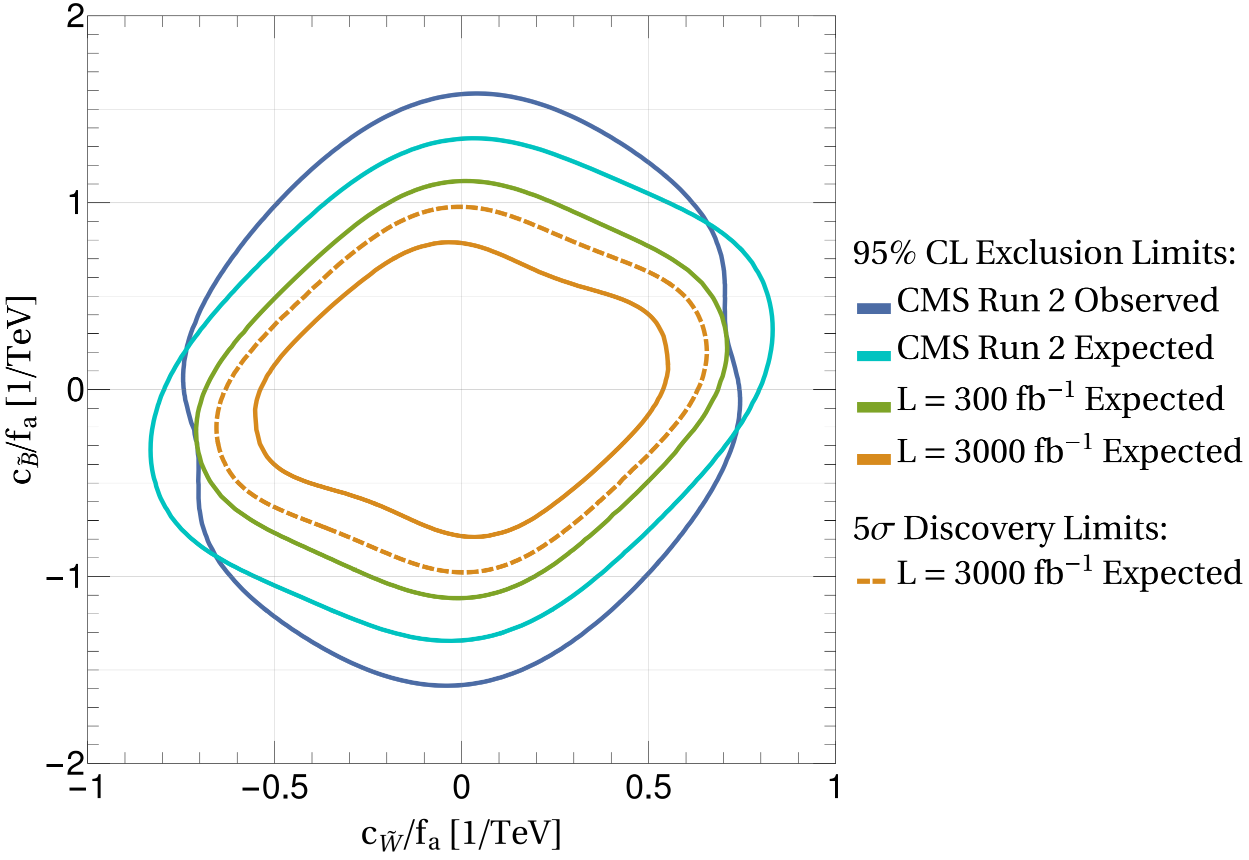




(for large fa and Ma < 100 GeV)

Results

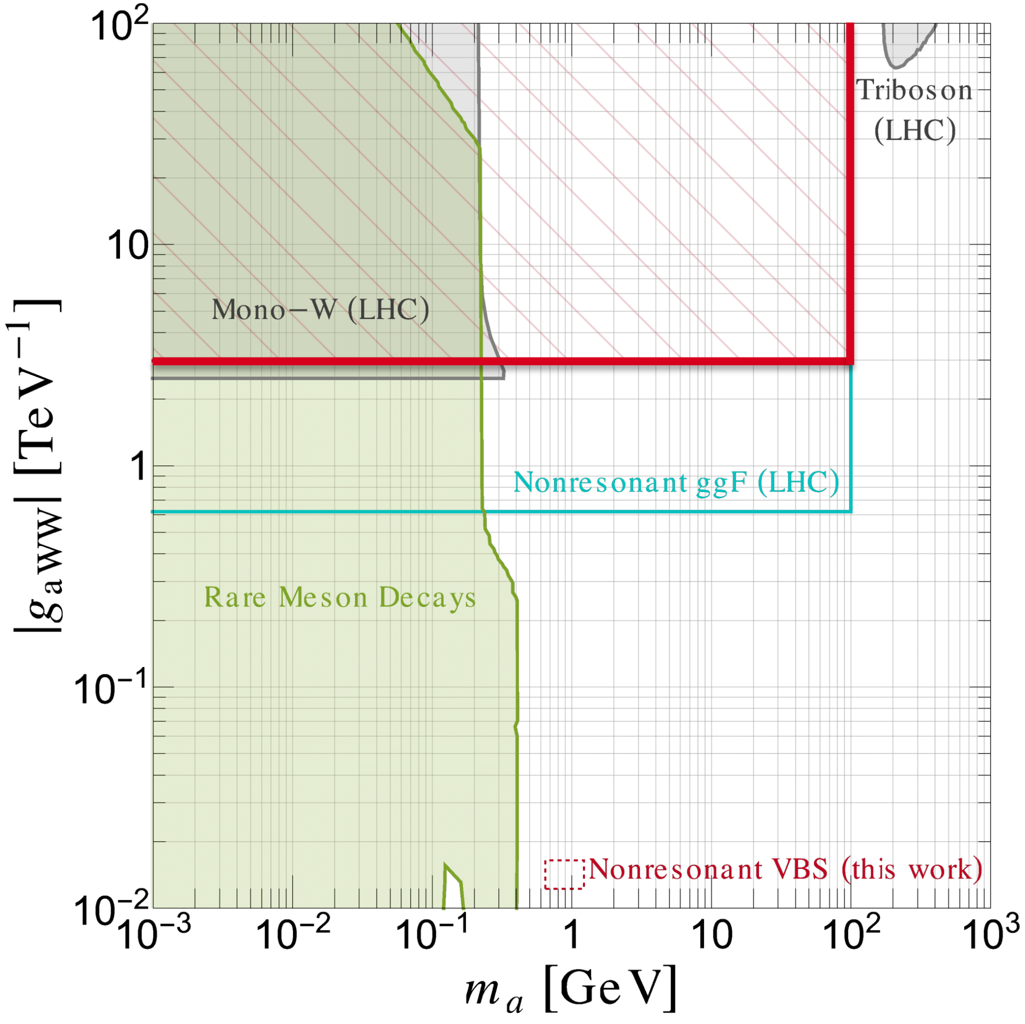


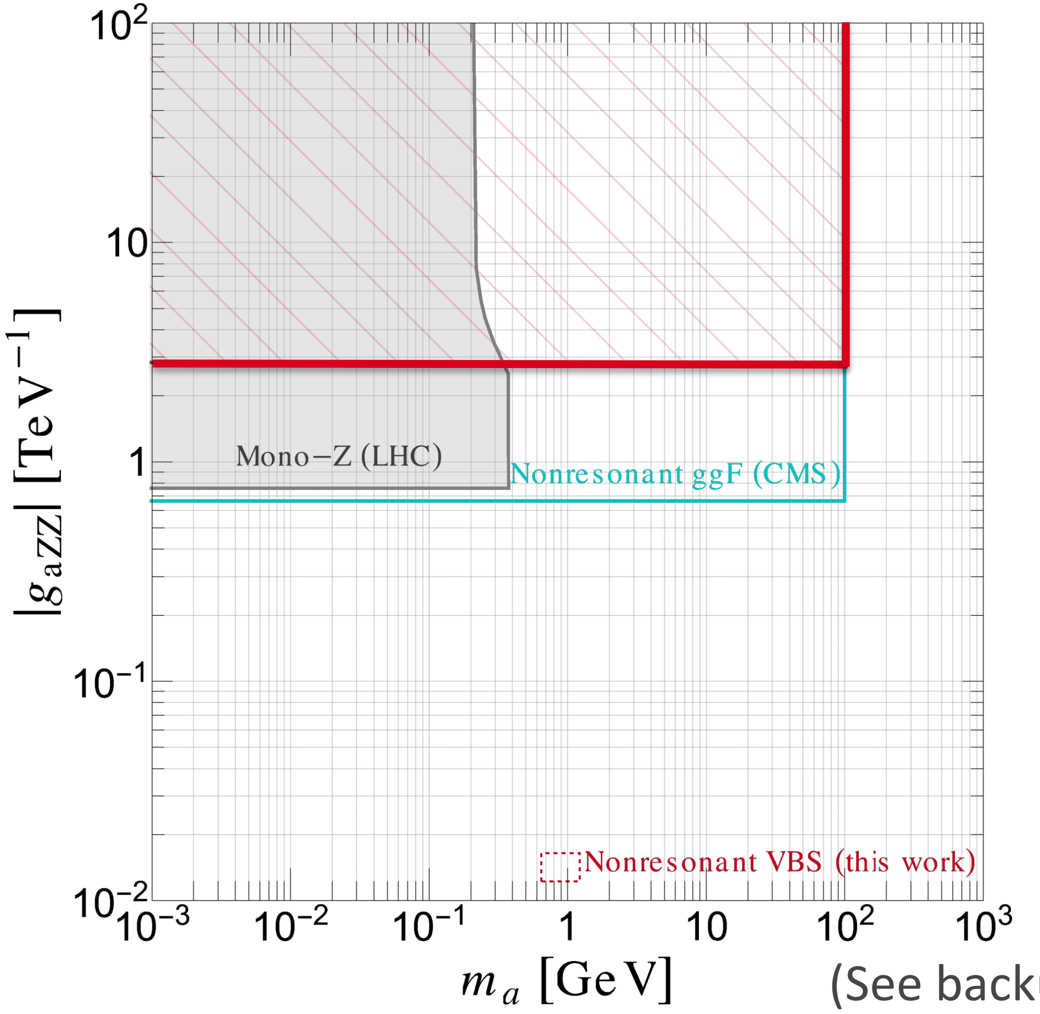


(for large fa and Ma < 100 GeV)

Results

- Limits are **very competitive** and probe **previously unexplored regions** of the param. space





(See backup slides)

Conclusions

- Access to **EWK couplings independently of the gluons**
- Limits **independent of the ALP mass and decay width** ($m_a \lesssim 100$ GeV)
- **Current limits** (CMS Run 2 data) and **projected limits** (Run 3 and HL)
- Limits are **very competitive** and probe **previously unexplored regions** of the param. space
- Great opportunity for a **dedicated ALP searches** at Run 3 and HL-LHC

→ ArXiv: 2202.03450

Physical couplings

$$g_{a\gamma\gamma} = \frac{4}{f_a}(s_\theta^2 c_{\widetilde{W}} + c_\theta^2 c_{\widetilde{B}})$$

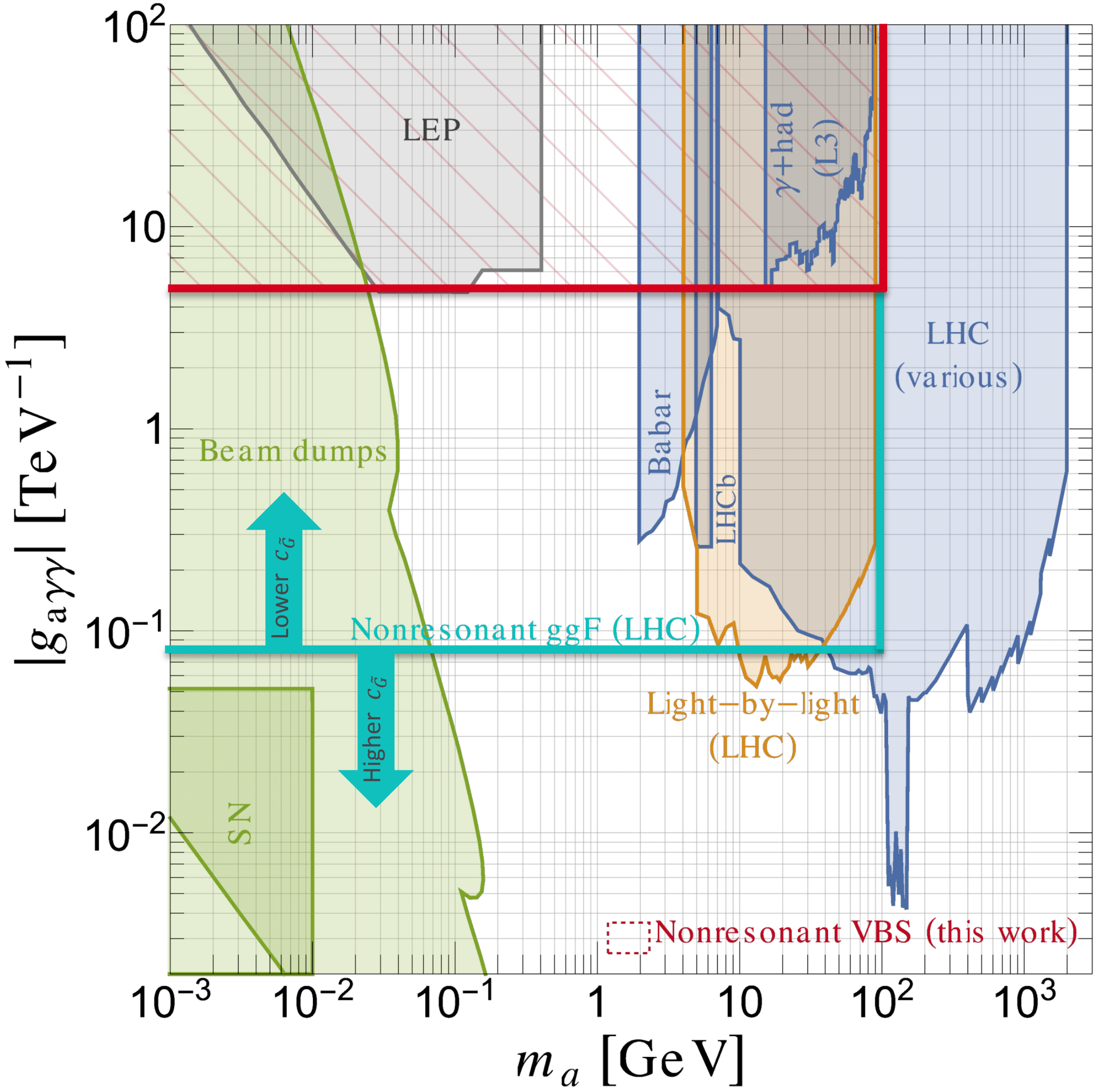
$$g_{aZZ} = \frac{4}{f_a}(c_\theta^2 c_{\widetilde{W}} + s_\theta^2 c_{\widetilde{B}})$$

$$g_{a\gamma Z} = \frac{4}{f_a} s_{2\theta}(c_{\widetilde{W}} - c_{\widetilde{B}})$$

$$g_{aWW} = \frac{4}{f_a} c_{\widetilde{W}}$$

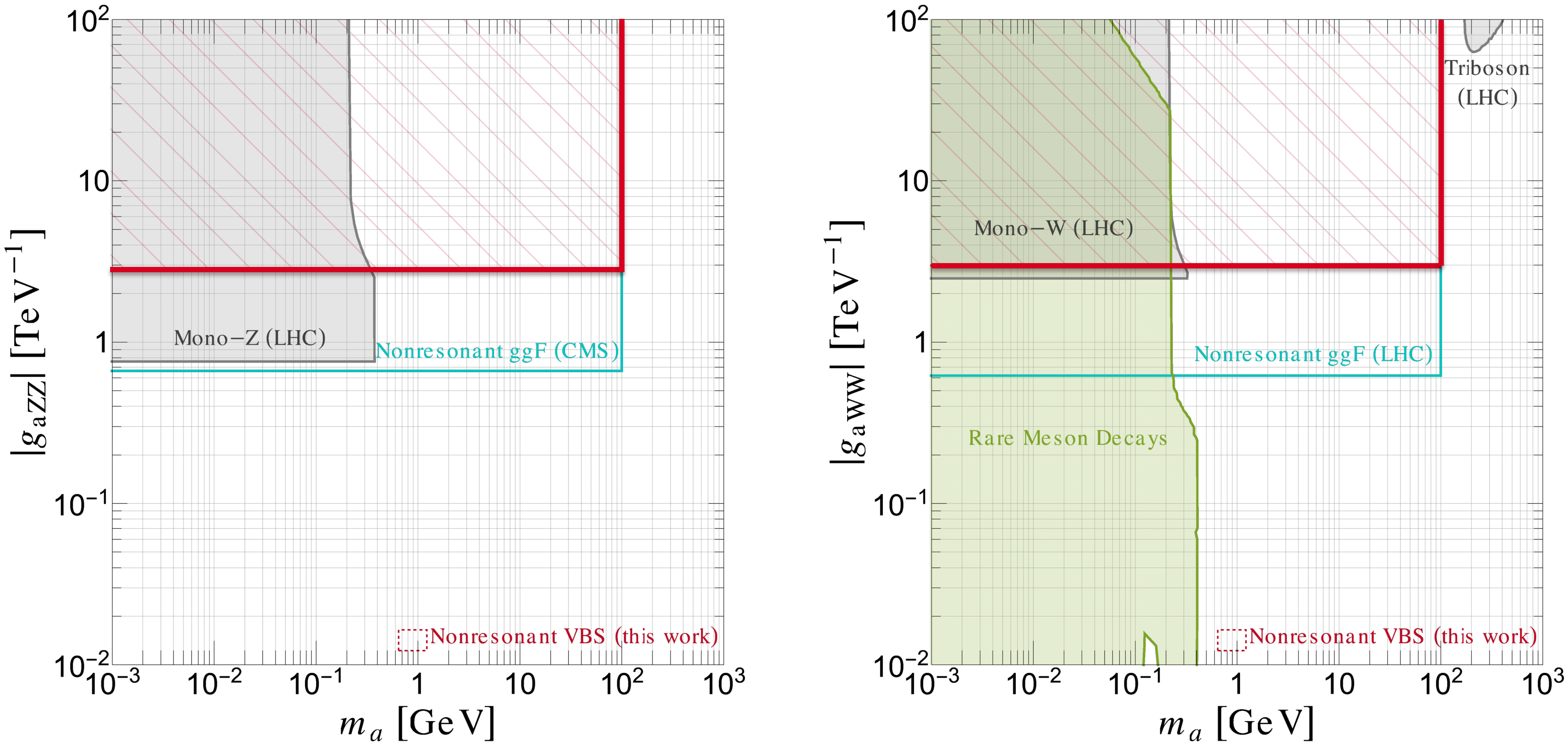
$$g_{agg} = \frac{4}{f_a} c_{\widetilde{G}}$$

Comparison to existing bounds



- **Red:** this work
- **Green:** no assumptions
- **Light blue:** nonresonant ggF. Depend on the coupling to gluons and asume g_{agg} = 1 TeV^{-1}
- **Dark blue:** gluon dominance, i.e., $g_{agg} \gg g_{aV_1V_2}$
- **Orange:** $BR(a \to \gamma\gamma)$= 1
- **Grey:** more elaborate assumptions on the EWK sector

Comparison to existing bounds



Comparison to existing bounds