Searches for Axion-Like Particles at CMS

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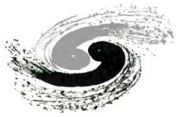
on behalf of CMS

TeVPA2021: TeV Particle Astrophysics 2021.24-29 Oct 2021. Chengdu (China)



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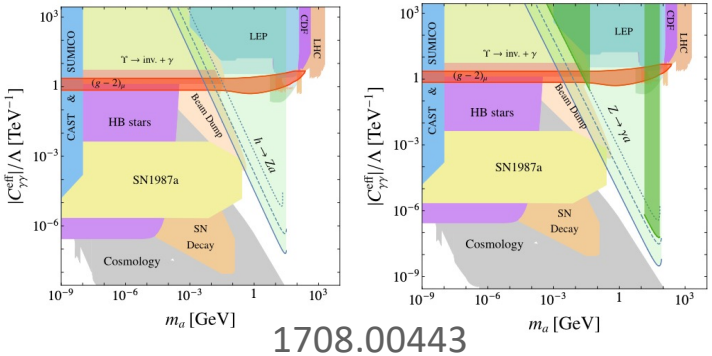
Axion Like Particles

- Gauge-singlets pseudoscalar particles.

$$\mathcal{L}_{\text{eff}}^{D\leq 5} = \frac{1}{2}(\partial_\mu a)(\partial^\mu a) - \frac{m_{a,0}^2}{2}a^2 + \frac{\partial^\mu a}{\Lambda}\sum_F \bar{\psi}_F \boldsymbol{C}_F \gamma_\mu \psi_F + g_s^2 C_{GG}\frac{a}{\Lambda}G^A_{\mu\nu}\tilde{G}^{\mu\nu,A} + g^2 C_{WW}\frac{a}{\Lambda}W^A_{\mu\nu}\tilde{W}^{\mu\nu,A} + g'^2 C_{BB}\frac{a}{\Lambda}B_{\mu\nu}\tilde{B}^{\mu\nu},$$

$$\mathcal{L}_{\text{eff}}^{D\geq 6} = \frac{C_{ah}}{\Lambda^2}(\partial_\mu a)(\partial^\mu a)\,\phi^\dagger\phi + \frac{C'_{ah}}{\Lambda^2}m_{a,0}^2 a^2\phi^\dagger\phi + \frac{C^{(7)}_{Zh}}{\Lambda^3}(\partial^\mu a)\left(\phi^\dagger iD_\mu\phi + \text{h.c.}\right)\phi^\dagger\phi + \dots.$$



1708.00443

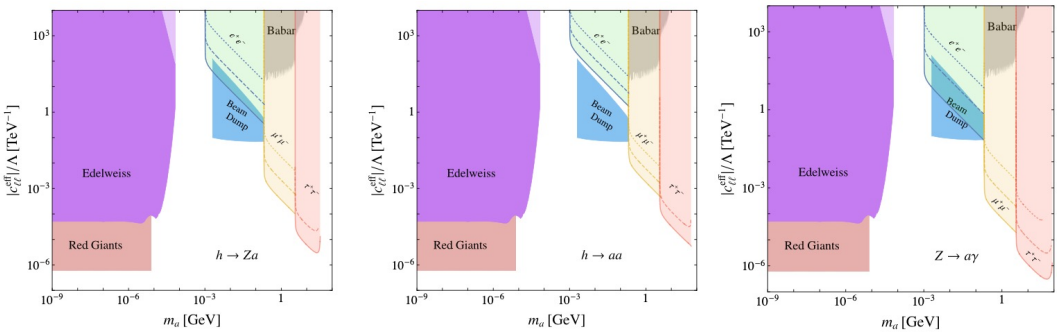
- (Approximate) shift Symmetry $a \to a + c$
- Appear in many well-motivated extensions of the SM
- Decay widths to photons and leptons:

$$\Gamma(a\to\gamma\gamma) \equiv \frac{4\pi\alpha^2 m_a^3}{\Lambda^2}\left|C^{\text{eff}}_{\gamma\gamma}\right|^2 \quad , \quad \Gamma(a\to\ell^+\ell^-) = \frac{m_a m_\ell^2}{8\pi\Lambda^2}\left|c^{\text{eff}}_{\ell\ell}\right|^2\sqrt{1-\frac{4m_\ell^2}{m_a^2}}$$

- Higgs Exotic decays:

$$\Gamma(h\to Za) = \frac{m_h^3}{16\pi\Lambda^2}\left|C^{\text{eff}}_{Zh}\right|^2\lambda^{3/2}\left(\frac{m_Z^2}{m_h^2},\frac{m_a^2}{m_h^2}\right)$$

$$\Gamma(h\to aa) = \frac{v^2 m_h^3}{32\pi\Lambda^4}\left|C^{\text{eff}}_{ah}\right|^2\left(1-\frac{2m_a^2}{m_h^2}\right)^2\sqrt{1-\frac{4m_a^2}{m_h^2}}$$

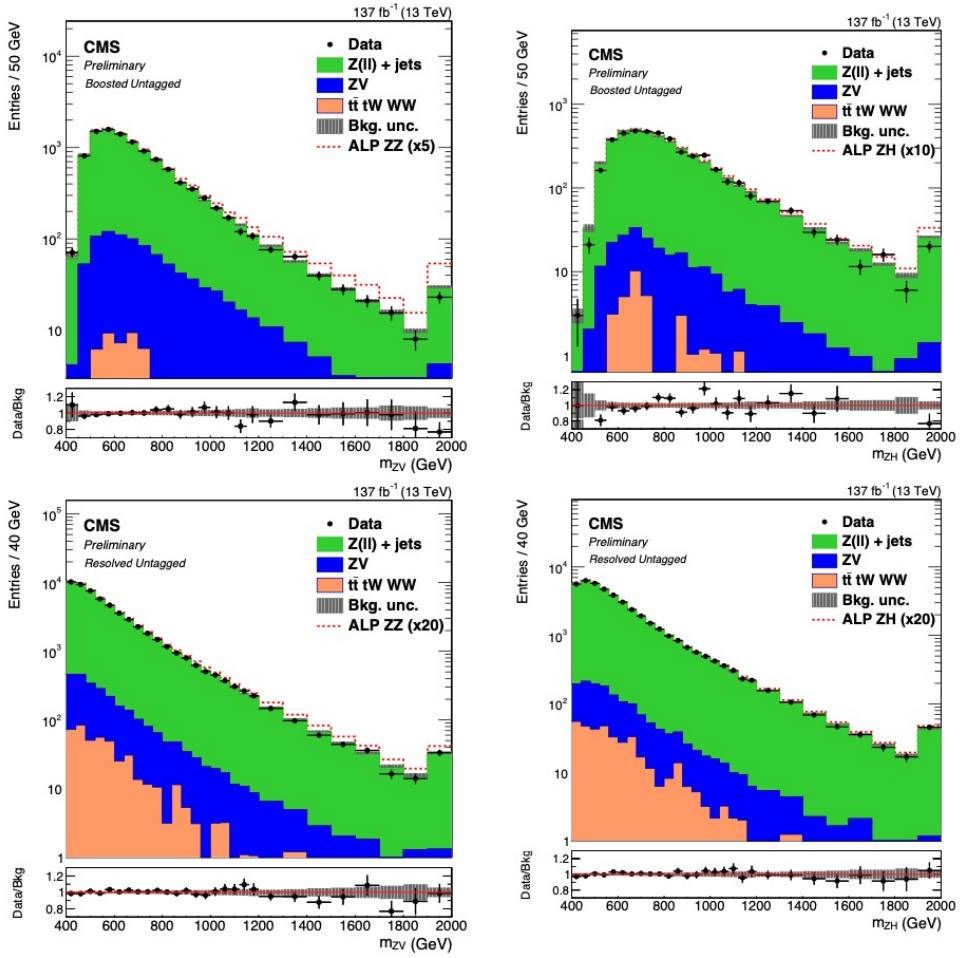


- Colliders allow searches in a wide range of ALP masses and couplings. We can explore ALP masses beyond astrophysical constraints, and even there, provide important crosschecks. At the LHC, natural sensitivity is to Λ scales in the TeV region.

Non resonant $pp \to a^* \to ZH, ZV$

CMS-B2G-20-013

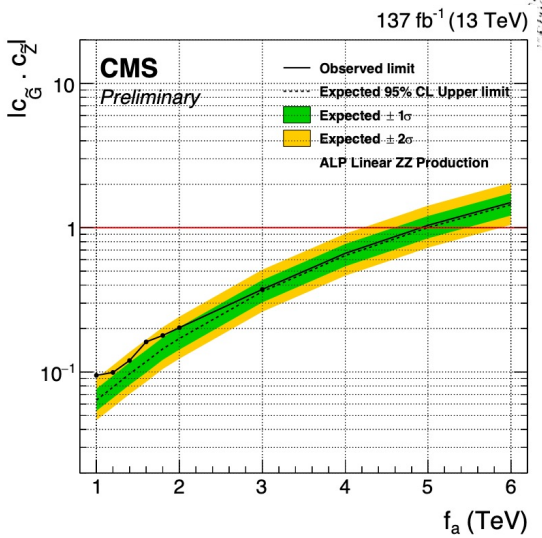
- Dataset:
  - Full-run2 dataset: 2016 - 2018 (137 fb^{-1})
  - $\sqrt{s} = 13\ TeV$
- Signature:
  - $Z \to \ell^+\ell^-$
  - Merged J or resolved jj di-jet
- Search for ALP mediated production of
  - Z boson + Higgs (chiral model)
  - Z boson + Z boson (linear model)
- Main background:
  - Z + jets
- Details about the signal modes [Phys.Rev.Lett. 124 (2020) 5, 051802]

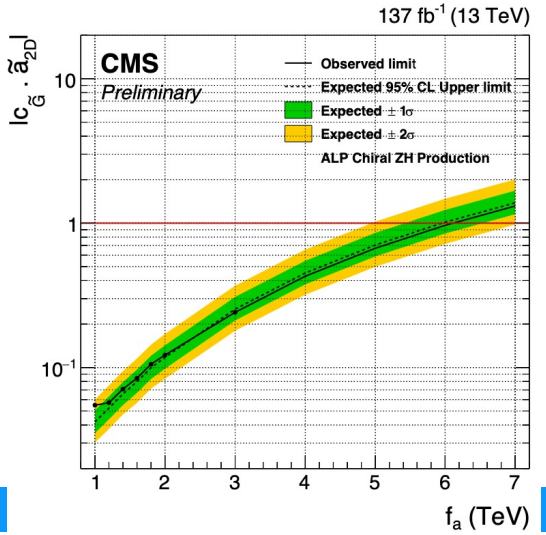


Non resonant $pp \rightarrow a^* \rightarrow ZH, ZV$

CMS-B2G-20-013

- Combined maximum likelihood fit to the mass distribution
- Exclusion region on the $c_i c_j - f_a$ plane for the chiral and linear models
  - 95 % CL limits obtained using CLs method
  - f_a > 3 TeV excluded extrapolating f_a = 3 TeV point linearly
- Limits on c_i/f_a:
  - $\frac{|c_{\widetilde{G}} c_{\widetilde{Z}}|}{f_a^2} < 0.0415(0.0400) TeV^{-2}$
  - $\frac{|c_{\widetilde{G}} c_{\widetilde{2D}}|}{f_a^2} < 0.0269(0.0281) TeV^{-2}$





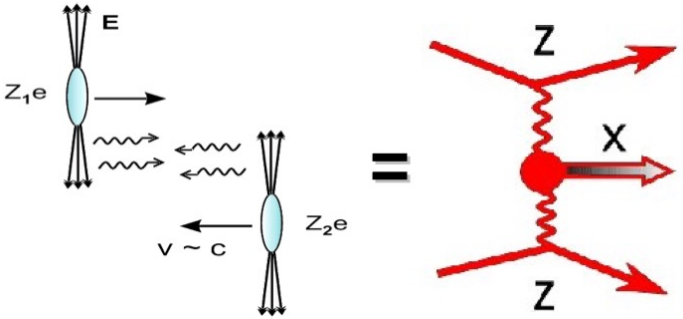
Light-by-Light Scattering

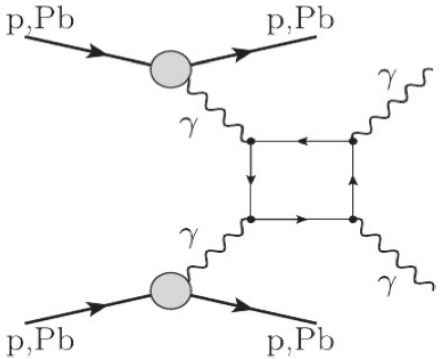
[Phys.Lett.B 797 (2019) 134826]

- PbPb collisions:
  - Electromagnetic ultra-peripheral collisions (UPC)
  - HE ions generate huge EM fields ($10^{14}\ T$) from coherent action of Z=82 p
  - Huge photon fluxes:
    - $\sigma(\gamma-\gamma)\sim 5\times 10^{7}$ for PbPb, lager than p,$e^{\pm}$
  - Beam-energy dependence:
    - Photon luminosities increase as $\propto log^{3}(\sqrt{s})$
  - LbyL x-sections:

System	$\sqrt{s_{\mathrm{NN}}}$ (TeV)	$\mathcal{L}_{\mathrm{AB}}\cdot\Delta t$ (per year)	$\sigma^{\mathrm{excl}}_{\gamma\gamma\to\gamma\gamma}$ $[m_{\gamma\gamma}>5\ \mathrm{GeV}]$	$N^{\mathrm{excl}}_{\gamma\gamma}$ (per year) [after cuts]
p-p	14	1 fb^{-1}	105 ± 10 fb	12
p-Pb	8.8	200 nb^{-1}	260 ± 26 pb	6
Pb-Pb	5.5	1 nb^{-1}	370 ± 70 nb	70

  - Large visible LbyL x-sections in PbPb UPCs at the LHC

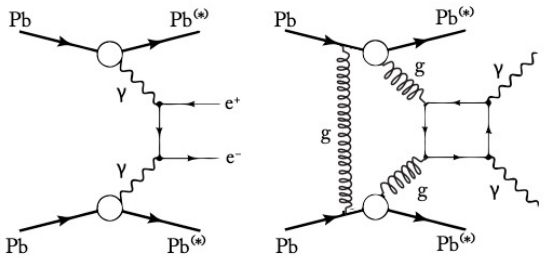


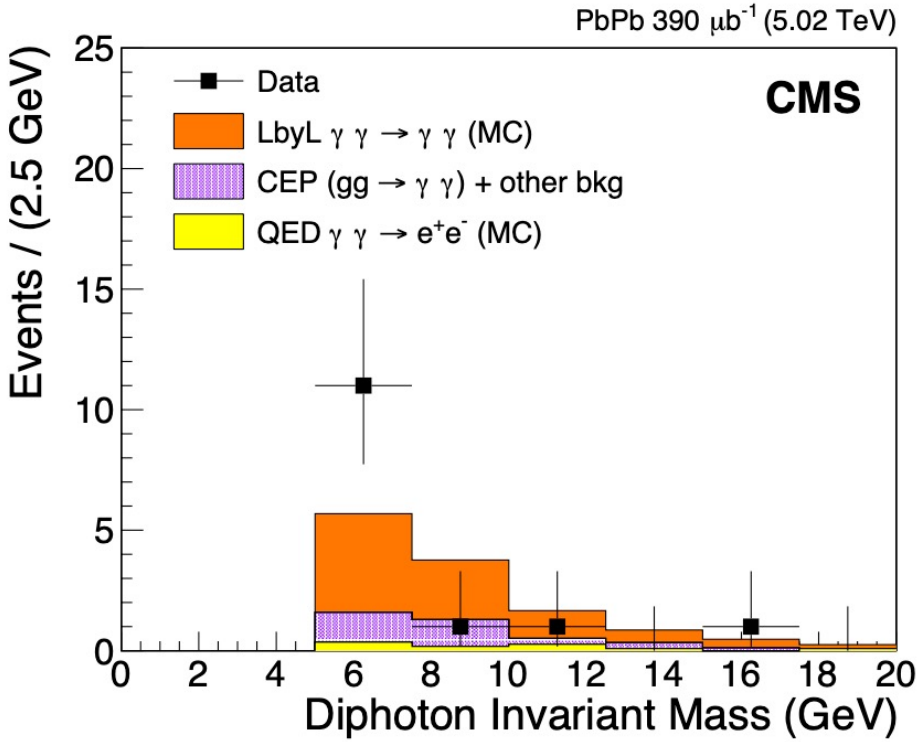


Light-by-Light Scattering

[Phys.Lett.B 797 (2019) 134826]

- Dataset:
  - 390 μb^{-1}
  - $\sqrt{s} = 5.02\ TeV$
- Signature:
  - $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$
- Selection of $a \rightarrow \gamma\gamma$:
  - $E_T^{\gamma} > 2GeV$
  - $|\eta| \leq 2.4$
  - $m_{\gamma\gamma} > 5GeV$ (reduce e^+e^-)
  - $P_T^{\gamma\gamma} \leq 1GeV$ (ensure exclusive production)
- Background:
  - QED e^+e^- production
  - CEP $\gamma\gamma$





Light-by-Light Scattering

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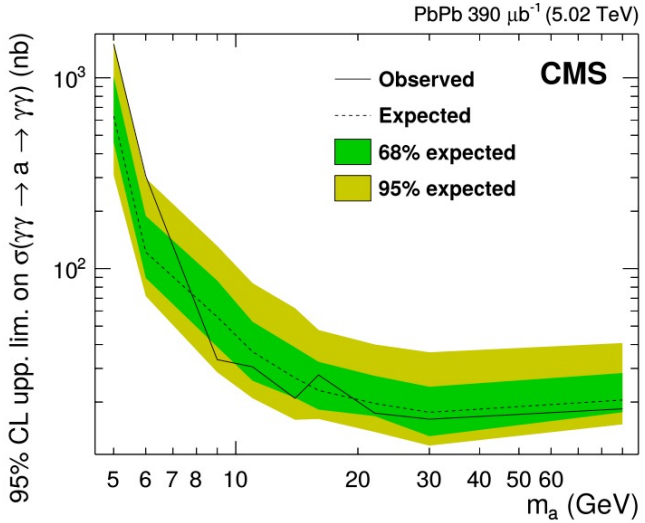
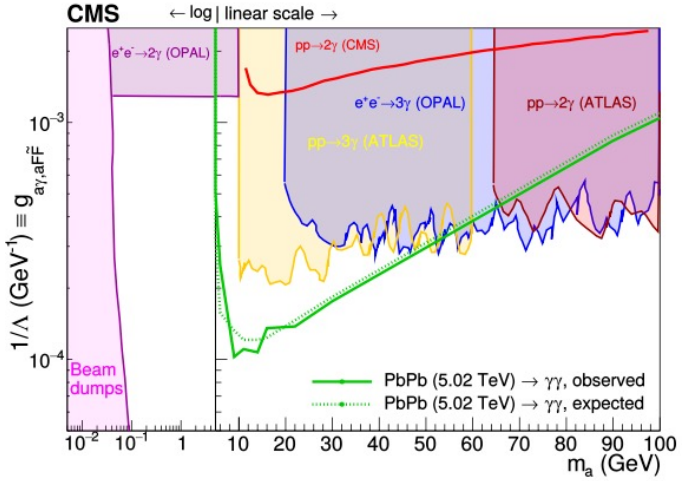
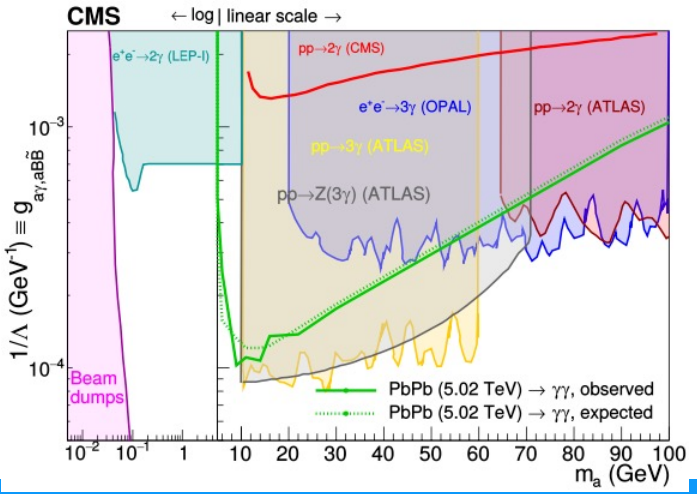




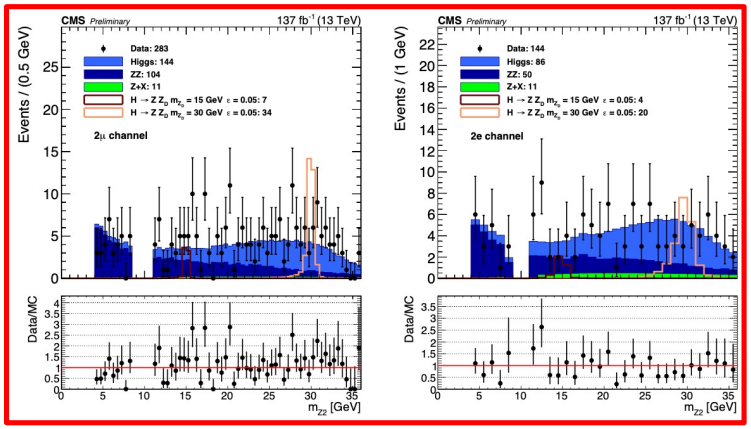


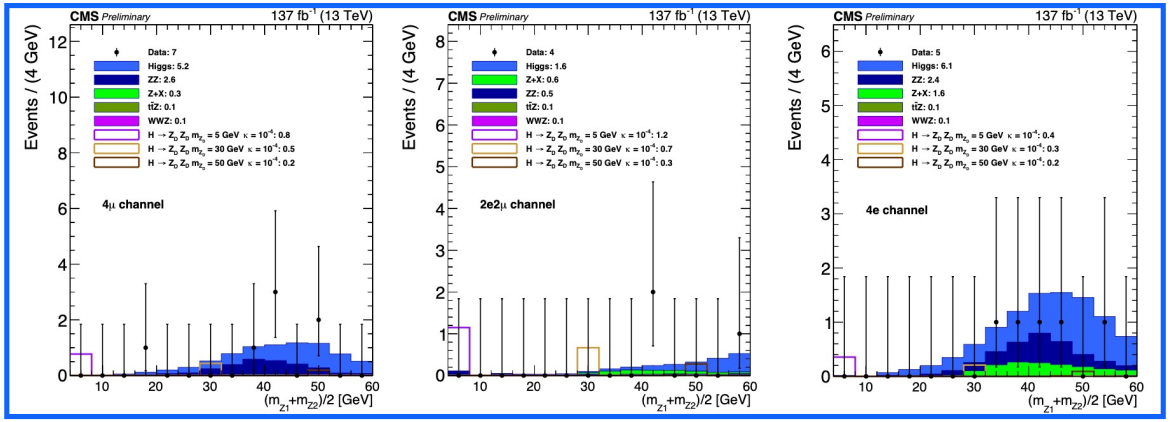
- Cross section upper limits:
  - CLs prescription with profile likelihood ratio at 95% CL
- Cross section limits interpreted as limits on the ALP couplings:
  - ALP only coupling to photons: $g_{a\gamma,aF\tilde{F}}$
  - ALP coupling also to Z: $g_{a\gamma,aB\tilde{B}}$

Low Mass Dilepton Resonance

CMS-HIG-19-007

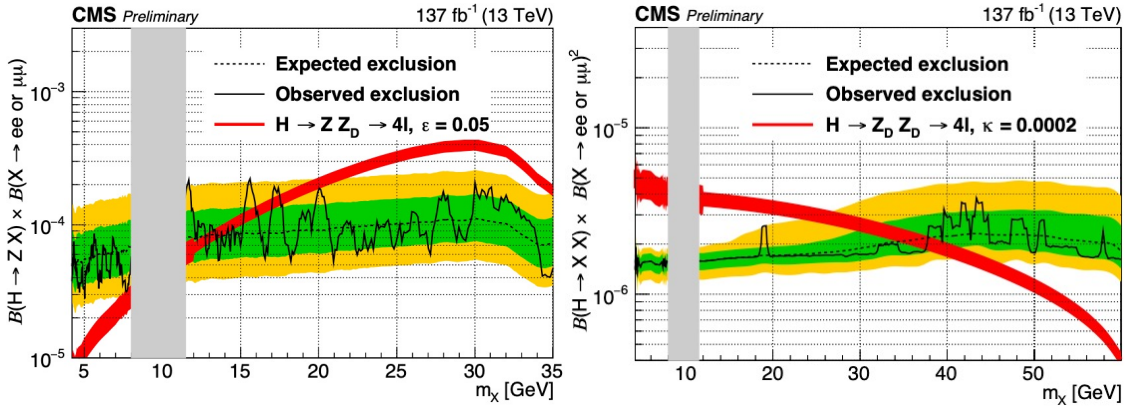
- Dataset:
  - Full-run2 dataset: 2016 - 2018 (136 fb^{-1})
  - $\sqrt{s} = 13\ TeV$
- Signature:
  - $Z \to \ell^+\ell^-$
  - $a \to \ell^+\ell^-$
- Search for Higgs Exotic decay
  - $H \to aa \to 4l$
  - $H \to Za \to 4l$
- Main background:
  - SM ZZ
  - Z + X
- Exclude narrow mass window around Y

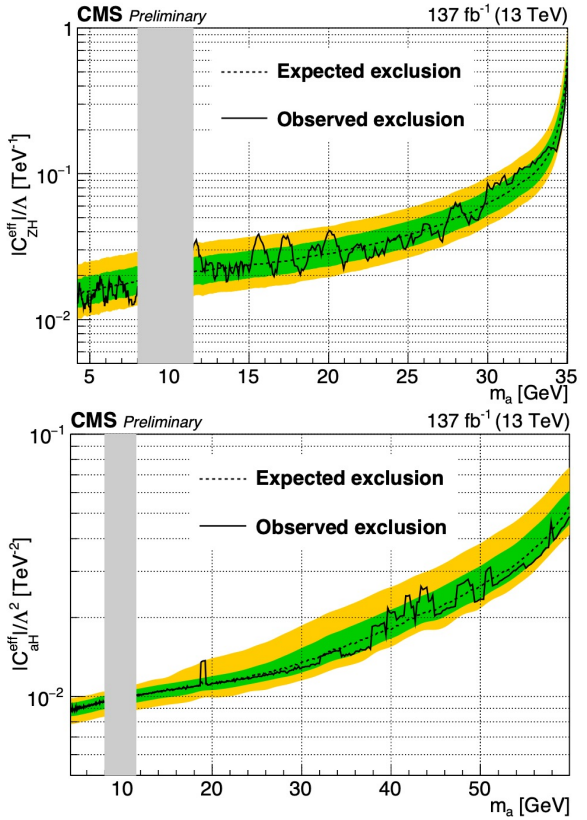




Low Mass Dilepton Resonance

CMS-HIG-19-007





- Model independent cross section upper limits:
  - CLs prescription with profile likelihood ratio at 95% CL
- Cross section limits interpreted as limits on the ALP couplings:
  - Assume $Br(a \to ll) = 100\%$
  - ALP coupling to Higgs and Z: C_{ZH}^{eff}/Λ^2
  - ALP only coupling to Higgs: C_{aH}^{eff}/Λ^2

Summary

- ALPs are pseudo Nambu-Goldstone bosons associated to Spontaneous Symmetry Breaking
- ALPs couple to different sectors of the SM
  - Higgs, Z/W, photon, lepton
- Different signatures probing various couplings covered in this talk:
  - Photons, Vector gauge bosons, Higgs…
- Further model independent search can also interpret ALPs model:
  - $h \to aa \to 2\mu 2b$
  - $h \to aa \to 4b$
  - $h \to aa \to 4\gamma$
  - $h \to aa \to 4\mu$ …
- Bright future ahead with new prospects coming from different experiments