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# Probing Axion-Like Particles and Neutral Triple Gauge Couplings at the CEPC

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Lecture of CEPC New Physics Workshop 2024

@ZZU, Aug, 31, 2024

CEPC

# Where to next?

- **Evidences for physics beyond the Standard Model**
  - Dark matter, Baryon asymmetry, Neutrino masses, Dark energy, ...
  - Hierarchy/Naturalness/Fine tuning problem

- We haven't found any new particles!

Where to next?

  - Build an even larger collider → go to high energy → discover new particles!

(No guaranteed discovery!)

  - Do precision measurements → discover new physics indirectly!

# How to look for new physics?

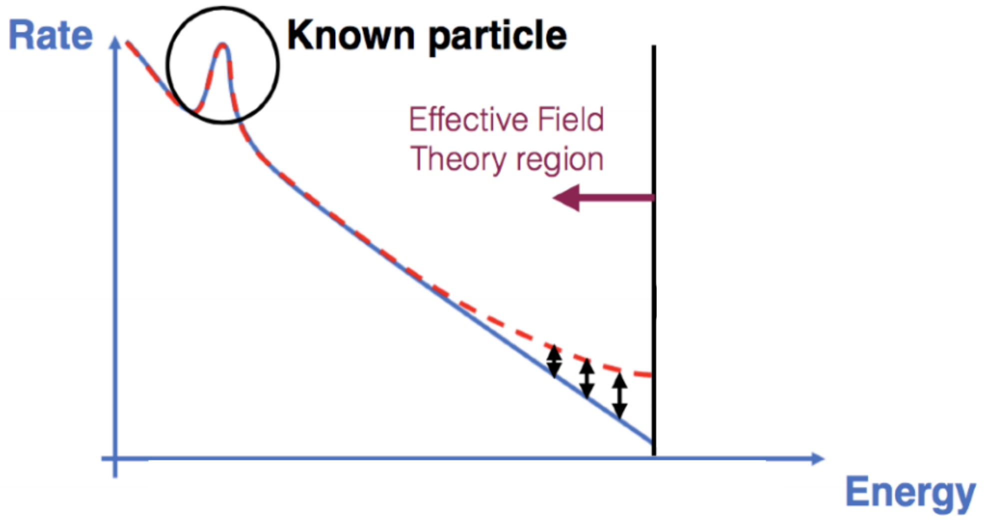
## How do we interpret the measurement results?

Model-dependent

SUSY, 2HDM…

New particles

ALP, W', Z'…




Model-Independent

Simplified models, EFT

New Interactions of SM particles

anomalous couplings

Deviations in tails

The first sign of new physics from precision measurements

# Contents

I. Axion-Like Particles (ALPs) @ CEPC

- ALPs in light by light scattering (LBL)
- ALPs in tri-photon production
- ALPs in Z decay
- ALPs in vector boson fusion (VBF)

II. Anomalous Gauge Couplings

III. Summary

# Properties of axion-like particles (ALPs)

- QCD axions: PecceiQuinn mechanism to solve "strong-CP"
- ALP: generalizations of QCD axions
- CP-odd neutral pseudoscalars
- Parameters: masses & couplings

Dimension-5 operators :

$$\mathcal{L}_{\rm eff}^{D\le 5} = \frac{1}{2}(\partial_\mu a)(\partial^\mu a) - \frac{M_a^2}{2}a^2 + \frac{\partial^\mu a}{\Lambda}\sum_F \bar\psi_F C_F \gamma_\mu \psi_F$$
$$+ g_s^2 C_{GG}\frac{a}{\Lambda}G^A_{\mu\nu}\tilde{G}^{\mu\nu,A} + g^2 C_{WW}\frac{a}{\Lambda}W^A_{\mu\nu}\tilde{W}^{\mu\nu,A} + g'^2 C_{BB}\frac{a}{\Lambda}B_{\mu\nu}\tilde{B}^{\mu\nu}$$

After electroweak symmetry breaking:

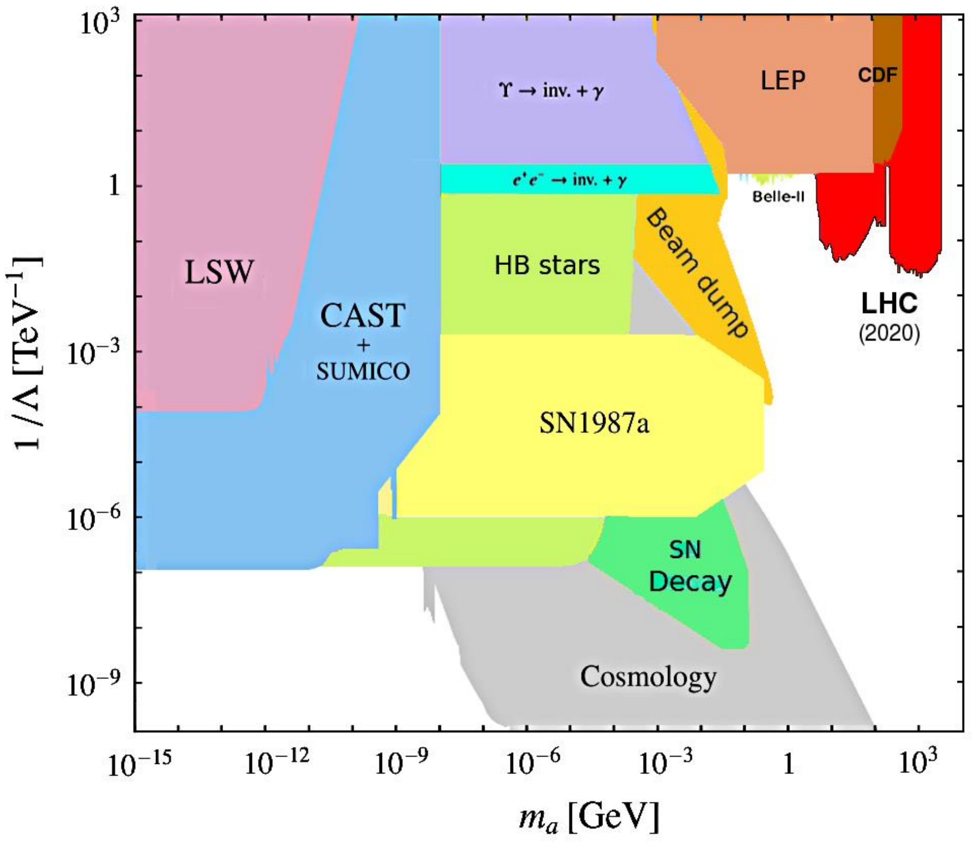
$$\mathcal{L}_{eff} = \frac{1}{2}(\partial^\mu a)(\partial_\mu a) - \frac{1}{2}m_a^2 a^2 + i g_{a\psi} a \sum_{\psi=Q,L} m_\psi^{diag}\bar\psi\gamma_5\psi$$
$$-\frac{1}{4}g_{a\gamma\gamma}aF_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{1}{4}g_{aZZ}aZ_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{1}{4}g_{a\gamma Z}aF_{\mu\nu}\tilde{Z}^{\mu\nu}$$
$$-\frac{1}{4}g_{aWW}aW_{\mu\nu}\tilde{W}^{\mu\nu}$$

with

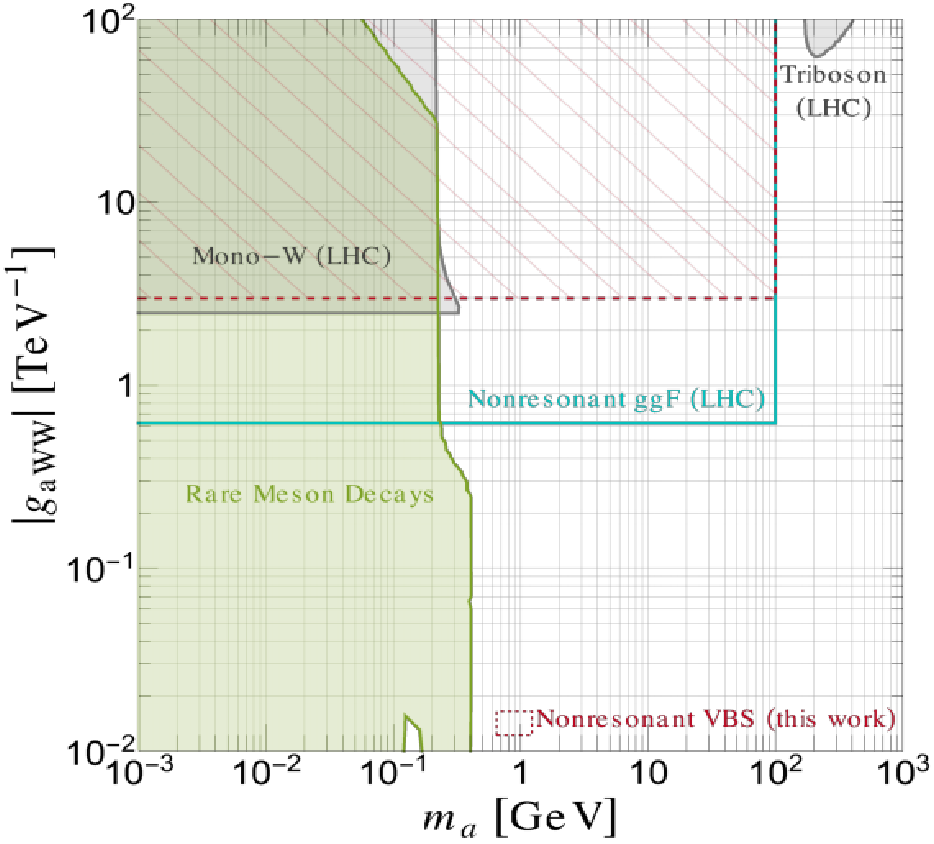
$$g_{a\gamma\gamma} = \frac{4}{f_a}(c_W^2 C_{\tilde B} + s_W^2 C_{\tilde W}), \quad g_{aZZ} = \frac{4}{f_a}(s_W^2 C_{\tilde B} + c_W^2 C_{\tilde W}),$$
$$g_{a\gamma Z} = \frac{8}{f_a}s_W c_W (C_{\tilde W} - C_{\tilde B}), \quad g_{aWW} = \frac{4}{f_a}C_{\tilde W}$$

# Constraints on the effective couplings of ALPs

D. Enterria (CERN), 2102.08971



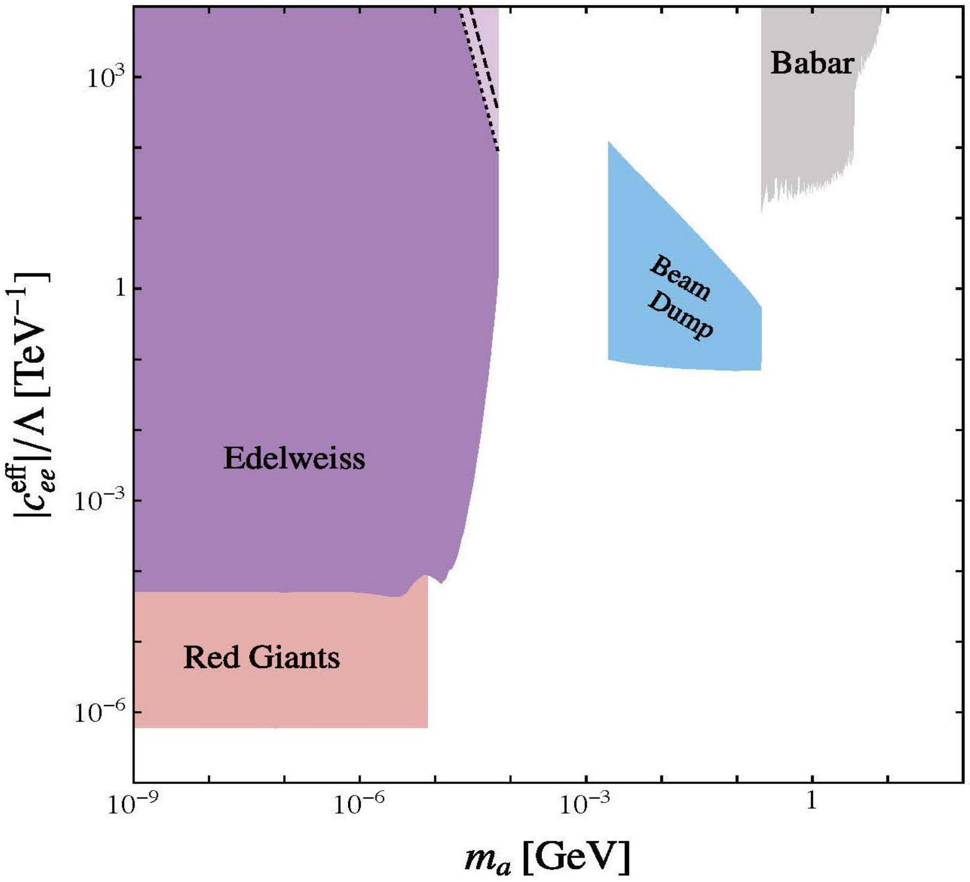

J. Bonilla et. al. , 2202.03450




Existing constraints on the ALP–photon coupling (left) and ALP–W coupling (right)

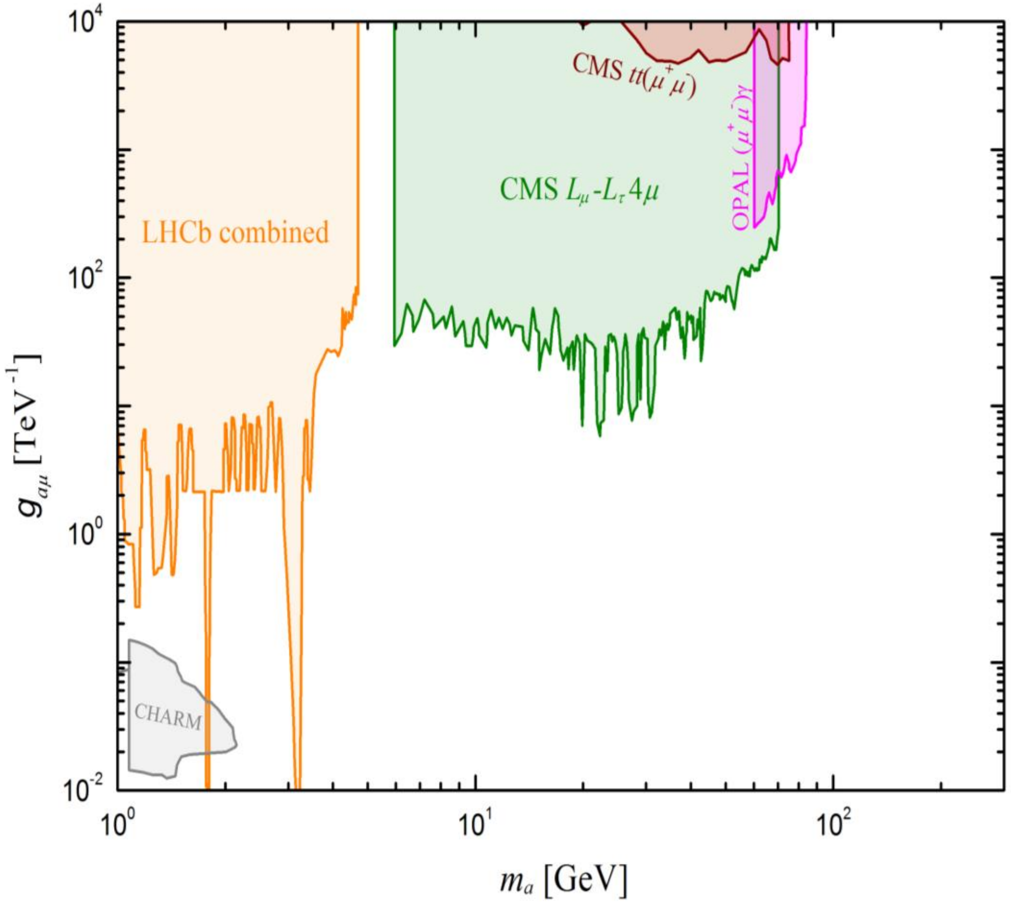
# Constraints on the effective couplings of ALPs

M. Bauera, M. Neubert and A. Thamm, 1708.00443




B. Döbrich, et. al. , 1810.11336

J. Liu, X.L. Ma, L.T. Wang, X.P, Wang, 2210.09335

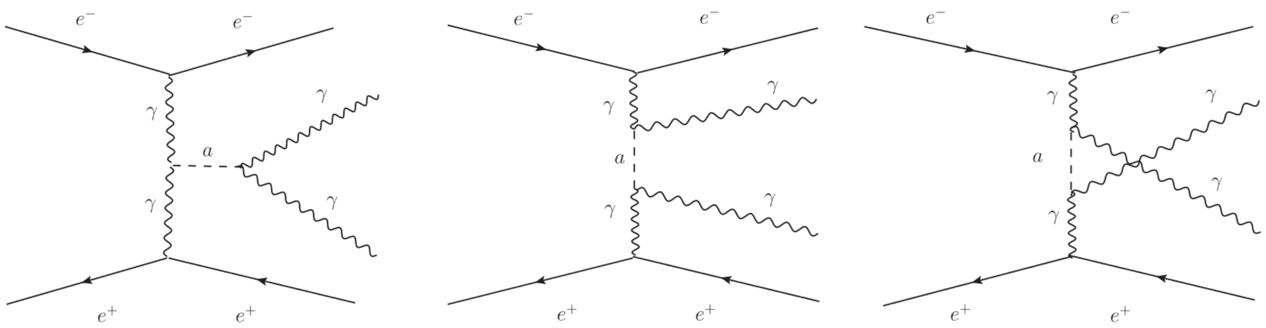



Existing constraints on the ALP–electron coupling (left) and ALP–muon coupling (right)

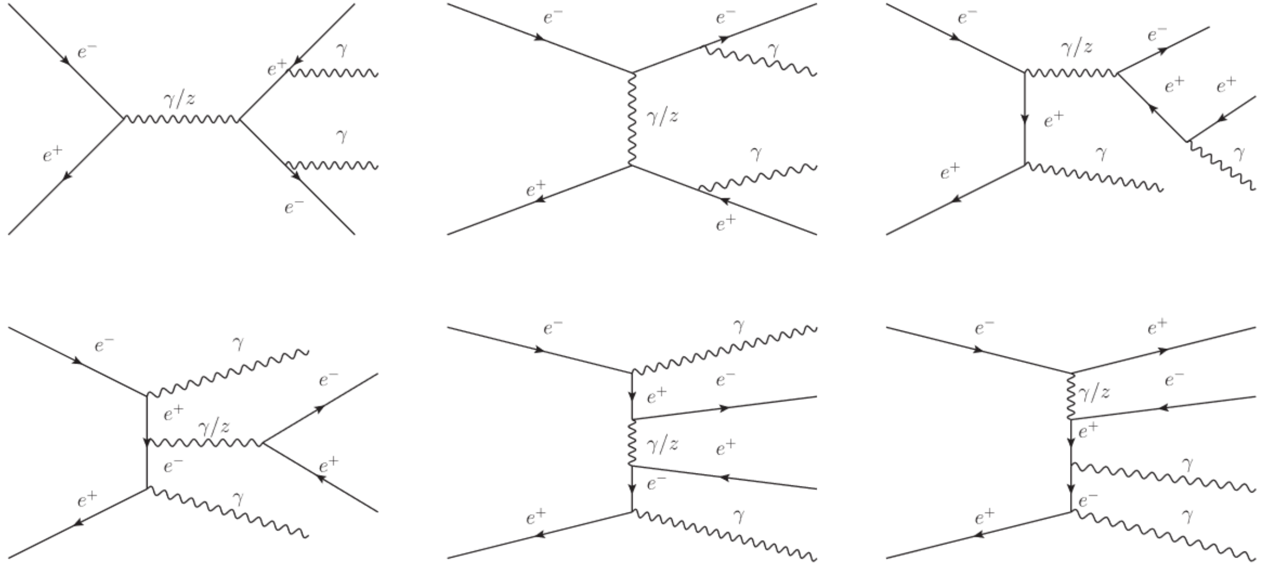
# ALPs in Light by Light (LBL) Scattering

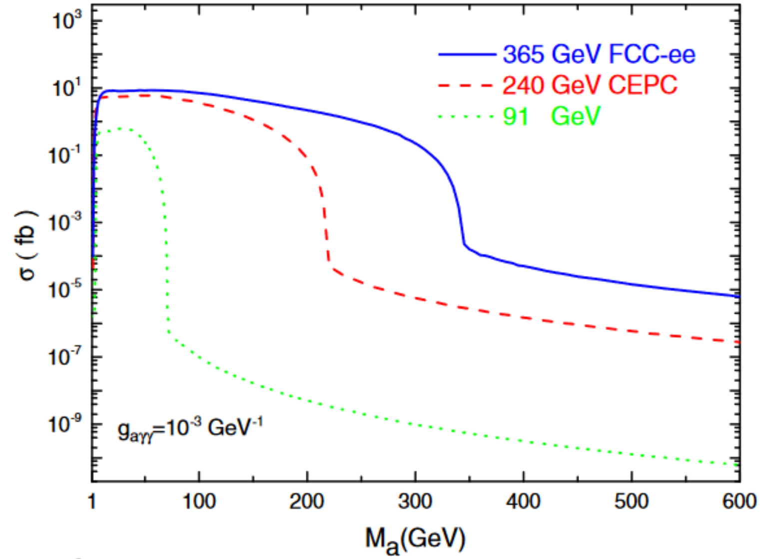
H.Y.Zhang, C.X.Yue, YCG, S.Yang, Phys. Rev. D (2021)

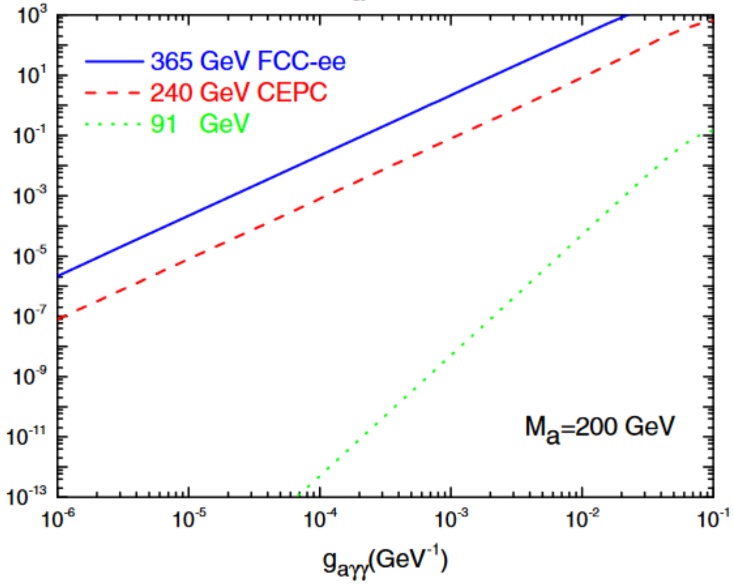
The Feynman diagrams of $e^+e^- \to a\gamma^* \to \gamma\gamma e^+e^-$



The typical diagrams for the background

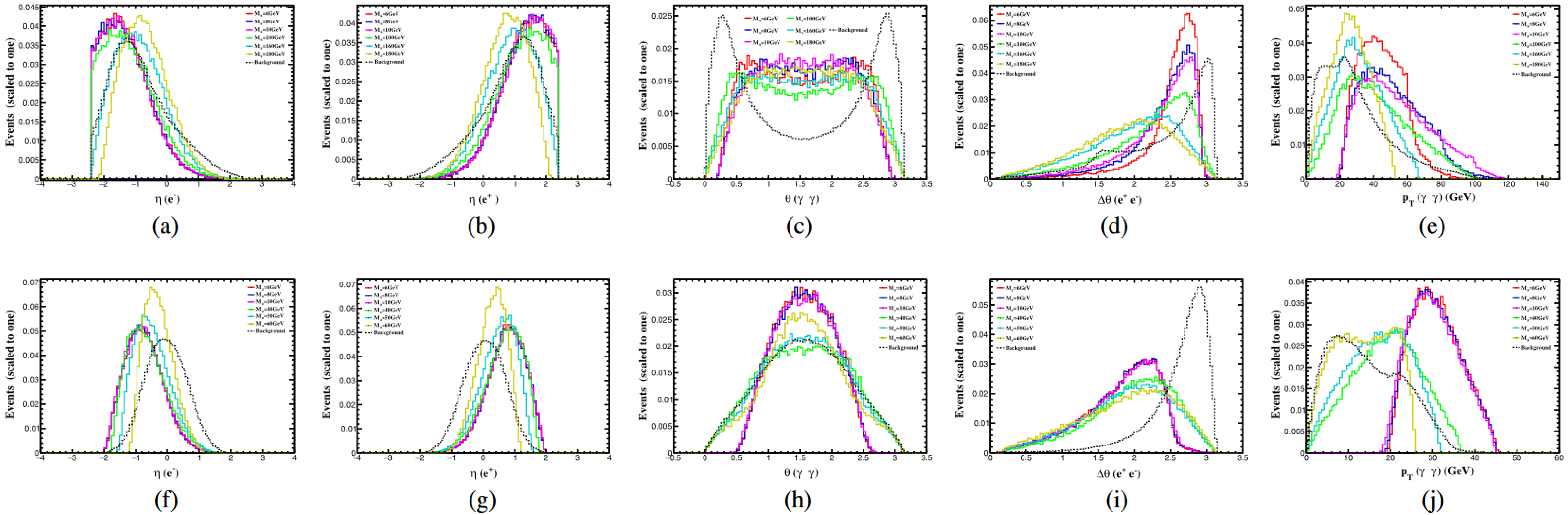




# ALPs in Light by Light (LBL) Scattering

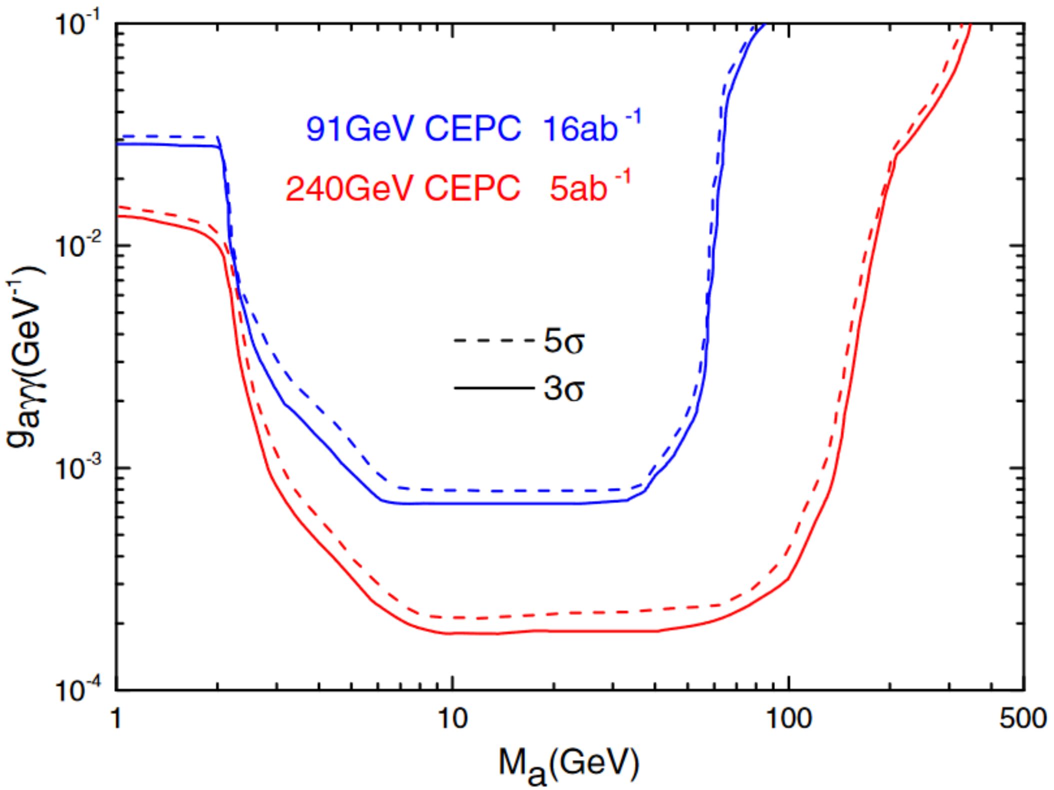
## Normalized distributions of η(e), θ(γγ), θ(ee), $p_T(\gamma\gamma)$



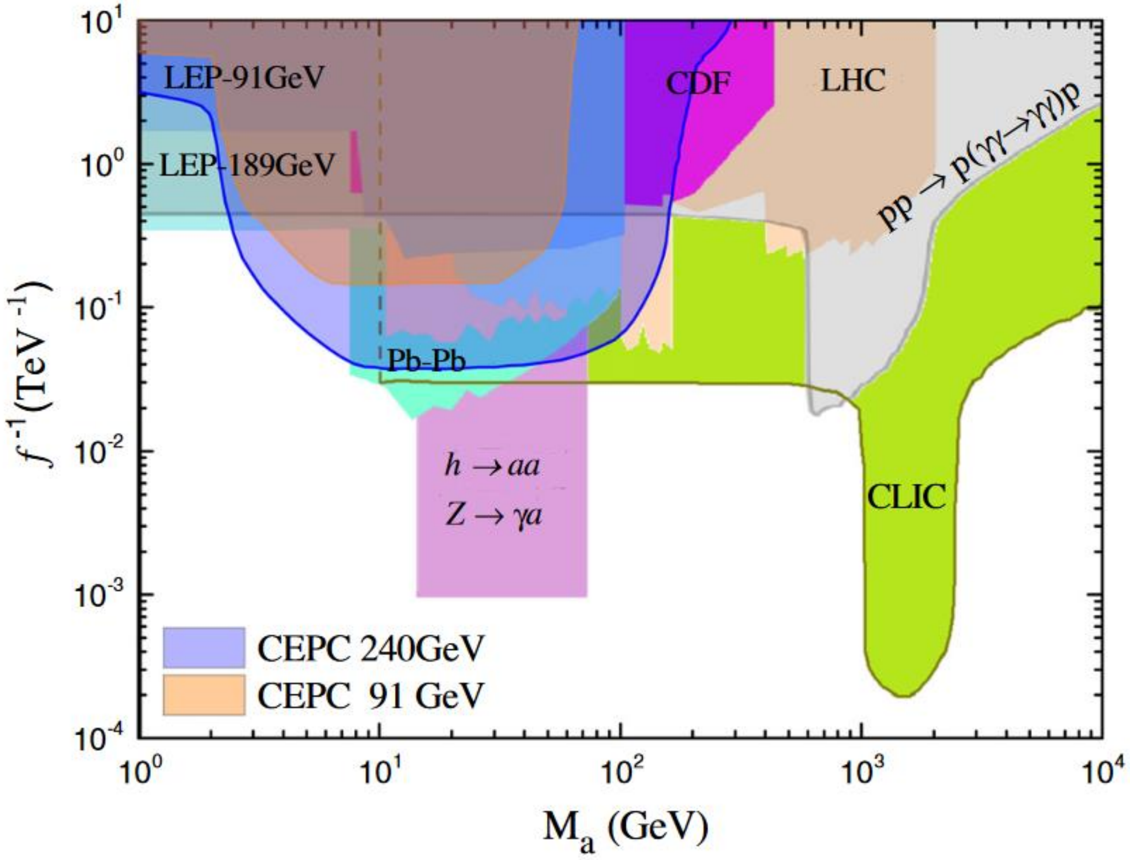

Cuts on kinematic observables :

| $\sqrt{s} = 240$ GeV | $\sqrt{s} = 91$ GeV |
| --- | --- |
| $0.4 < \eta(e^+) < 2.4$ | $-0.3 < \eta(e^+) < 0.9$ |
| $-2.4 < \eta(e^-) < -0.4$ | $-0.9 < \eta(e^-) < 0.3$ |
| $0.7 < \theta(\gamma\gamma) < 2.4$ | $0.7 < \theta(\gamma\gamma) < 2.4$ |
| $\Delta\theta(e^+e^-) < 2.9$ | $\Delta\theta(e^+e^-) < 2.4$ |
| $p_T(\gamma\gamma) > 45$ GeV | $p_T(\gamma\gamma) > 20$ GeV |

# ALPs in Light by Light (LBL) Scattering




The sensitivities of the CEPC

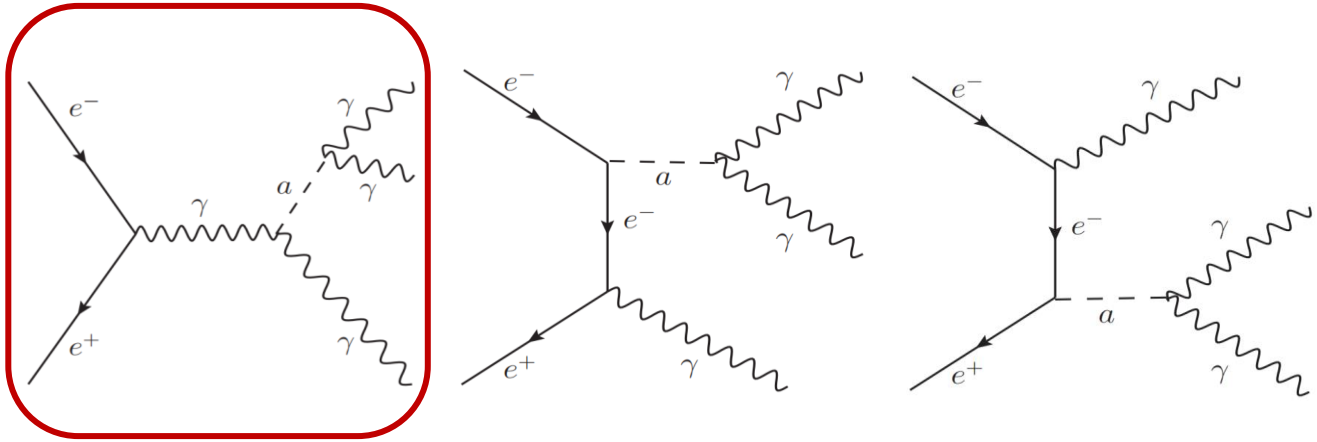



The 95% C.L. exclusion regions on the ALP couplings

# ALPs in Tri-Photon Production

- The Feynman diagrams for the process of $e^+e^- \to a\gamma \to 3\gamma$

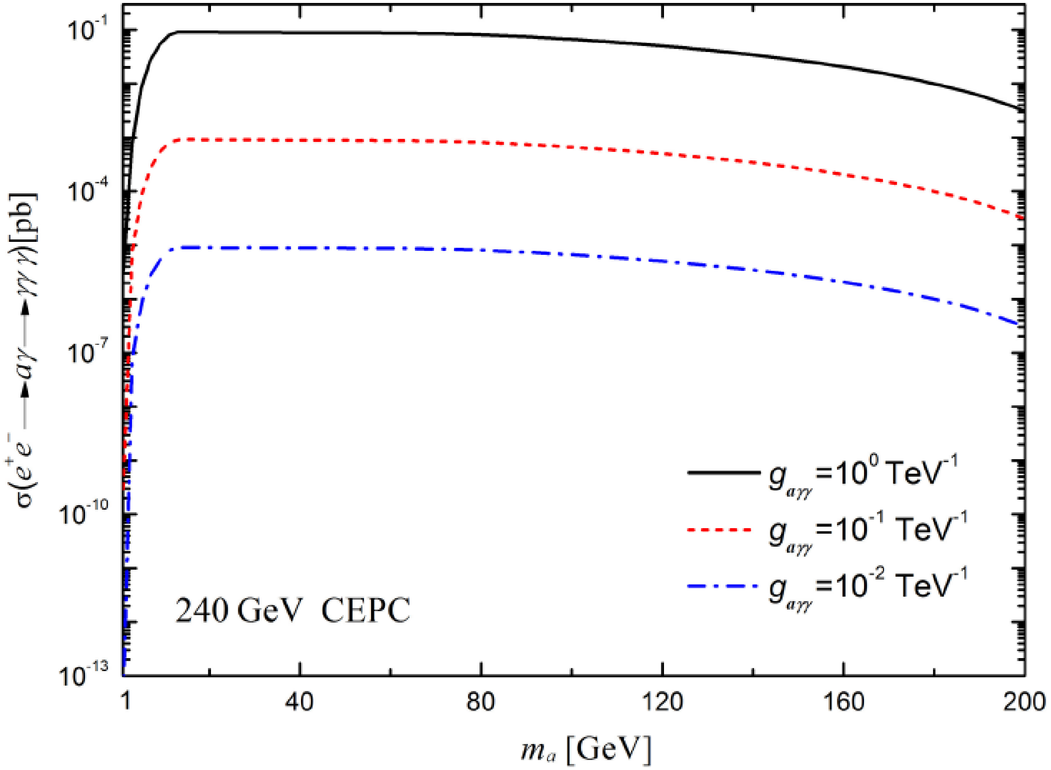
H. Wang, C.X. Yue, YCG, et. al. J. Phys. G (2022)




$$C_{\tilde{W}} = C_{\tilde{B}} \Rightarrow g_{a\gamma\gamma} = g_{aZZ} = g_{aWW} \text{ and } g_{a\gamma Z} = 0$$

CEPC: $E_{CM} = 240\,\text{GeV}$ $\mathcal{L} = 5.6\,\text{ab}^{-1}$

$$1\,\text{GeV} < m_a \le 200\,\text{GeV}$$




The cross section of the process $e^+e^- \to a\gamma \to 3\gamma$

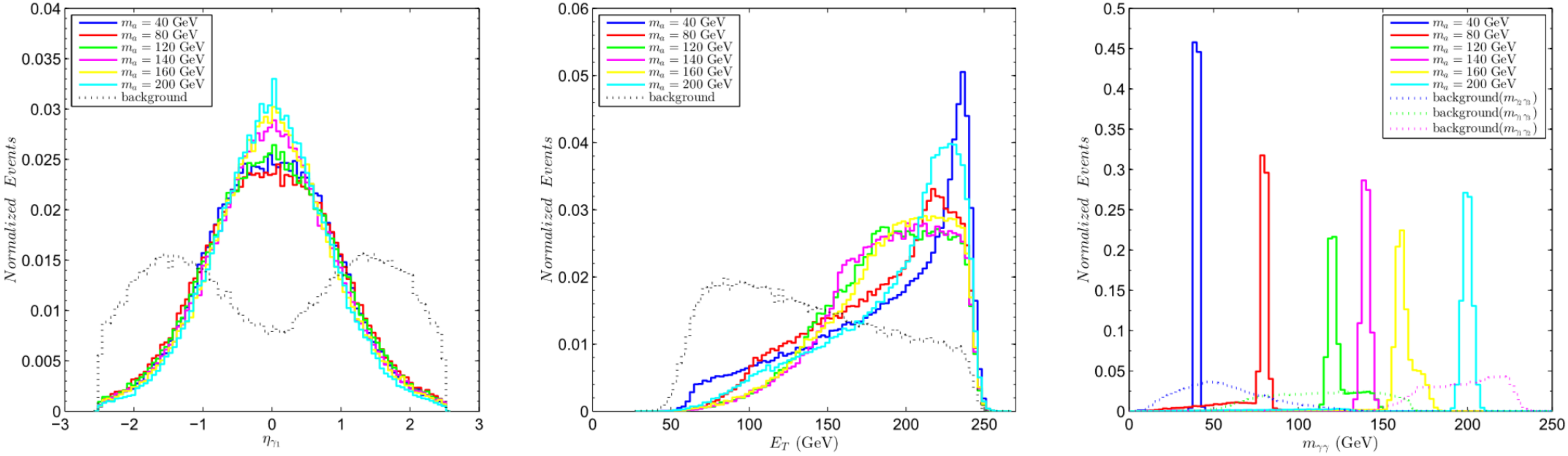
# ALPs in Tri-Photon Production

Basic cuts: $p_T^\gamma > 10\ \text{GeV},\ |\eta_\gamma| < 2.5,\ \Delta R_{\gamma\gamma} > 0.2$

$m_a \leq 20$ GeV → $N_\gamma \geq 1$

$m_a > 20$ GeV → $N_\gamma \geq 3$

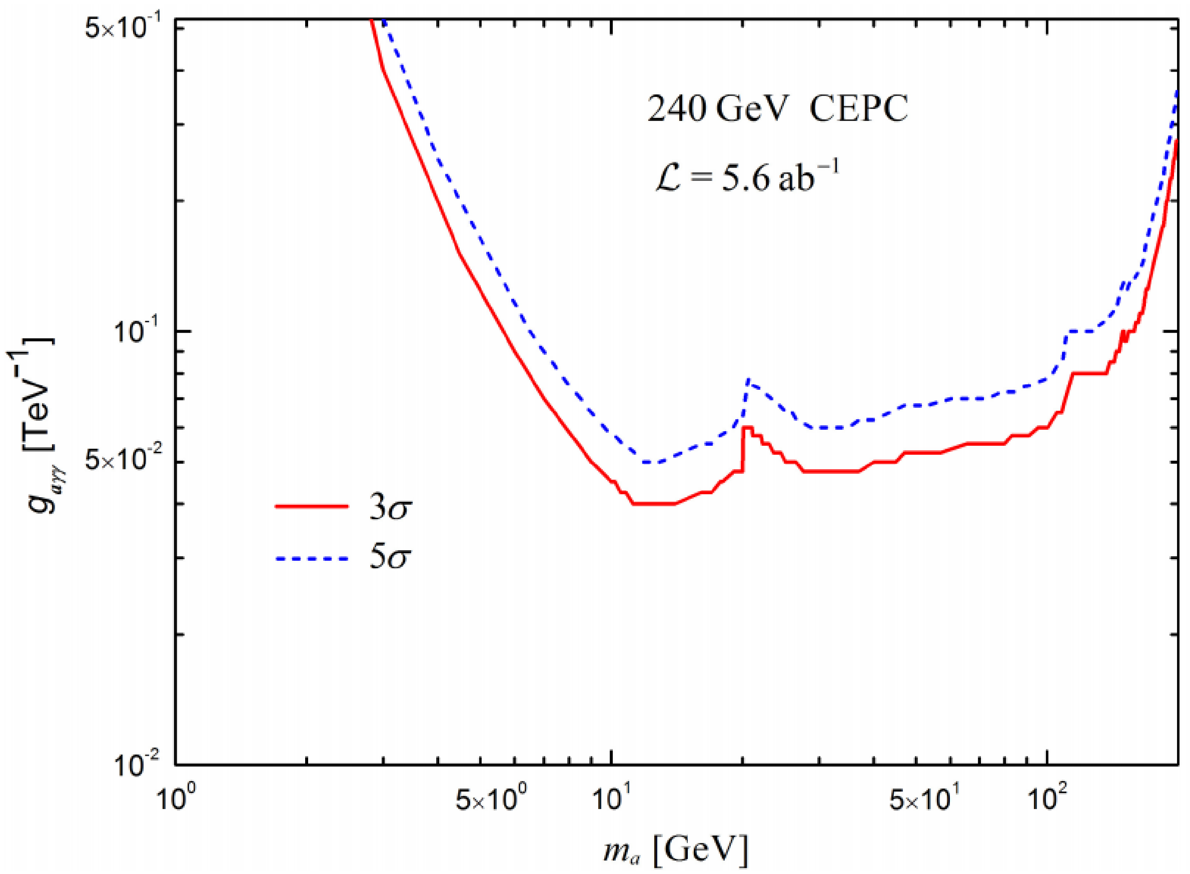
Normalized distributions of $\eta_{\gamma_1}, E_T, m_{\gamma\gamma}$

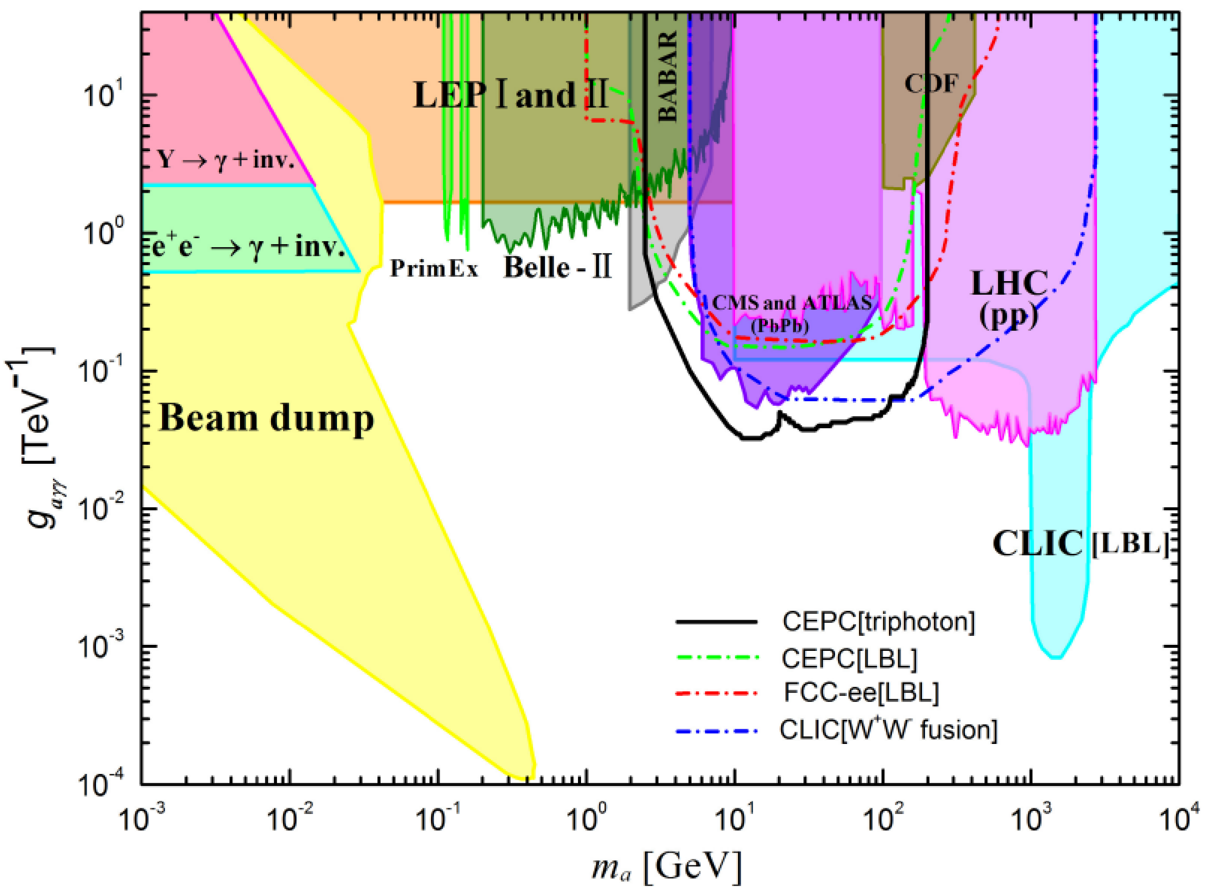



high mass ALP → $\gamma_1\gamma_2$

low mass ALP → $\gamma_2\gamma_3$

# ALPs in Tri-Photon Production



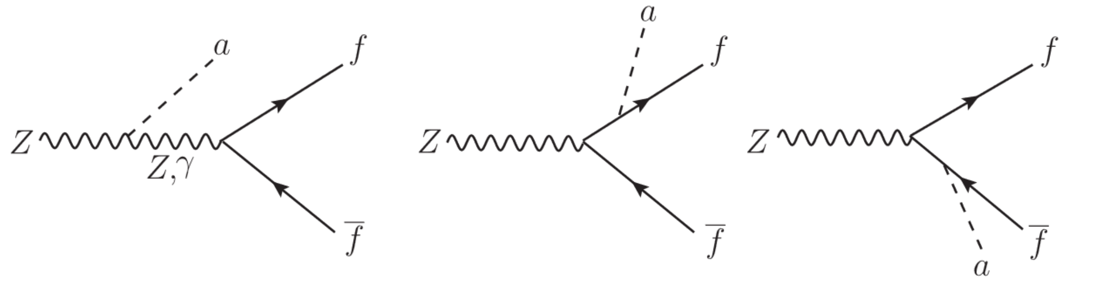

Left: The 3$\sigma$ and 5$\sigma$ curves for the process $e^+e^- \to a\gamma \to 3\gamma$ in the $m_a$ - $g_{a\gamma\gamma}$ plane

Right: The promising sensitivities as $g_{a\gamma\gamma} \in [0.0325, 0.37]\text{GeV}^{-1}$ with $m_a \in [2.9, 190]$ GeV at 2$\sigma$ level

# ALPs in the decay $Z \to a f \bar{f}$

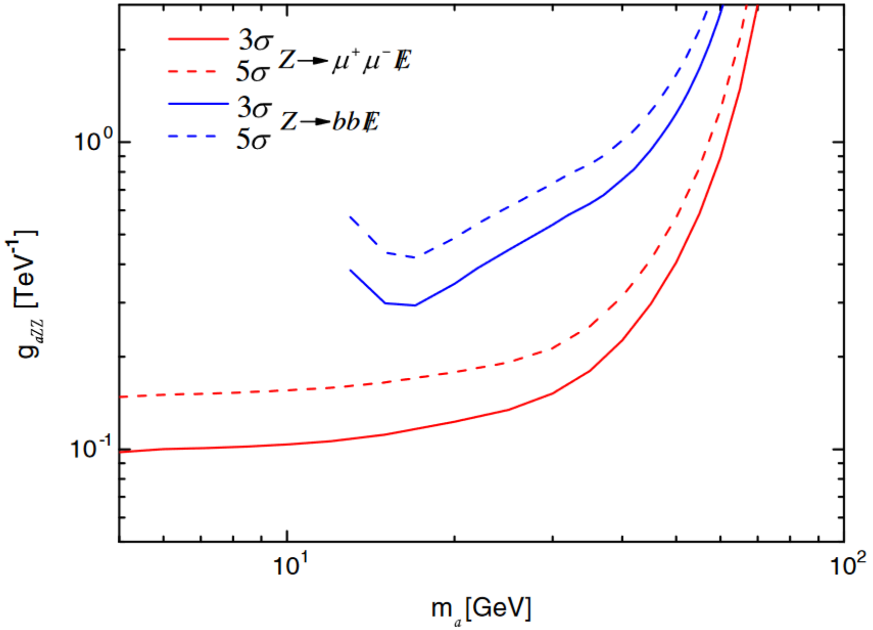
The Feynman diagrams for exotic Z decay $Z \to a f \bar{f}$

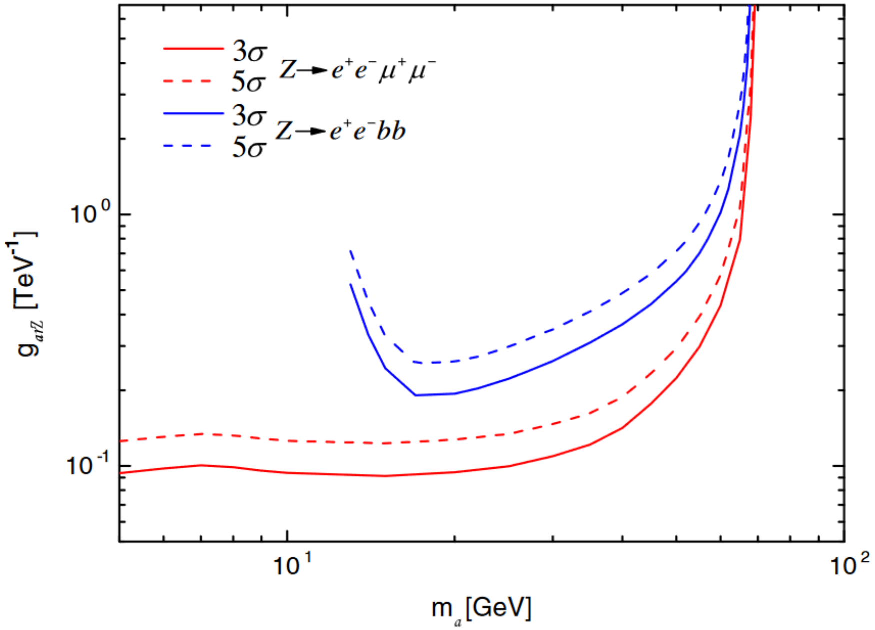
C.X. Yue, S. Yang, H. Wang, Phys. Rev. D (2022)




**A.** $Z \to \mu^+\mu^- \not{E}$ **B.** $Z \to bb\not{E}$

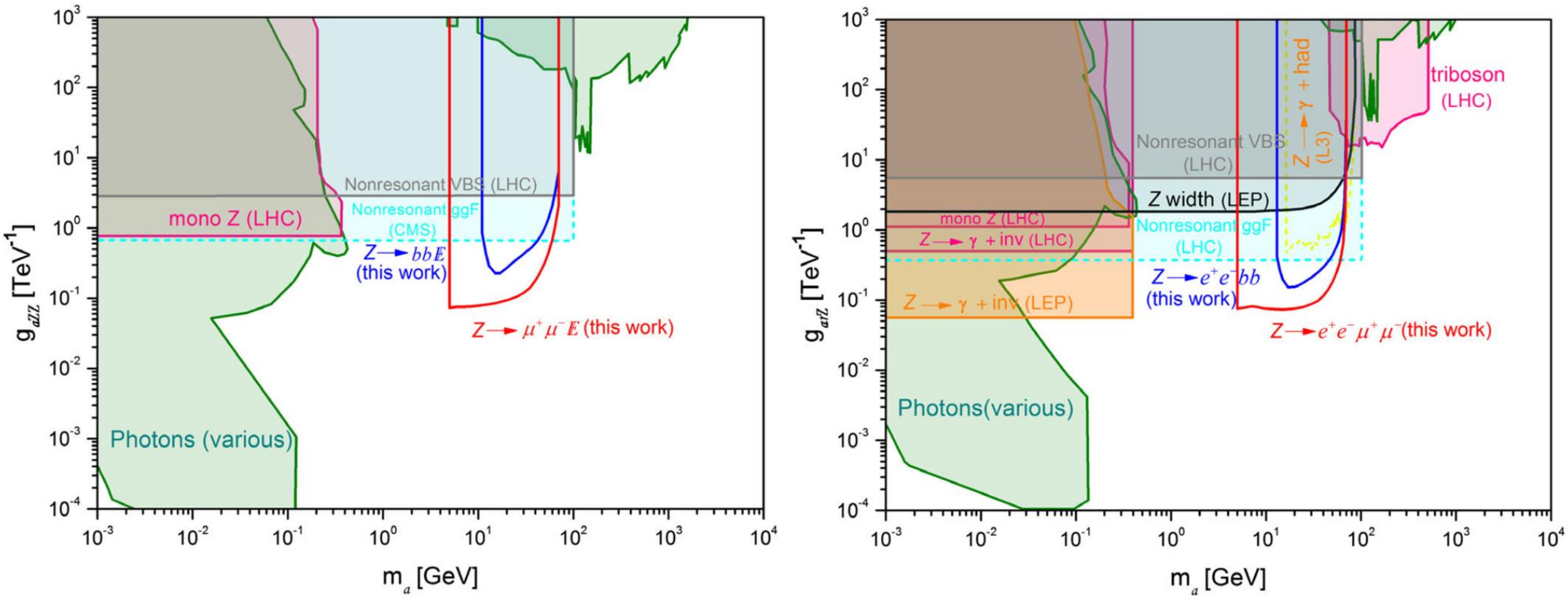
**C.** $Z \to e^+e^-\mu^+\mu^-$ **D.** $Z \to e^+e^-bb$




3σ and 5σ discovery curves for the Z factory with 1ab$^{-1}$ integrated luminosity in the planes $m_a$-$g_{aZZ}$($g_{a\gamma Z}$)

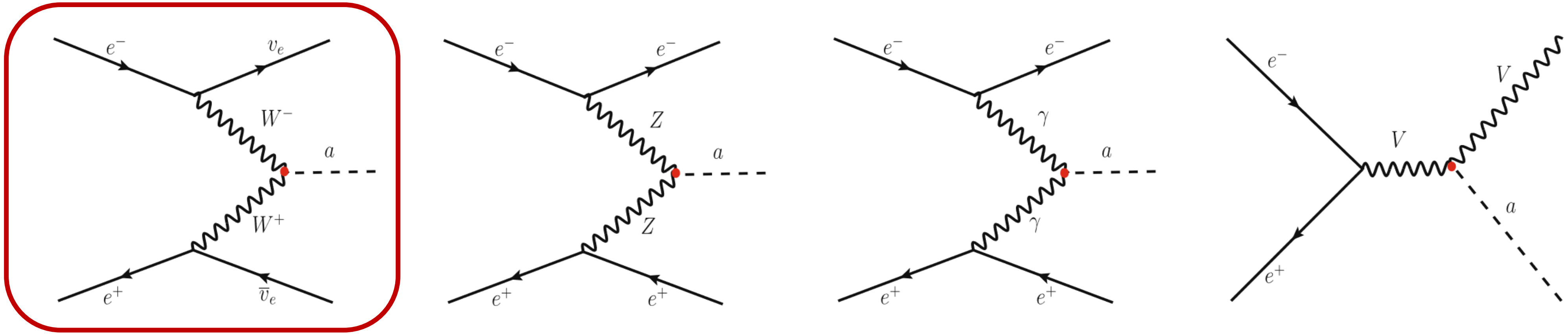
# ALPs in the decay $Z \to a f \bar{f}$



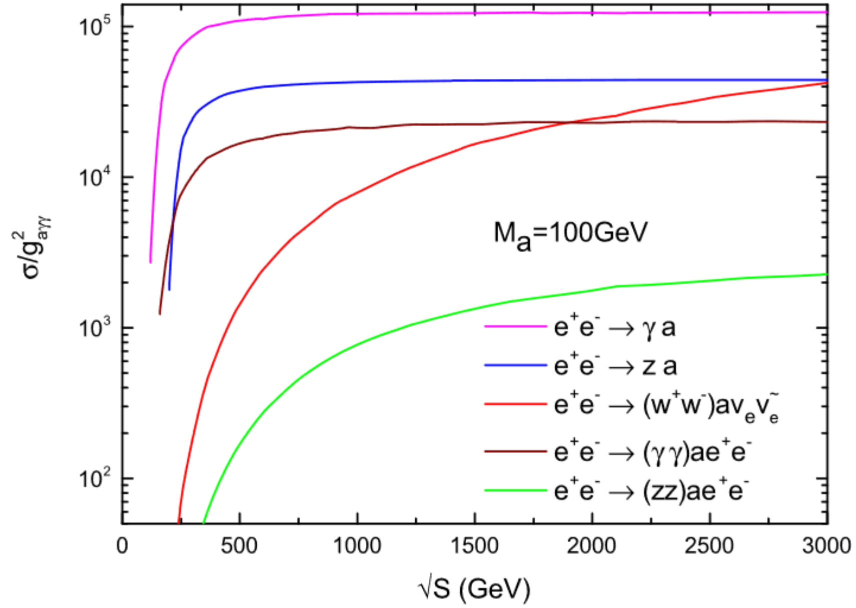

Sensitivity bounds on $g_{aZZ}$ (left) and $g_{a\gamma Z}$ (right) at 95% C.L. from exotic Z decays and other current exclusion regions.

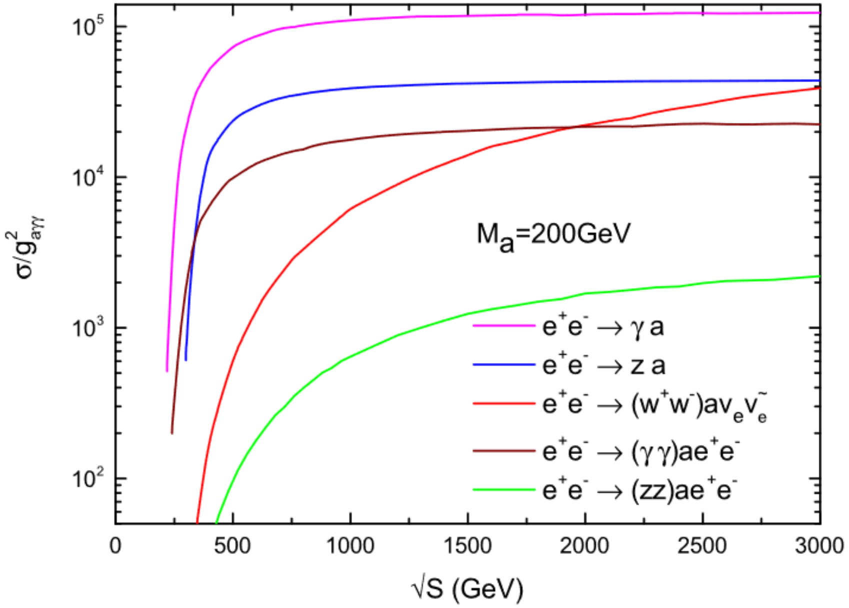
# ALPs in Vector Boson Fusion (VBF)

- The Feynman diagrams for the process of $e^+e^- \to \nu\bar{\nu}a(\to\gamma\gamma)$ C.X.Yue, H.Y. Zhang, H.Wang, Eur. Phys. J. C(2022)




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



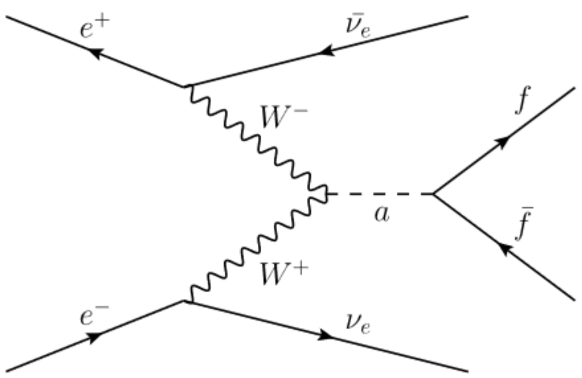

(c): S.C. İnan et. al. , 2003.01978
S.C. İnan et. al. , 2007.01693
H.-Y. Zhang et. al. , 2103.05218

(d): M. Bauer et. al. ,1808.10323

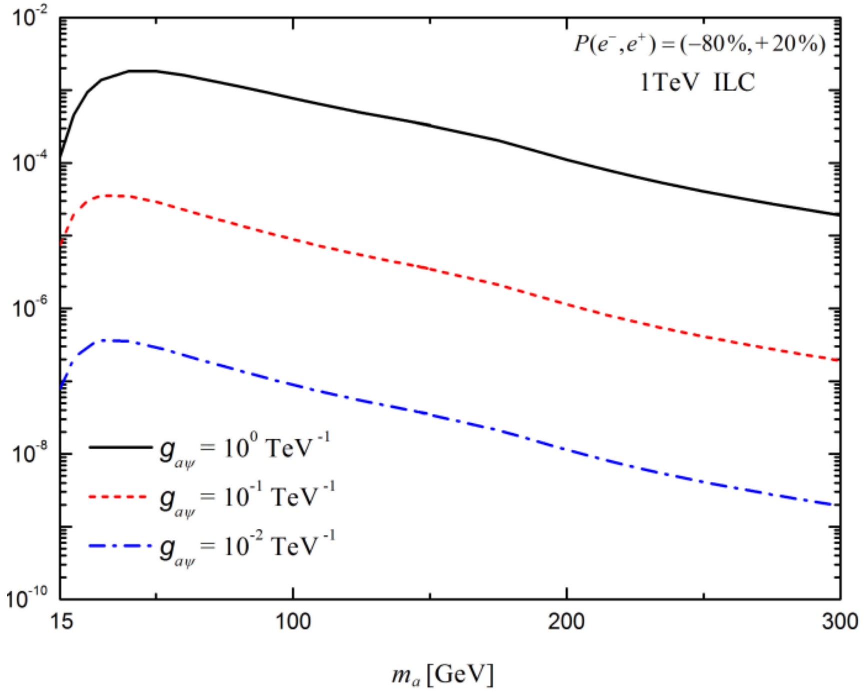
# ALPs in Vector Boson Fusion (VBF)

The Feynman diagrams for the process of $e^+e^- \to \nu\bar{\nu}a(\to f\bar{f})$

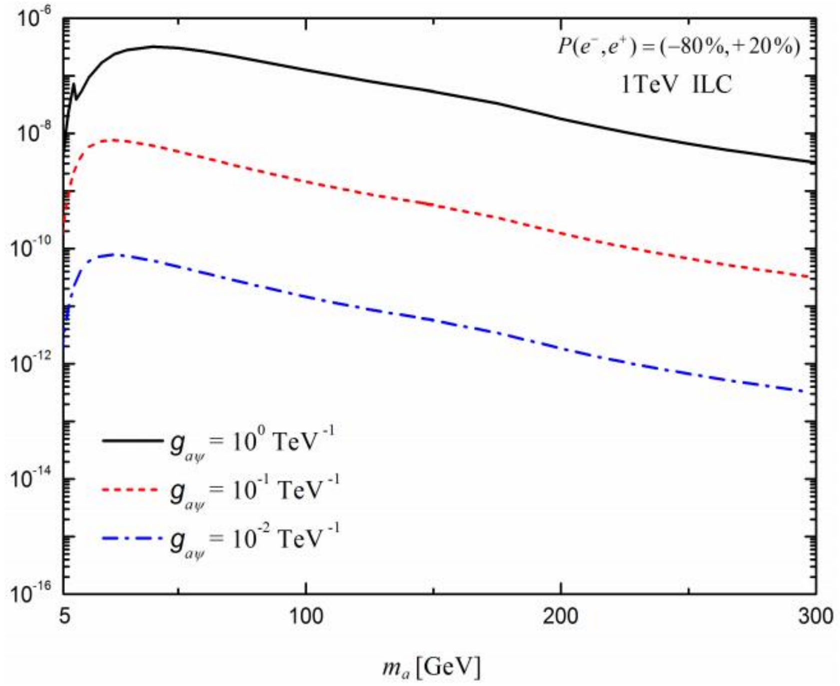
C.X.Yue, H.Wang, Y.Q.Wang, Phys. Lett. B (2024)




$e^-e^+ \to \nu_e\bar{\nu}_e a(a \to b\bar{b})$

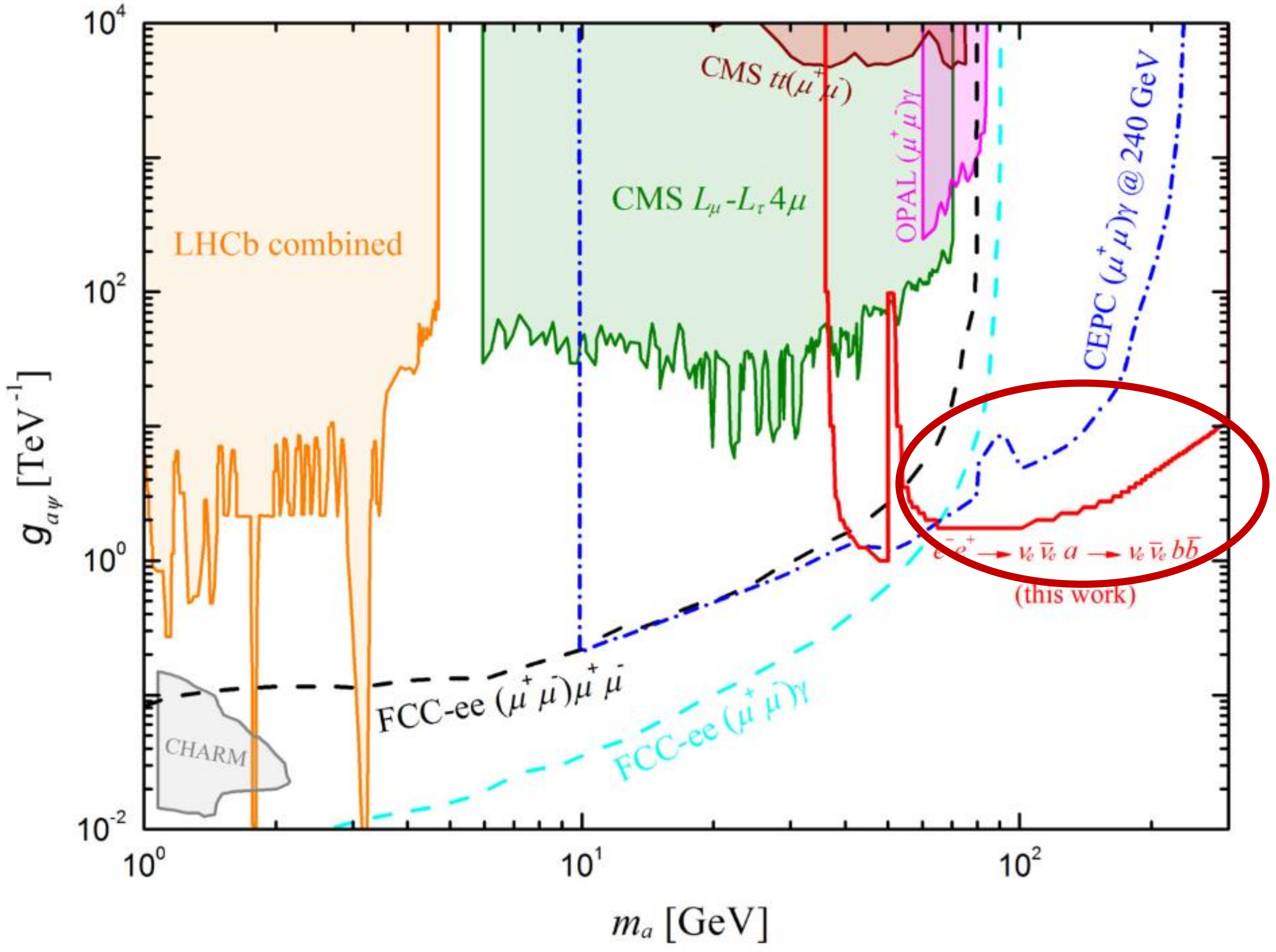



$e^-e^+ \to \nu_e\bar{\nu}_e a(a \to \mu^+\mu^-)$




The production cross sections of the $W+W-$ fusion processes for two decay channel

# ALPs in Vector Boson Fusion (VBF)




$m_a \in [65, 300]\,\text{GeV}$

CEPC: $m_a \in [37, 50]\,\text{GeV}$ ⟶ $g_{a\Psi} \to 1\,\text{TeV}^{-1}$

CLIC: $m_a \in [52, 300]\,\text{GeV}$ ⟶ $g_{a\Psi} \to 1.75\,\text{TeV}^{-1}$

# Contents

I. axion-like particles (ALPs)

II. Neutral Triple Gauge Couplings (nTGCs)

- nTGC in Zγ production
- nTGC in ZZ production

III. Summary

# Dimension-8 Operators affecting nTGC

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{SM} + \sum_i \frac{C_{6i}}{\Lambda^2}\mathcal{O}_{6i} + \sum_j \frac{C_{8j}}{\Lambda^4}\mathcal{O}_{8j} + \ldots$$

$$\mathcal{L}_{aQGC} = \sum_{i=0}^{2} \frac{f_{S_i}}{\Lambda^4} O_{S_i} + \sum_{j=0}^{7} \frac{f_{M_j}}{\Lambda^4} O_{M_j} + \sum_{k=0}^{9} \frac{f_{T_k}}{\Lambda^4} O_{T_k}$$

$$\mathcal{L}_{\rm nTGC} = \frac{\mathrm{sign}(c_{\tilde{B}W})}{\Lambda^4_{\tilde{B}W}}\mathcal{O}_{\tilde{B}W} + \frac{\mathrm{sign}(c_{B\tilde{W}})}{\Lambda^4_{B\tilde{W}}}\mathcal{O}_{B\tilde{W}} + \frac{\mathrm{sign}(c_{\tilde{W}W})}{\Lambda^4_{\tilde{W}W}}\mathcal{O}_{\tilde{W}W} + \frac{\mathrm{sign}(c_{\tilde{B}B})}{\Lambda^4_{\tilde{B}B}}\mathcal{O}_{\tilde{B}B},$$

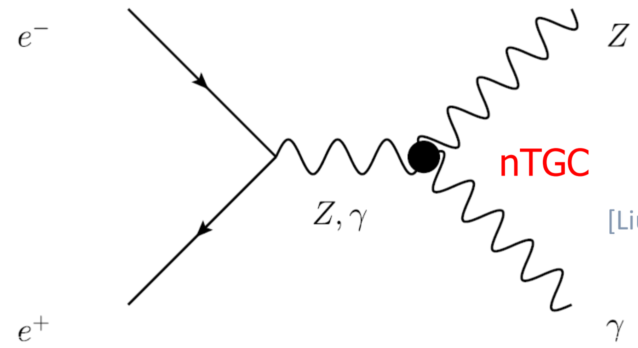
$$\begin{aligned}
\mathcal{O}_{\tilde{B}W} &= iH^\dagger \tilde{B}_{\mu\nu} W^{\mu\rho}\{D_\rho, D^\nu\} H + h.c.,\\
\mathcal{O}_{B\tilde{W}} &= iH^\dagger B_{\mu\nu} \tilde{W}^{\mu\rho}\{D_\rho, D^\nu\} H + h.c.,\\
\mathcal{O}_{\tilde{W}W} &= iH^\dagger \tilde{W}_{\mu\nu} W^{\mu\rho}\{D_\rho, D^\nu\} H + h.c.,\\
\mathcal{O}_{\tilde{B}B} &= iH^\dagger \tilde{B}_{\mu\nu} B^{\mu\rho}\{D_\rho, D^\nu\} H + h.c.,
\end{aligned}$$

[C. Degrande, J. High Energy Phys. 02 (2014) 101]

The nTGCs provide a unique window to the BSM because they can arise from SMEFT operators only at the level of dim-8 or higher.

# Diboson productions (ZA)

- nTGC in the $e^+ e^- \to Z\gamma$ process

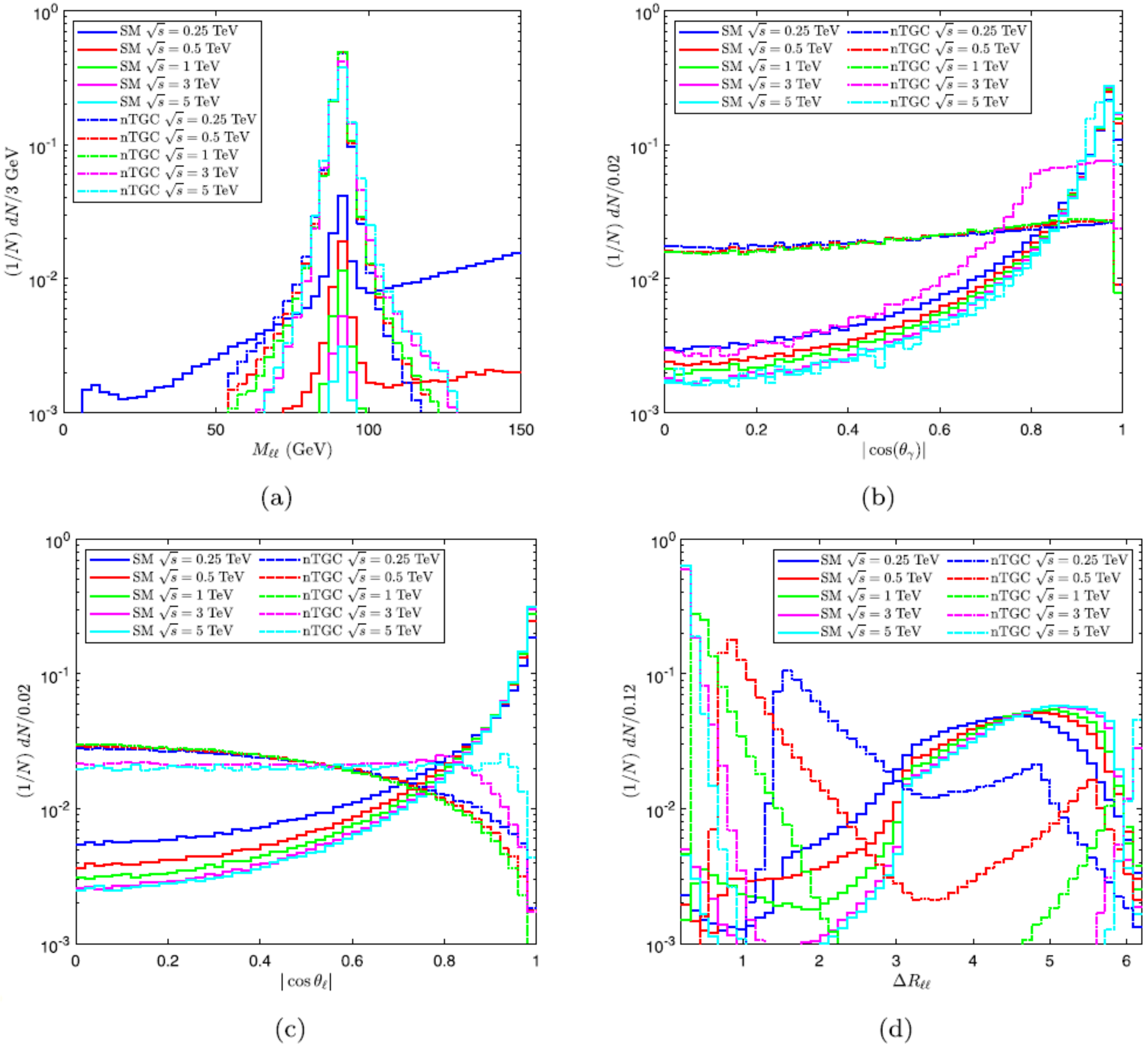



[JE, Ge, He, Xiao, arXiv: 1902.06631]

[JE, He, Xiao, arXiv:2008.04298]

[Liu, Xiao, Li, JE, He, Yuan, arXiv: 2404.15937 ]

Q. Fu, J.-C. Yang, C.-X. Yue, Y.-C. Guo, Nucl. Phys. B 972 (2021) 115543




The constraints on $\text{sign}(c_{\tilde{B}W})/\Lambda^4_{\tilde{B}W}$ (TeV$^{-4}$) at $\mathcal{L} = 2$ ab$^{-1}$ for leptonic decays.

| $\mathcal{S}_{stat}$ | $\sqrt{s}$ (GeV) | | | | |
|---|---|---|---|---|---|
| | 250 | 500 | 1000 | 3000 | 5000 |
| 2 | [−25.7, 85.4] | [−5.2, 8.7] | [−1.0, 1.2] | [−0.12, 0.12] | [−0.054, 0.056] |
| 3 | [−34.9, 94.6] | [−6.7, 10.2] | [−1.3, 1.5] | [−0.15, 0.15] | [−0.067, 0.069] |
| 5 | [−50.1, 109.8] | [−9.0, 12.5] | [−1.7, 1.9] | [−0.19, 0.19] | [−0.088, 0.090] |

The expected constraints on $\text{sign}(c_{\tilde{B}W})/\Lambda^4_{\tilde{B}W}$ (TeV$^{-4}$) at $\mathcal{L} = 2$ ab$^{-1}$ for hadronic Z decays.

| $\mathcal{S}_{stat}$ | $\sqrt{s}$ (GeV) | | | | |
|---|---|---|---|---|---|
| | 250 G | 500 | 1000 | 3000 | 5000 |
| 2 | [−10.5, 76.9] | [−1.0, 14.8] | [−0.35, 1.3] | [−0.030, 0.064] | [−0.013, 0.013] |
| 3 | [−14.9, 81.3] | [−1.5, 15.2] | [−0.48, 1.4] | [−0.040, 0.074] | [−0.016, 0.016] |
| 5 | [−22.7, 89.1] | [−2.3, 16.1] | [−0.69, 1.6] | [−0.055, 0.089] | [−0.020, 0.020] |

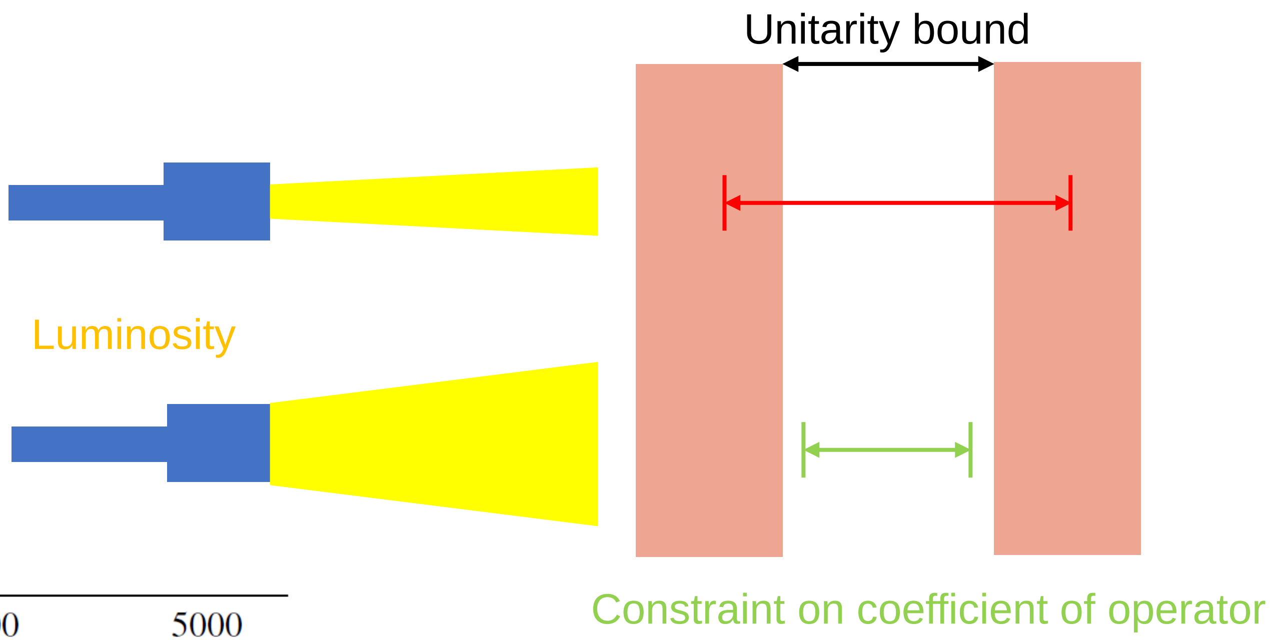
# Diboson productions (ZA)

Unitary bounds can constrain operators directly for diboson production

$$\Lambda_{\tilde{B}W}^{+-,0+} \geq \left(\frac{e^2\sqrt{s}v^2\left(s-M_Z^2\right)}{48\sqrt{2}\pi M_Z c_W^2}\right)^{\frac{1}{4}}, \quad \Lambda_{\tilde{B}W}^{+-,++} \geq \left(\frac{e^2v^2\left(s-M_Z^2\right)}{48\sqrt{2}\pi c_W^2}\right)^{\frac{1}{4}},$$

$$\Lambda_{\tilde{B}W}^{-+,0+} \geq \left(\frac{e^2\sqrt{s}\left(1-2s_W^2\right)v^2\left(s-M_Z^2\right)}{96\sqrt{2}\pi M_Z s_W^2 c_W^2}\right)^{\frac{1}{4}},$$

$$\Lambda_{\tilde{B}W}^{-+,++} \geq \left(\frac{e^2\left(2s_W^2-1\right)v^2\left(M_Z^2-s\right)}{96\sqrt{2}\pi s_W^2 c_W^2}\right)^{\frac{1}{4}},$$

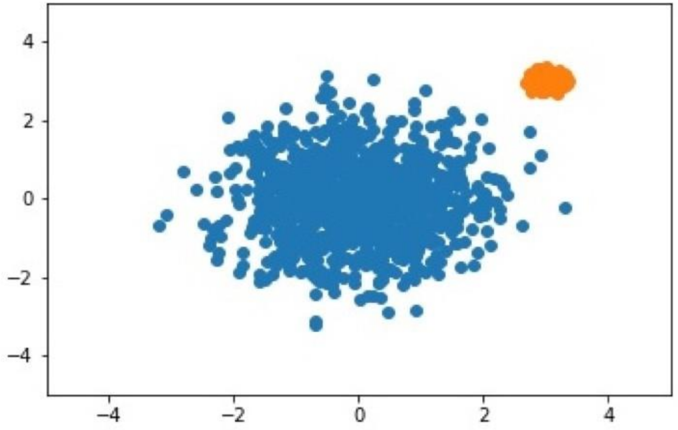



The constraints on $\Lambda_{\tilde{B}W}$ from unitarity bounds.

| $\sqrt{s}$ (GeV) | 250 | 500 | 1000 | 3000 | 5000 |
|---|---|---|---|---|---|
| $\Lambda_{\tilde{B}W}$ (GeV) | $>49.4$ | $>85.4$ | $>144.5$ | $>330.0$ | $>484.2$ |

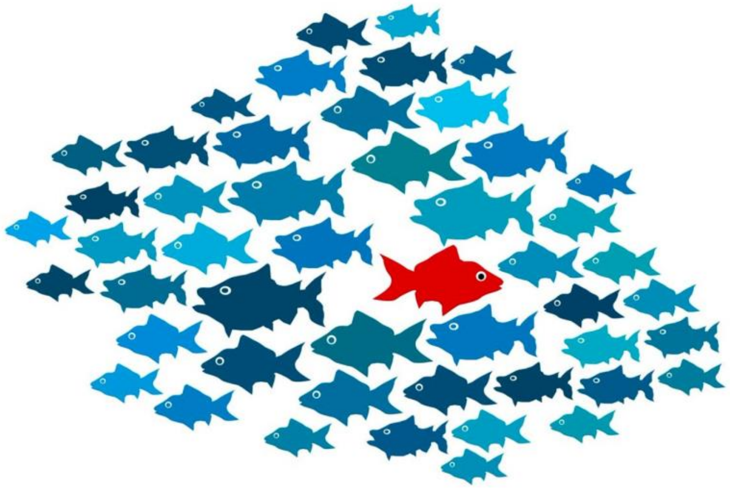
The unitarity bounds tell us the minimum integrated luminosity required to study nTGC and aQGC

# Machine Learning: Anomaly detection

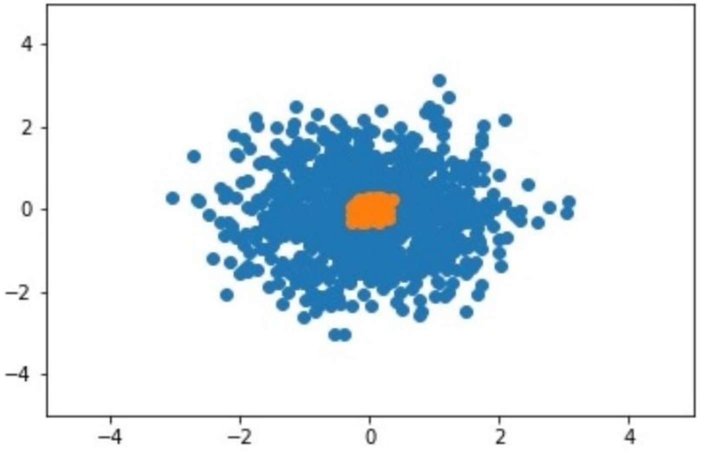



**Outlier Detection**

- Searching for unique or unexpected events
- In HEP, this is the tails of distributions or uncovered phase space

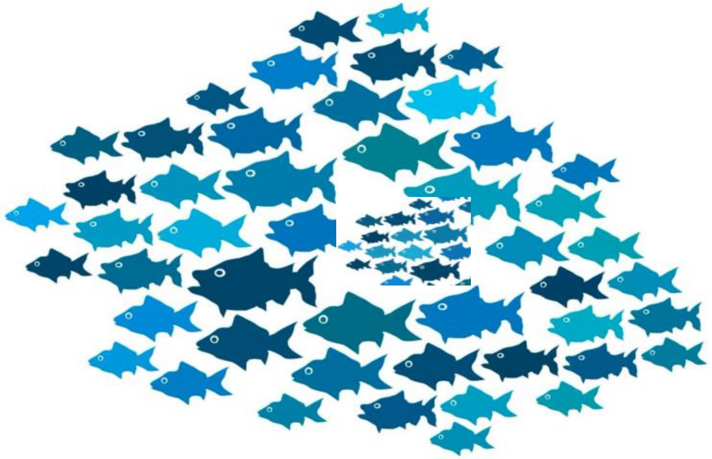


[1807.10261, 1808.08979, 1808.08992, 1811.10276, 1903.02032, 1912.10625, 2004.09360, 2006.05432, 2007.01850, 2007.15830, 2010.07940, 2102.08390, 2104.09051, 2105.07988, 2105.10427, 2105.09274, 2106.10164, 2108,03986, 2109.10919, 2110.06948, 2112.04958, 2203.01343,2206.14225, 2303.14134, 2304.03836, 2306.03637, 2308.02671, 2309.10157, 2309.13111, ... ]



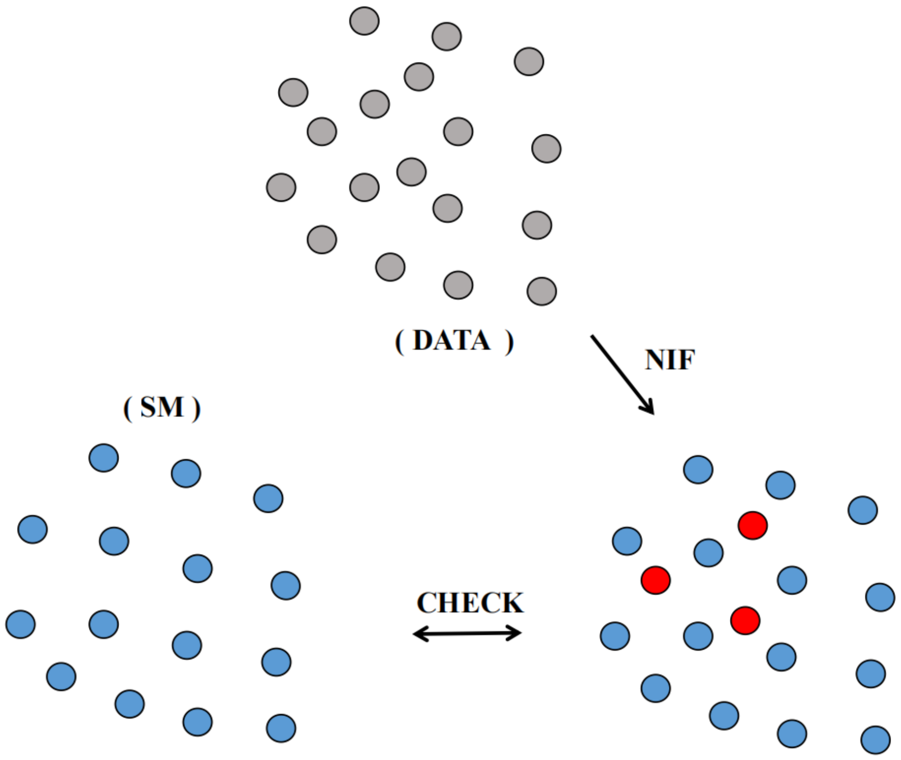

**Overdensity detection**

- Analogous to the traditional bump hunting
- Searching for new physics effect of interference term dominate



[1805.02664, 1806.02350, 1902.02634, 1912.12155, 2001.05001, 2001.04990, 2012.11638, 2106.10164, 2109.00546, 2202.00686, 2203.09470, 2208.05484, 2210.14924, 2212.11285, 2305.04646, 2305.15179, 2306.03933, 2307.11157, 2309.12918, 2310.06897, 2310.13057, ....]

# Nested IF (NIF)




## Nested Isolation Forest（NIF）：

- ✓ Interference effects dominate
- ✓ Training data set: SM data is used to establish the reference value of anomaly distribution
- ✓ Calculate the change in the anomaly score:

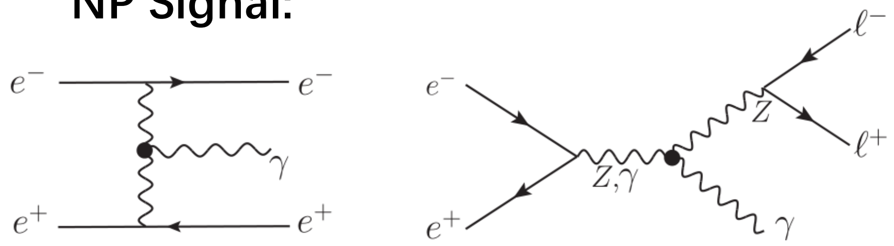
$$\Delta a^i = a^i_{data} - a^i_{SM}$$

NIF can identify the signals that overlap with the background through the distribution density

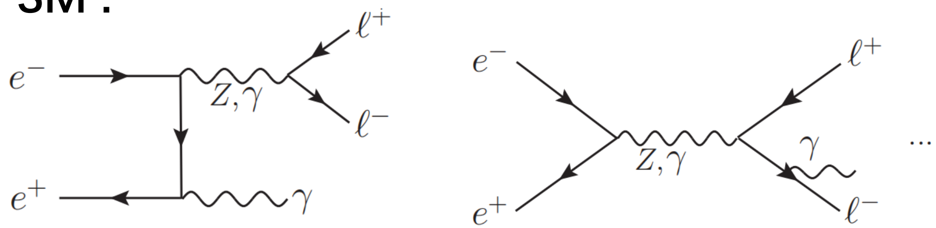
# Search for nTGC by NIF in $e^+ e^- \to Z\gamma$

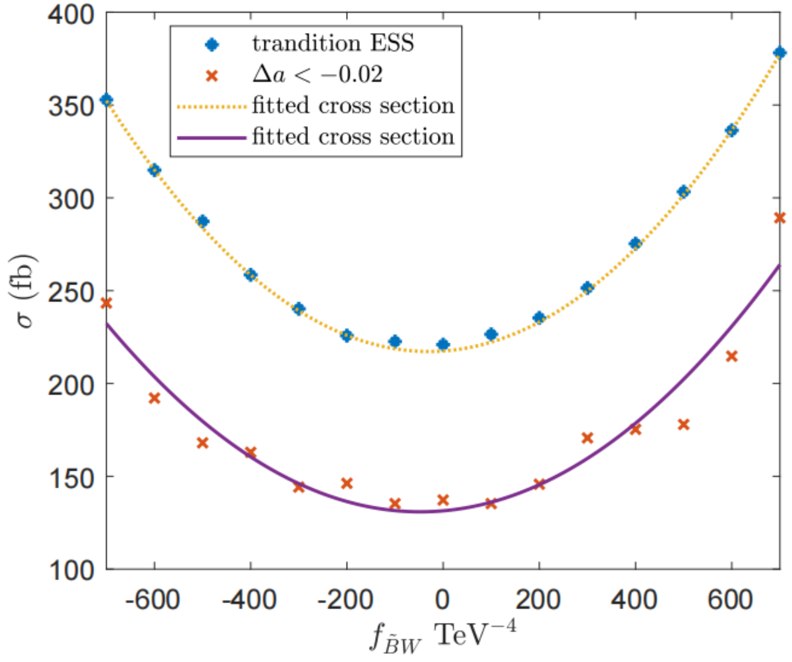
*J.C. Yang, Y-C. Guo, Nucl. Phys. B 977 (2022) 115735*

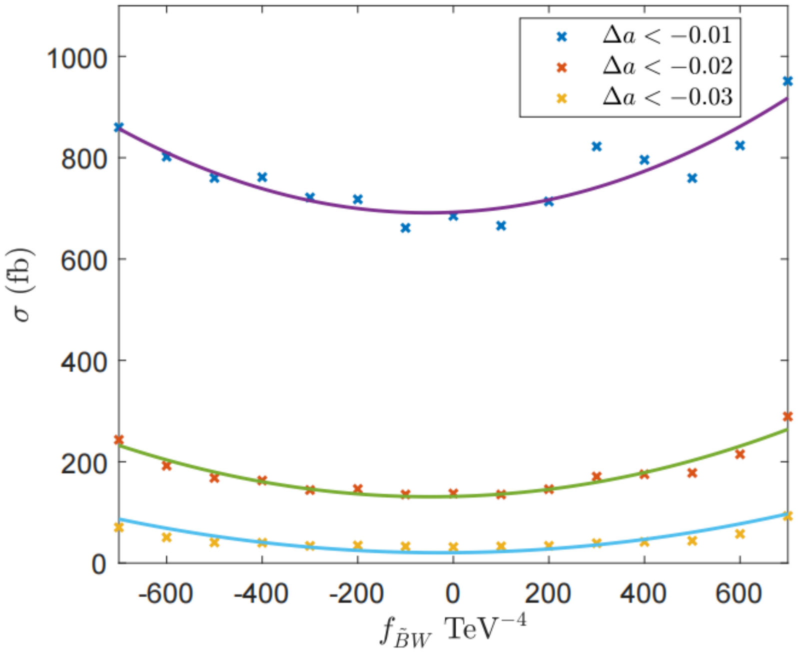
**NP Signal:**



**SM :**





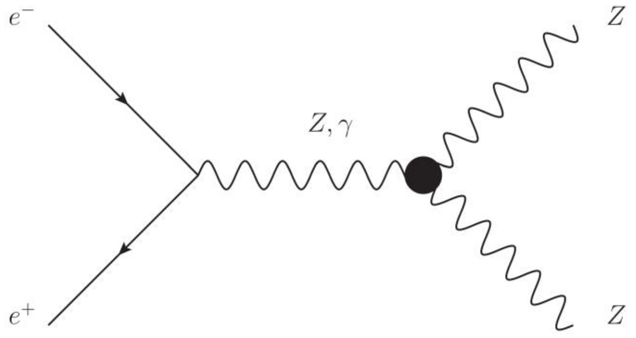

Left: Cross section obtained by kinematic analysis and NIF algorithm (function of $f_{\tilde{B}W}$ )

Right: The effect of NIF algorithm with different conditions

# Diboson productions (ZZ)

- nTGC in the $e^+ e^- \to ZZ$ process

*Y.-C. Guo, C.J.Pan, M.Q.Ruan & J.C.Yang, to be uploaded to arXiv.org*




$$\sigma_{\rm pol}^{\rm SM}(ZZ) = -\left(16\left(c_W^2-1\right)^2 (P_{e^+}+1)(P_{e^-}-1)s_W^4 + \left(1-2c_W^2\right)^4 (P_{e^+}-1)(P_{e^-}+1)\right)$$

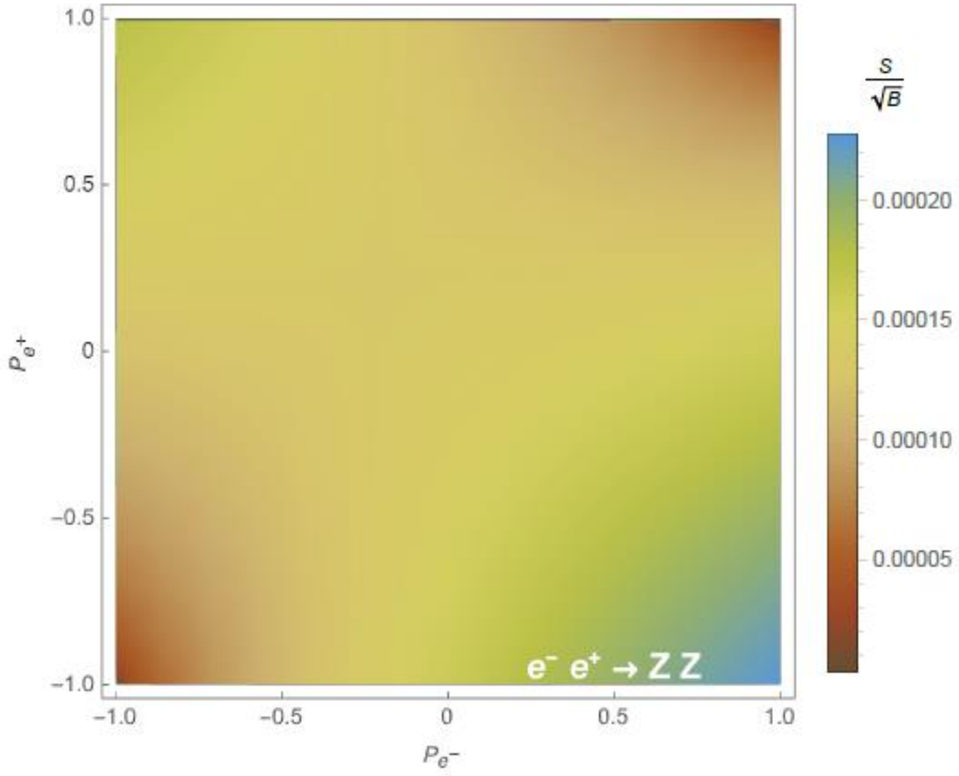
$$\times \frac{e^4\sqrt{s-4M_Z^2}\left(\sqrt{s}\left(s-2M_Z^2\right)\sqrt{4M_Z^2-s} + \left(4M_Z^4+s^2\right)\cot^{-1}\left(\frac{2M_Z^2-s}{\sqrt{s}\sqrt{4M_Z^2-s}}\right)\right)}{128\pi c_W^4 s^2 s_W^4 \left(2M_Z^2-s\right)\sqrt{4M_Z^2-s}},$$

$$\sigma_{\rm pol}^{\rm int}(ZZ) = \left(4\left(c_W^2-1\right)(P_{e^+}+1)(P_{e^-}-1)s_W^2 + \left(1-2c_W^2\right)^2 (P_{e^+}-1)(P_{e^-}+1)\right)$$

$$\times \frac{e^2 M_Z^2\sqrt{s-4M_Z^2}\left(\sqrt{s}\left(2M_Z^2+s\right)\sqrt{4M_Z^2-s} + 4M_Z^2\left(s-M_Z^2\right)\cot^{-1}\left(\frac{2M_Z^2-s}{\sqrt{s}\sqrt{4M_Z^2-s}}\right)\right)}{32\pi\Lambda_{\tilde{B}W}^4 c_W s^2 s_W \sqrt{4M_Z^2-s}},$$

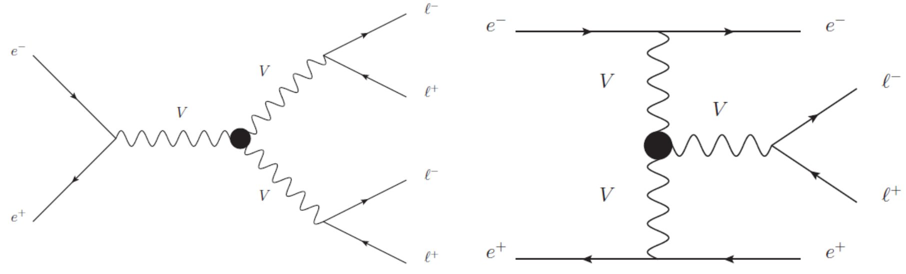
$$\sigma_{\rm pol}^{\rm nTGC}(ZZ) = -\frac{c_W^2 M_Z^2 s_W^2 \left(s-4M_Z^2\right)^{\frac{5}{2}} (P_{e^-}P_{e^+}-1)}{24\pi\Lambda_{\tilde{B}W}^8\sqrt{s}}.$$

Effect of initial beam polarization at e+e- Colliders

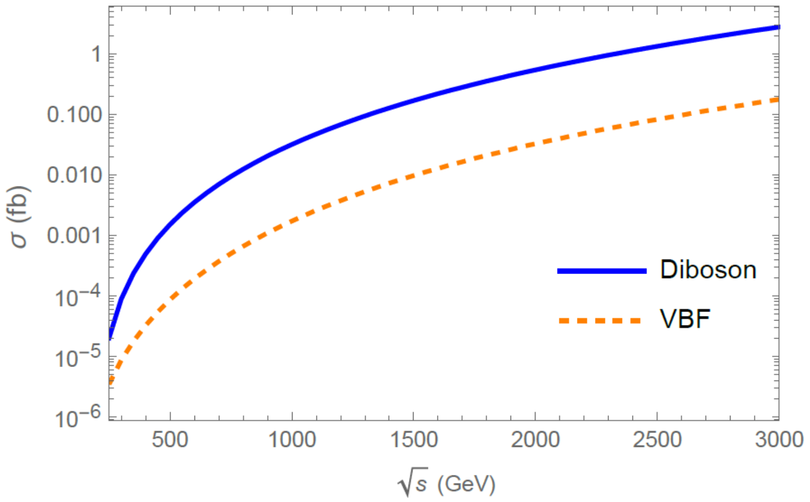


# Diboson productions (ZZ)

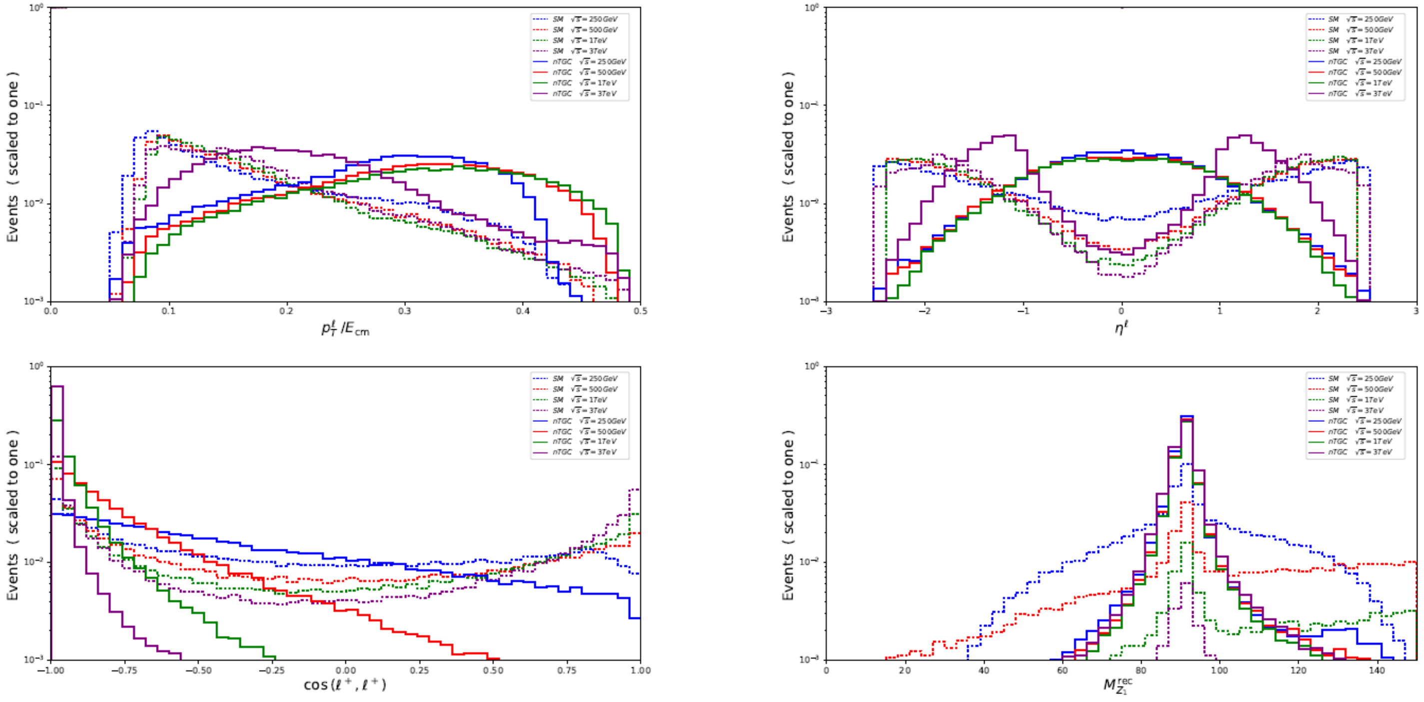
- nTGC signal of $e^+e^- \to 2l\,2l'$




(a) (b)



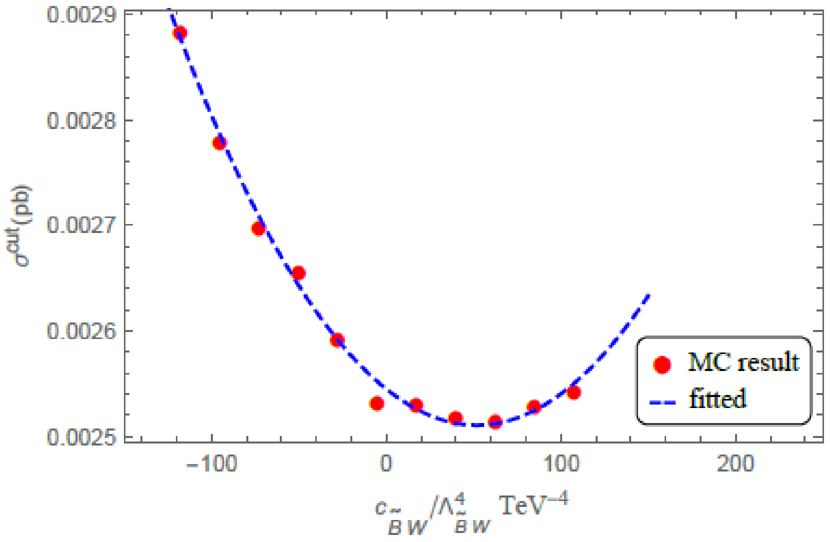

The normalized distributions of observables for $ZZ$ leptonic decays




| | $\sqrt{s}$=250 GeV | | $\sqrt{s}$=500 GeV | | $\sqrt{s}$=1000 GeV | | $\sqrt{s}$=3000 GeV | |
|---|---|---|---|---|---|---|---|---|
| | SM | NP | SM | NP | SM | NP | SM | NP |
| Basic Cuts | 22.83 | 0.254 | 11.64 | 0.161 | 5.301 | 0.109 | 1.336 | 0.022 |
| $p_T^\ell/E_{\rm cm} > 0.15$ | 11.01 | 0.228 | 5.696 | 0.148 | 2.625 | 0.101 | | |
| $\|\eta^\ell\| < 1.5$ | 9.244 | 0.225 | 4.105 | 0.143 | 1.677 | 0.098 | | |
| $\cos(\ell^+,\ell^+) < 0.6$ | | | | | | | 0.567 | 0.022 |
| $M_{Z_1,Z_2}^{\rm rec} \in (80,100)$ GeV | 3.626 | 0.180 | 0.621 | 0.126 | 0.110 | 0.086 | 0.016 | 0.018 |
| Efficiency $\epsilon$ | 10% | 46% | 3.1% | 49% | 1.2% | 47% | 0.7% | 60% |

# Diboson productions (ZZ)

$$\sigma^{\rm ac}_{\rm nTGC} = \epsilon_{\rm SM}\sigma_{\rm SM} + \epsilon_{\rm NP}\sigma_{\rm NP} + \frac{{\rm sign}(c_{\tilde{B}W})}{\Lambda^4_{\tilde{B}W}}\hat{\sigma}_{\rm int} \ ,$$




(a) 250 GeV

$$\mathcal{S}_{\rm stat} = \sqrt{2\left[(N_{\rm bg}+N_s)\ln(1+N_s/N_{\rm bg}) - N_s\right]}$$

**Table 5**: The expected constraints on ${\rm sign}(c_{\tilde{B}W})/\Lambda^4_{\tilde{B}W}$ (TeV$^{-4}$) for $e^+e^- \to 2\ell 2\ell'$ at each energy point of CEPC, ILC and CLIC with corresponding design luminosities.

| $S_{stat}$ | $\sqrt{s}$ (GeV) | | | |
|---|---|---|---|---|
| | 250 | 500 | 1000 | 3000 |
| 2 | [-10.2,96.2] | [-5.5,13.3] | [-0.84,1.26] | [-0.066,0.074] |
| 3 | [-14.7,100.7] | [-7.4,15.3] | [-1.10,1.52] | [-0.084,0.092] |
| 5 | [-22.8,108.7] | [-10.9,18.6] | [-1.56,1.98] | [-0.115,0.123] |

- $ee \to ZZ \to 2l\,2l'$
- $ee \to ZZ \to 4j$
- $ee \to ZZ \to lljj$
- $ee \to ZZ \to ll\nu\bar{\nu}$
- $ee \to ZZ \to jj\nu\bar{\nu}$

## Combine on the Coefficients for different Channels of Z Decays

| $S_{stat}$ | $\sqrt{s}$ (GeV) | | | |
|---|---|---|---|---|
| | 250 | 500 | 1000 | 3000 |
| 2 | [-4.1,4.7] | [-0.58,0.59] | [-0.12,0.20] | [-0.0032,0.0036] |
| 3 | [-6.0,7.2] | [-0.80,0.81] | [-0.16,0.25] | [-0.0040,0.0044] |
| 5 | [-9.2,11.2] | [-1.15,1.17] | [-0.22,0.32] | [-0.0054,0.0058] |

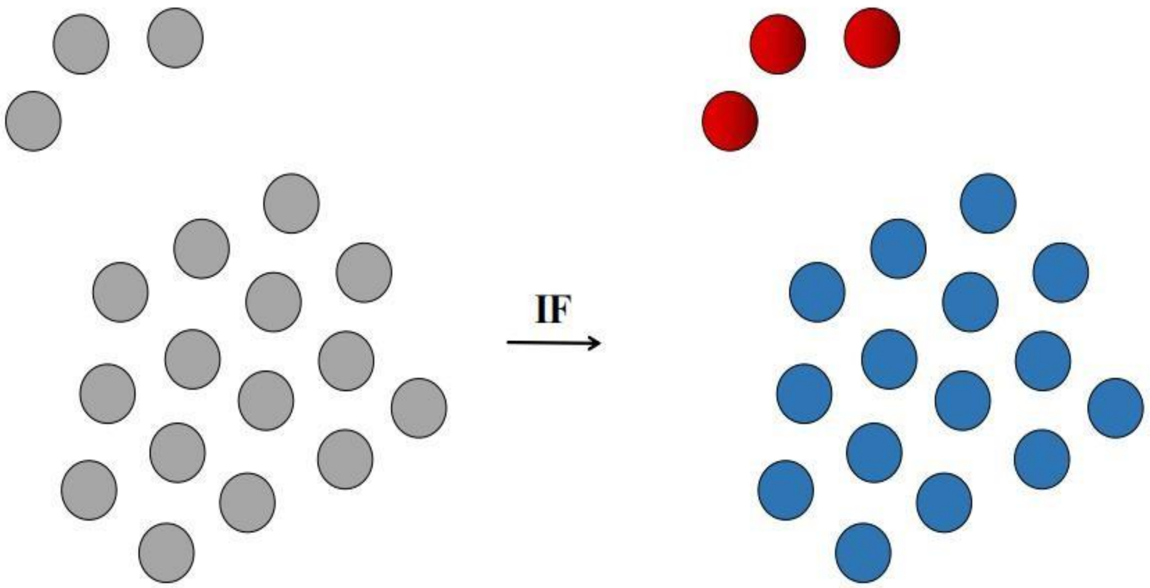
# Summary

- ALP appears naturally in broad extensions of the SM. The CEPC can complement LHC measurements of ALP coupling to SM particles.
- Search for new physics indirectly as well as directly. nTGCs provide windows of opportunity for probing indirectly possible physics BSM
- Polarized beams optimize measurement of coupling to axion-like particles, as well as nTGCs.
- Testing entanglement and Bell inequalities in di-boson production can bring new opportunities to CEPC

# Thank you !

# Back up

## Isolation Forest (IF)




Dim-2 data for example， NP and SM background

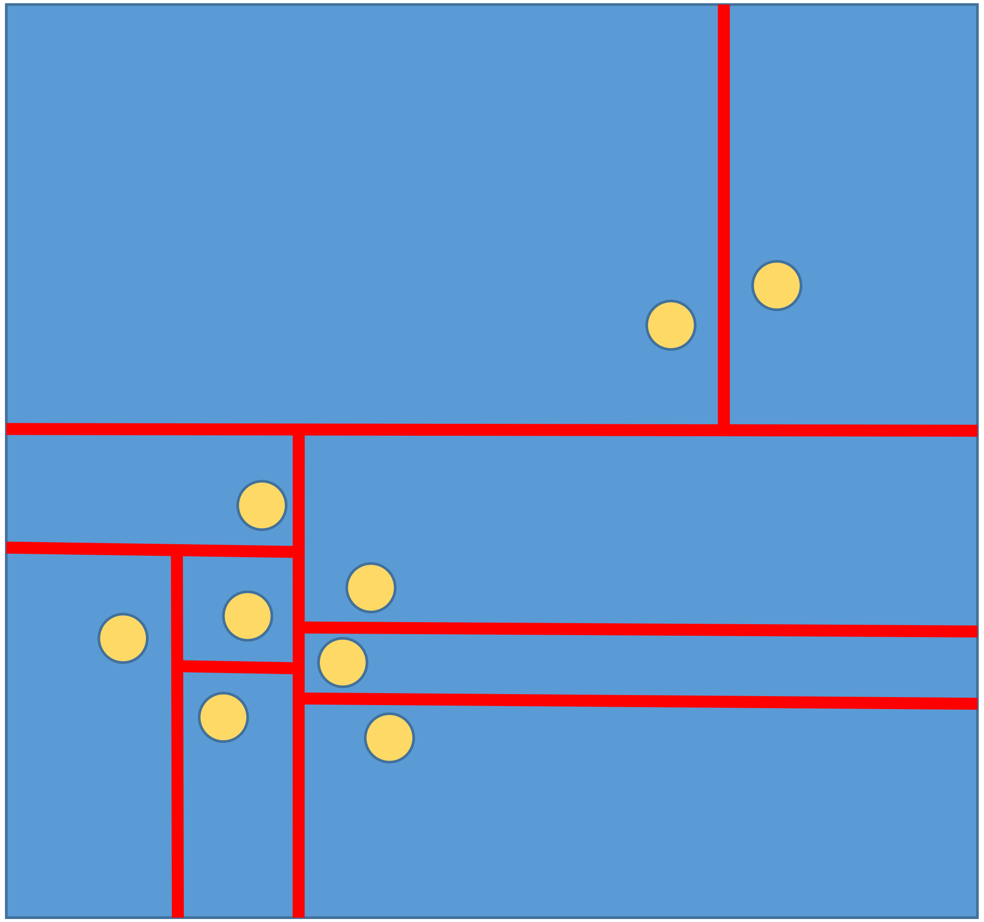
- **IF：** "Few and different" anomaly event
  New physics signal

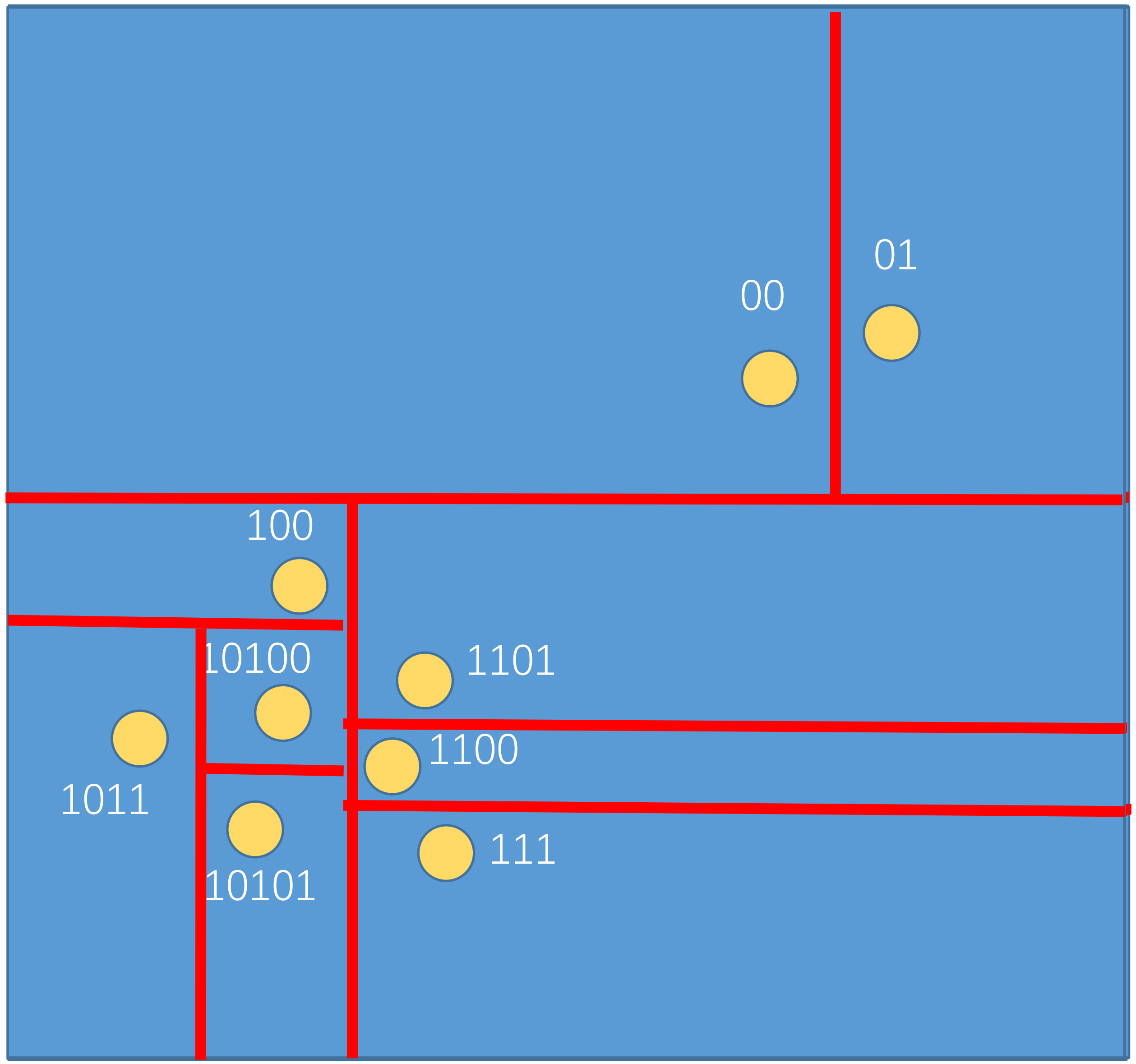
- Anomaly score $a$ : quantify the distance of the data point from the center point of all events

F. T. Liu, K. M. Ting and Z. Zhou, *Isolation forest*, in *2008 Eighth IEEE International Conference on Data Mining*, pp. 413–422, 2008, DOI.

# Isolation tree

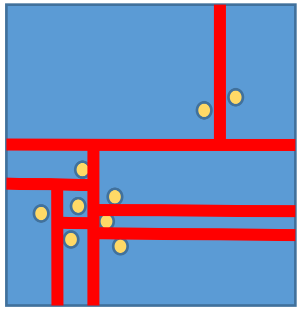
- Randomly choose a undivided leaf
- Randomly choose a dimension
- Divide
- Repeat until every node is either partitioned.



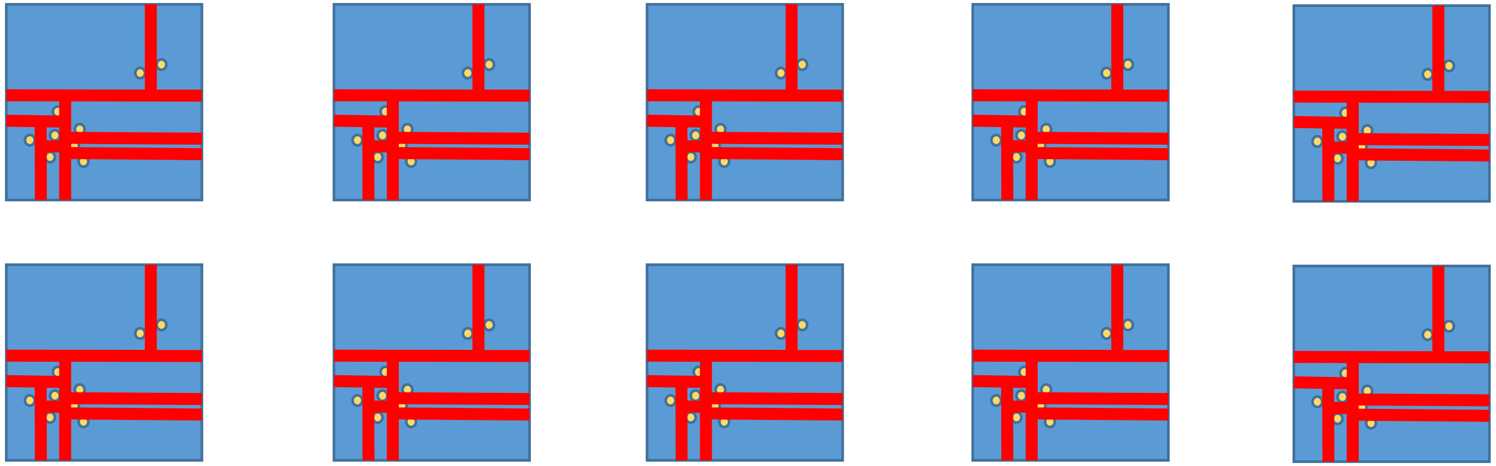

01
00
100
10100
1101
1100
1011
111
10101

# Tree -> Forest

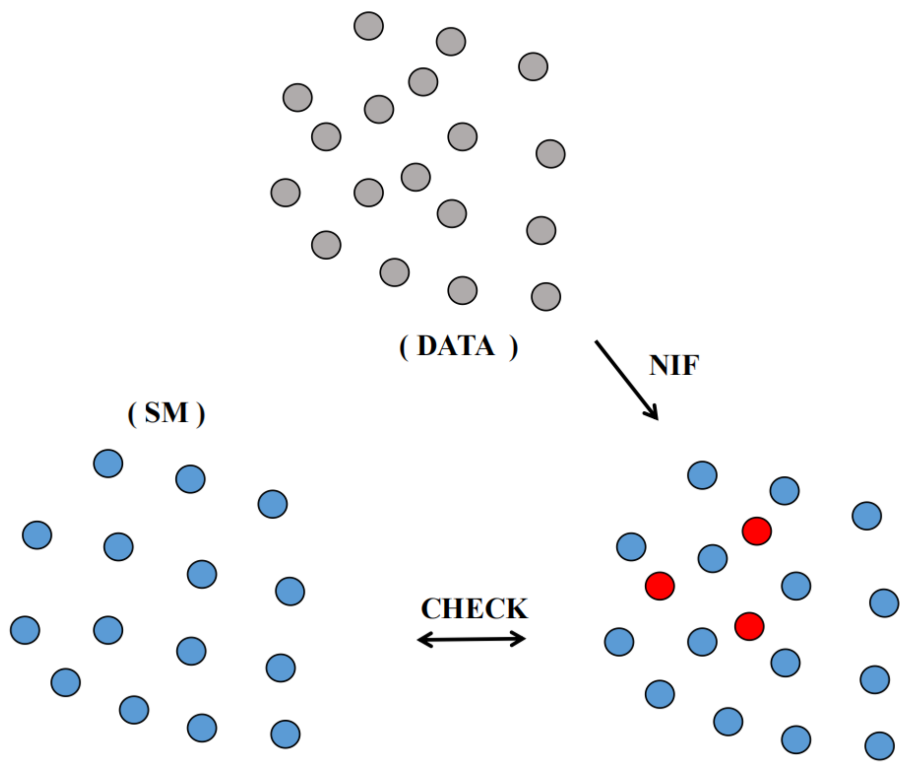
- Isolation tree:



- Isolation forest:



# Nested IF (NIF)

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