ALPs searches at BESIII

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Motivation

Axion-like particles (ALPs)

- Pseudo-Goldstone bosons arising from some spontaneously broken global symmetry
- Predicted by many BSM theories and proposed as cold DM candidates
- The ALP-photon coupling $g_{a\gamma\gamma}$ is mostly discussed $\rightarrow$ ALP decays to two photons
- Independent mass and coupling bounded by experiments $\rightarrow$ $m_a \sim O(\text{GeV})$ mainly from electron-positron colliders

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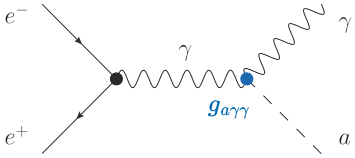
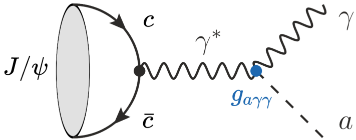
- Non-resonant ALP production



- Resonant ALP production



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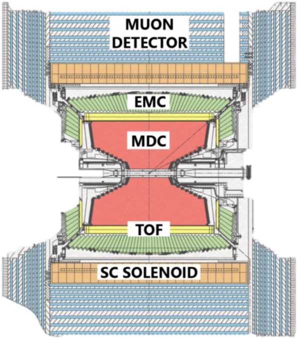
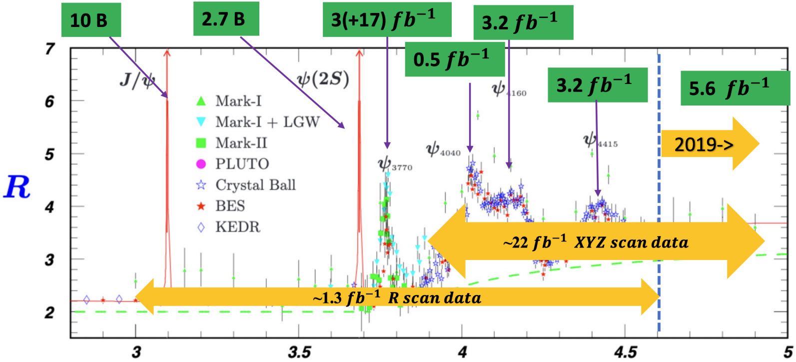
BESIII experiment

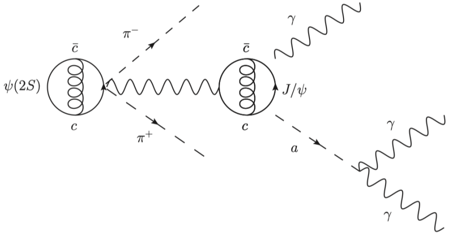
- BESIII runs at BEPCII accelerator in Beijing, which is a symmetric e^+e^- collider
- BESIII has collected the largest J/ψ and $\psi(2S)$ data samples on threshold



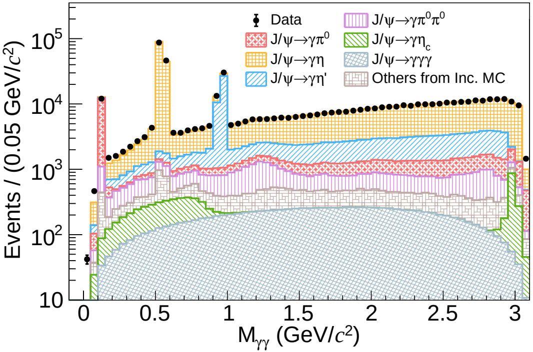


Analysis strategy

- Use $(2.71 \pm 0.01) \times 10^9$ $\psi(3686)$ events with $\psi(3686) \to \pi^+\pi^- J/\psi$ decays
- Search for $J/\psi \to \gamma a$, $a \to \gamma\gamma$. a has negligible decay width and lifetime
- Preclude the pollution from non-resonant production and avoid QED background

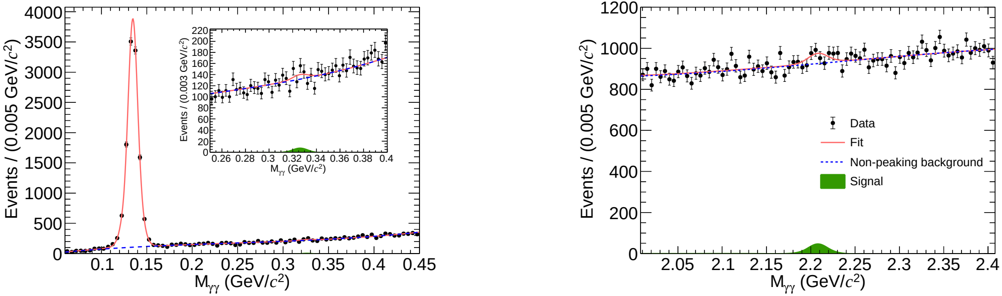


- Blind analysis strategy
- Three $\gamma\gamma$ combinations per event
- Exclude intervals around π^0, η, η' peaks



Fitting procedure

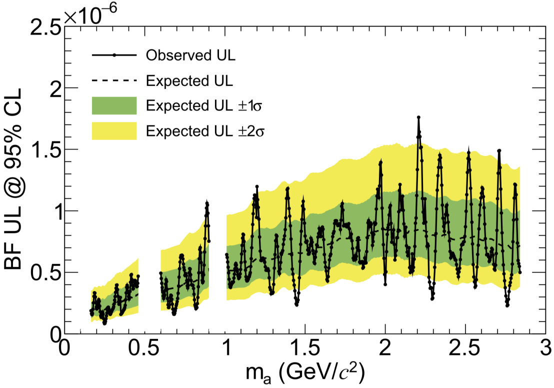
- Perform unbinned maximum likelihood fits to the $M_{\gamma\gamma}$ distribution with 674 mass hypotheses in the range of $0.165 \leq m_a \leq 2.84$ GeV$/c^2$
- Step size is less than half the signal resolution (σ), $\sigma = 6 \sim 11$ MeV$/c^2$
- Fit intervals ($35 \sim 90\sigma$) are mass-dependent
- Likelihood function includes signal, peaking and non-peaking backgrounds



Upper limits of $\mathcal{B}(J/\psi \to \gamma a)$

- No significant ALP signal observed, maximum local significance $\sim 2.6\sigma$
- A one-sided frequentist profile-likelihood (CLs) method used to compute 95% CL upper limits
- 4.4% systematic uncertainty on signal efficiency, other uncertainties are studied by performing spurious signal test and alternative fits, and the maximum upper limits are recorded

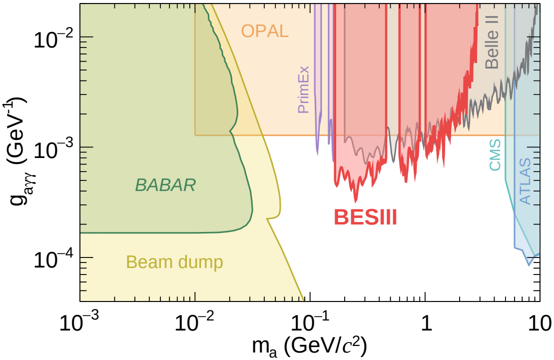
- Observed limits range from 8.3×10^{-8} to 1.8×10^{-6} in the search region



Exclusion limits of ALP-photon coupling

$$g_{a\gamma\gamma} = \sqrt{\frac{\mathcal{B}(J/\psi \to \gamma a)}{\mathcal{B}(J/\psi \to e^+e^-)} \left(1 - \frac{m_a^2}{m_{J/\psi}^2}\right)^{-3} \frac{32\pi\alpha_{\rm em}}{m_{J/\psi}^2}}$$

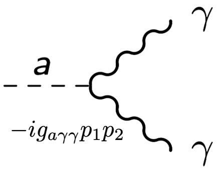
- Exclude the region of $g_{a\gamma\gamma} > 3 \times 10^{-4}$ GeV^{-1} for m_a around 0.25 GeV/c^2, three times better than Belle II result
- The constraints are the most stringent to date for $0.165 \leq m_a \leq 1.468$ GeV/c^2



Backup

ALP Lagrangian

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}\left(\partial_\mu a \partial^\mu a - m_a^2 a^2\right) - \frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu}$$



- Partial width $\Gamma_a = g_{a\gamma\gamma}^2 m_a^3/64\pi$, decay length $L_a = \frac{E_a}{m_a\Gamma_a}$
- $g_{a\gamma\gamma} = 10^{-4}$, $m_a = 0.165$ GeV$/c^2 \Rightarrow L_a \sim 1$ cm
- $m_a = 0.165$ GeV$/c^2$, opening angle of the photons $> 12^\circ$
- Non-resonant ALP production: $\sigma_{e^+e^-\to\gamma a} = \frac{g_{a\gamma\gamma}^2\alpha_{\text{em}}}{24}\left(1 - \frac{m_a^2}{s}\right)^3$

Event selection

- Two oppositely charged tracks are required, and their recoil mass lies in (3.080, 3.114) GeV/c^2
- More than 3 photon candidates are required
- A four-constraint kinematic fit applied to the $\pi^+\pi^-\gamma\gamma\gamma$ combinations and the smallest χ^2_{4C} is less than 40
- The energy deposition of the remaining photons E_{other} is less than 0.1 GeV
- Signal efficiency: 30% $\sim$ 35%