BSM particle searches at BESIII

Peicheng Jiang

Peking University

August 23, 2022

Outline

1. BSM particle searches at BESIII

2. Dark photon searches
   - Search for visible dark photons decays
   - Search for invisible dark photons decays

3. CP-odd light Higgs and ALP searches
   - Search for CP-odd light Higgs
   - Search for axion-like particles

4. Summary

BSM particle searches at BESIII

BSM particles:

- Dark photon (DP), CP-odd Light Higgs, axion-like particle (ALP)...
- Predicted by BSM theories, eg. NMSSM, SUSY, string theory
- Provid a portal connecting SM particles to the dark sector and could be dark matter candidates
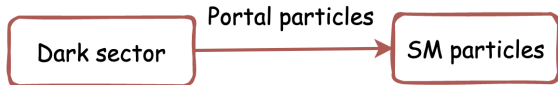
Searches performed at BESIII:

- The largest data samples of J/ψ (10 B) and $\psi(3686)$ (2.7 B), and over 20 fb^{-1} data above 4.0 GeV in total
- Based on a blind analysis to avoid possible bias
- Common statistic methods to extract the results (Bayesian, Profile-likelihood...)

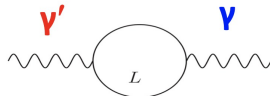# Dark photon searches

Dark photon searches

Dark photon (γ', A', U)

A spin-one boson associated with a new Abelian gauge symmetry $\mathrm{U}(1)_D$

- Massless kind (not our topic in this talk)
  - $\mathrm{U}(1)_D$ stays unbroken
  - Do not interact directly with SM
  - Can induce FCNC transitions, eg. $c \to u$
- **Massive kind**
  - $\mathrm{U}(1)_D$ is spontaneously broken
  - Kinetically mix with SM photon γ with strength ϵ
  - Visible decays into SM particles ($2m_e < m_{\gamma'} < 2m_\chi$)
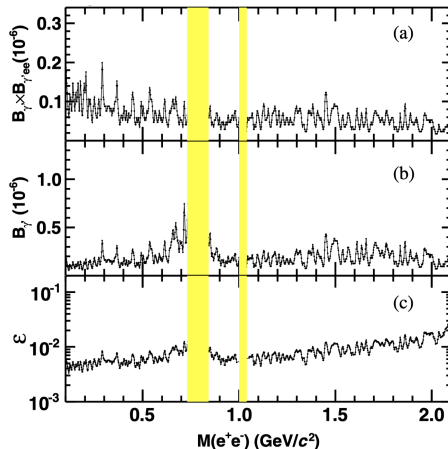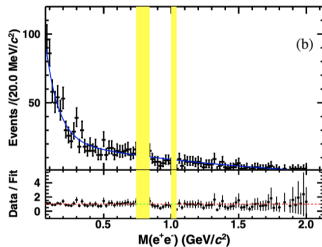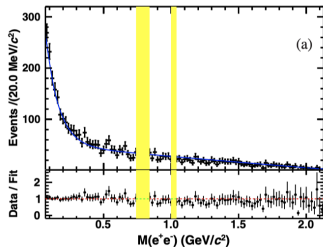 - Invisible decays into DM ($m_{\gamma'} > 2m_\chi$)

Heavy Charged Leptons L
(carry $\mathrm{U}(1)_d$ charge)

$$\mathcal{L} = -\varepsilon e J^\mu A'_\mu$$

Search for dark photons in $J/\psi \to \gamma'\eta'$, $\gamma' \to e^+e^-$

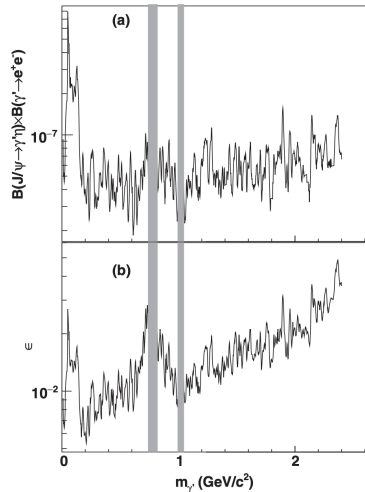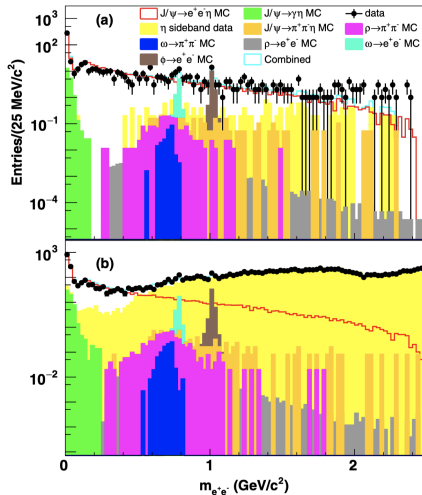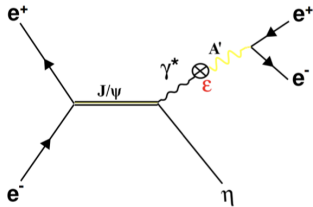**Phys. Rev. D 99, 012013 (2019)**

- Using 1.3 billion J/ψ events
- $\mathcal{B}(J/\psi \to \gamma\eta') \sim 1 \times 10^{-3}$
- two η' decay modes $\eta' \to \gamma\pi^+\pi^-$ and
  $\eta' \to \pi^+\pi^-\eta(\gamma\gamma)$ $\varepsilon < [3.4 \times 10^{-3}, 2.6 \times 10^{-2}]$

Search for dark photons in $J/\psi \to \gamma'\eta$, $\gamma' \to e^+e^-$

- Using 1.3 billion J/ψ events
- $\mathcal{B}(J/\psi \to \gamma\eta) \sim 5 \times 10^{-3}$
- two η decay modes $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$

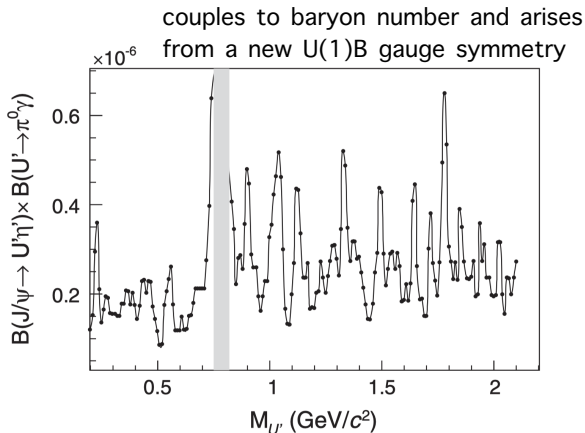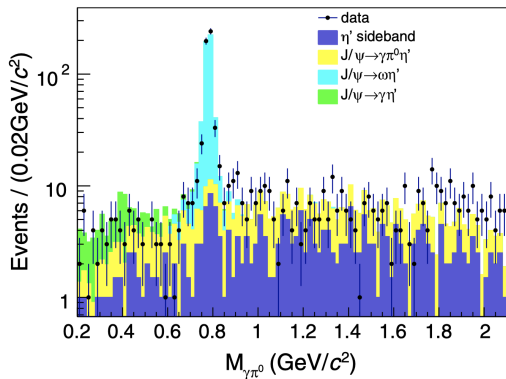**Phys. Rev. D 99, 012006 (2019)**

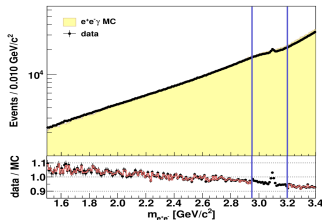# Search for dark photons in $J/\psi \to \gamma'\eta'$, $\gamma' \to \gamma\pi^0$

- Using 1.3 billion J/ψ events
- $\mathcal{B}(J/\psi \to \gamma\eta') \sim 1 \times 10^{-3}$ **Phys. Rev. D 102, 052005 (2020)**
- η' reconstructed by $\eta' \to \pi^+\pi^-\eta(\gamma\gamma)$
- Excluding the mass region around the ω peak (0.75 to 0.82 GeV/c^2)

couples to baryon number and arises from a new U(1)B gauge symmetry

Search for visible dark photon decays using ISR

- Using 2.93 fb^{-1} of data taken at $\sqrt{s} = 3.773$ GeV (17 fb^{-1} coming)

- Using untagged ISR photon (predicted by calculating the missing momentum)

- Search for $e^+e^- \to \gamma'\gamma_{\text{ISR}}$ with $\gamma' \to \mu^+\mu^-$, $\gamma' \to e^+e^-$

- Excluding area around the J/ψ resonance
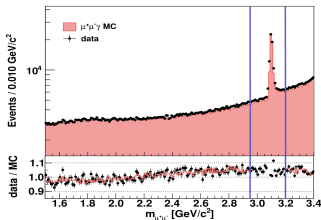
- Mass range $m_{\gamma'}$ between 1.5 and 3.4 GeV/c^2

- Below the $\pi^+\pi^-$ state becomes dominant and above the $q\bar{q}$ processes polute the spectrum too much
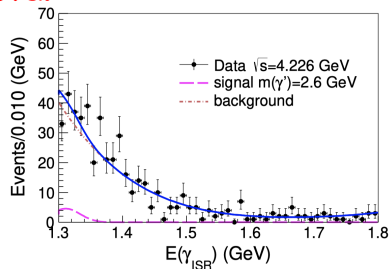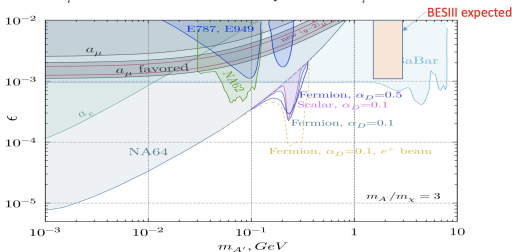
Phys. Lett. B 774, 252 (2017)
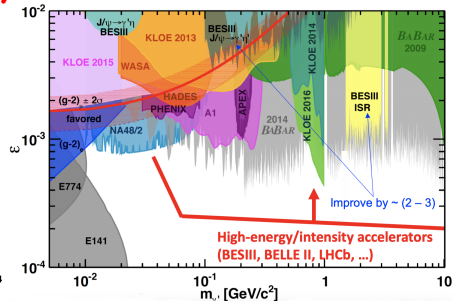
Search for invisible dark photon decays using ISR

- Using 14.9 fb^{-1} of data taken at $\sqrt{s} = 4.13$ to 4.60 GeV

- Search for $e^+e^- \to \gamma_{\text{ISR}}\gamma'$ with $\gamma' \to \chi\bar{\chi}$

- No charged tracks and large uncertainty of the start time, require EMC time [-10,25]$\times$50 ns

- Saturation effect of EMC electronics happens around $E_\gamma = 2.0\text{GeV}$, require $E_\gamma < 1.8\text{GeV}$
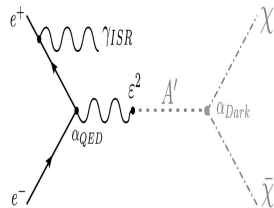
Waiting for spokespersons approval

CP-odd light Higgs and ALP searches
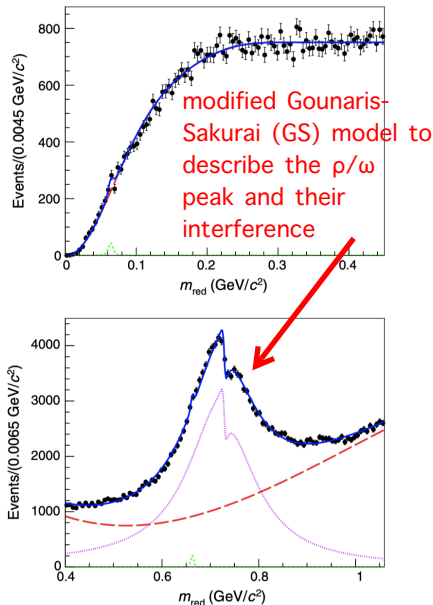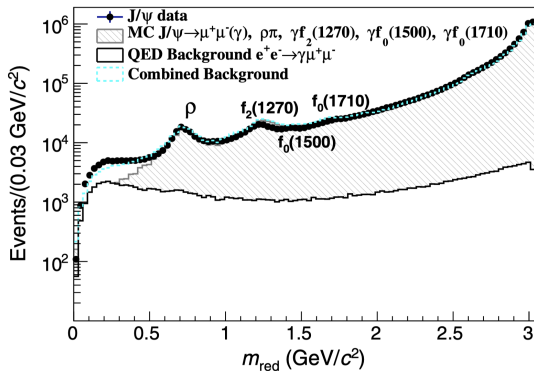
CP-odd light Higgs and axion-like particles

CP-odd light Higgs

- Pseudoscalar bosons predicted by NMSSM
- $\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to l^+ l^-)} = \frac{G_F m_q^2 g_q^2 C_{\mathrm{QCD}}}{\sqrt{2}\pi\alpha} \left(1 - \frac{m_{A^0}^2}{m_V^2} \right)$
- $g_c = \cos\theta_A / \tan\beta$ for the c-quark and $g_b = \cos\theta_A \tan\beta$ for the b-quark
- $\tan\beta$ is the ratio of up- and down-type Higgs doublets and $cos\theta_A$ is the fraction of the nonsinglet component of the A^0

Axion-like particles (ALPs)

- Pseudo-Goldstone bosons arising from some spontaneously broken global symmetry, addressing the strong CP or hierarchy problems
- Predominantly couples to photons with a coupling strength $g_{a\gamma\gamma}$
- ALP masses and couplings are independent

Search for di-muon decays of CP-odd light Higgs

- Using 9 billion J/ψ events collected in 2009, 2018, and 2019

- Search for $J/\psi \rightarrow \gamma A^0$, $A^0 \rightarrow \mu^+\mu^-$

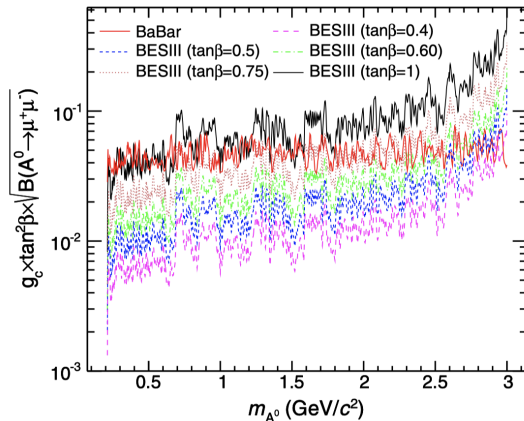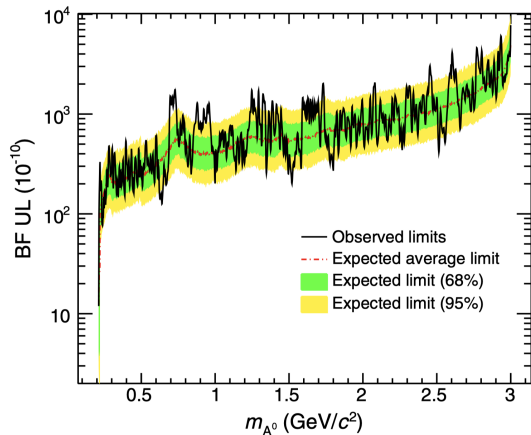- $m_{\mathrm{red}} = \sqrt{m_{\mu^+\mu^-}^2 - 4m_\mu^2}$

modified Gounaris-Sakurai (GS) model to describe the ρ/ω peak and their interference

Search for di-muon decays of CP-odd light Higgs

UL of $\mathcal{B}\left(J/\psi \rightarrow \gamma A^0\right) \times \mathcal{B}\left(A^0 \rightarrow \mu^+\mu^-\right)$ in range of $(1.2 - 778.0) \times 10^{-9}$ @90% CL for $0.212 \leq m_{A^0} \leq 3.0 \mathrm{GeV}/c^2$
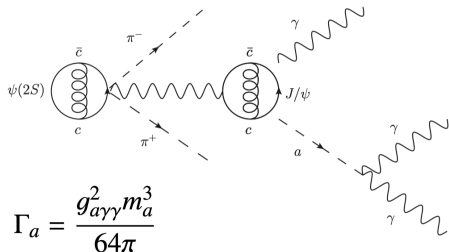
Better than the BABAR measurement in the low-mass region for $\tan\beta = 1.0$
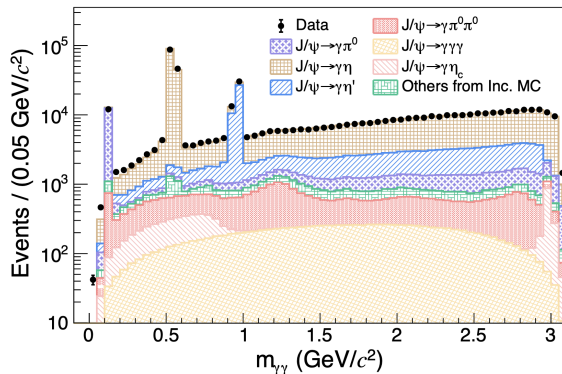
Phys. Rev. D 105, 012008 (2022)

Search for axion-like particles via $J/\psi \to \gamma a$

- Using 2.7 billion $\psi(3686)$ events with $\psi(3686) \to \pi^+\pi^- J/\psi$ decays
- Search for $J/\psi \to \gamma a$, $a \to \gamma\gamma$
- Preclude the polution from non-resonant ALP production $e^+e^- \to \gamma a$

- Three ALP candidates per event
- Dominant backgrounds from $J/\psi \to \gamma\pi^0, \gamma\eta$ and $\gamma\pi^0$
- Excluding mass intervals around π^0, η, η' peaks
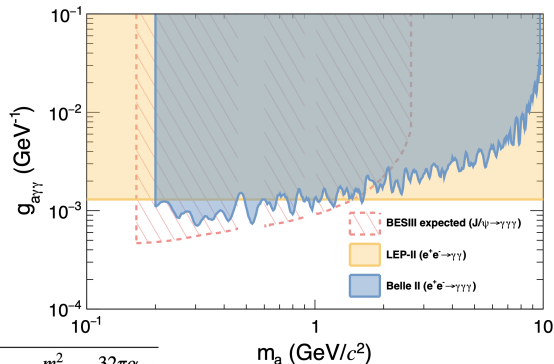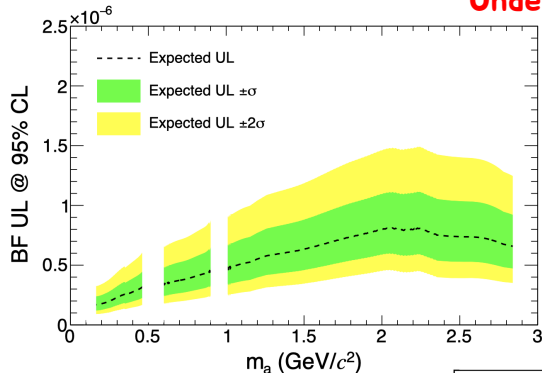

$$\Gamma_a = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}$$

Expected UL of $\mathcal{B}\left(J/\psi \rightarrow \gamma a\right)$ in range of $(1.7 - 8.1) \times 10^{-7}$ @95% CL for $0.165 \leq m_a \leq 2.84 \mathrm{GeV}/c^2$

Expected UL of $g_{a\gamma\gamma}$ is $(4.7 \sim 9.0) \times 10^{-4}$ GeV^{-3} in the mass region below 1 GeV/c^2, better than Belle II's result

Under reviewing

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

Summary

- BESIII plays an important role in BSM particle searches
- Sensitivity is comparable to B-factory for visible and invisible dark photon searches, better for light CP-odd Higgs and ALP searches in low-mass region
- BESIII has enormous potentials with unique datasets and analysis techniques