Dark sector search at BESIII

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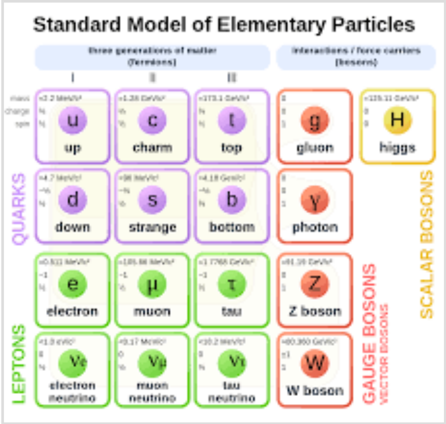
Peking University

On behalf of the BESIII collaboration

Apri 11, Genova, Italy

Dark sector

There is nothing new to be discovered in physics now.



Dark sector

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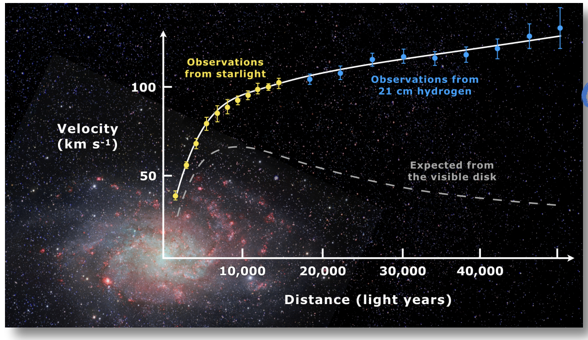
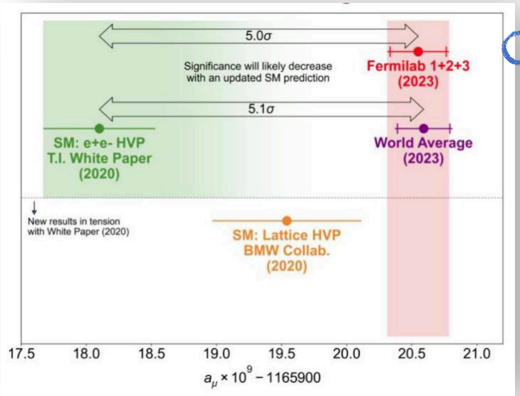
Galactic rotation curve

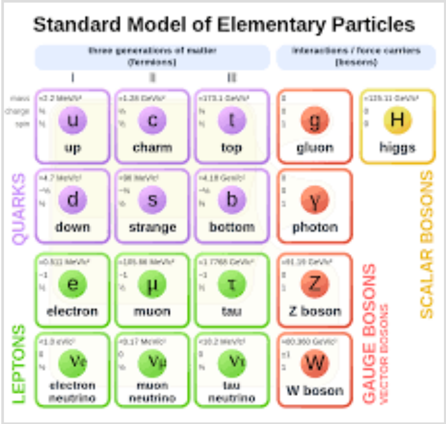


arXiv:astro-ph/0403324

$g_\mu - 2$ anomaly



PRL 131, 161802(2023)



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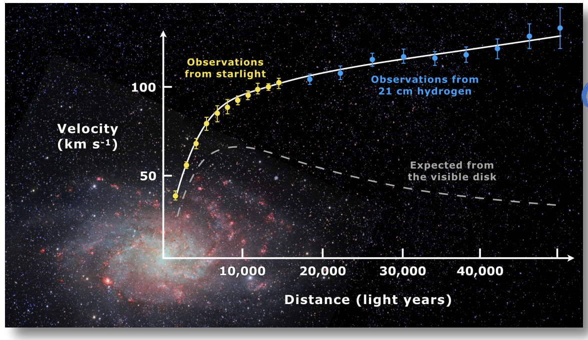

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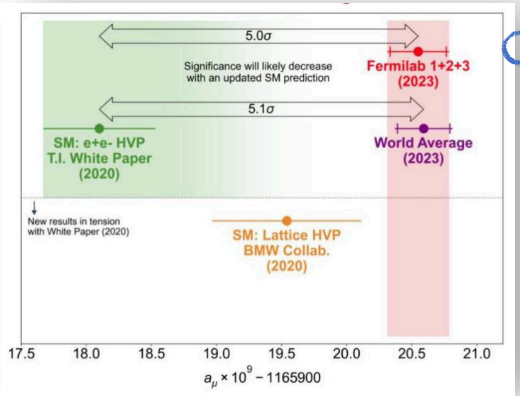
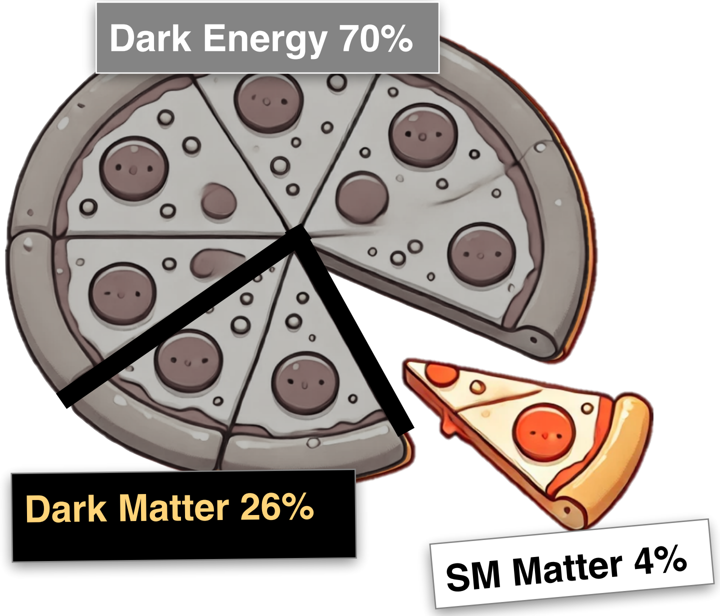


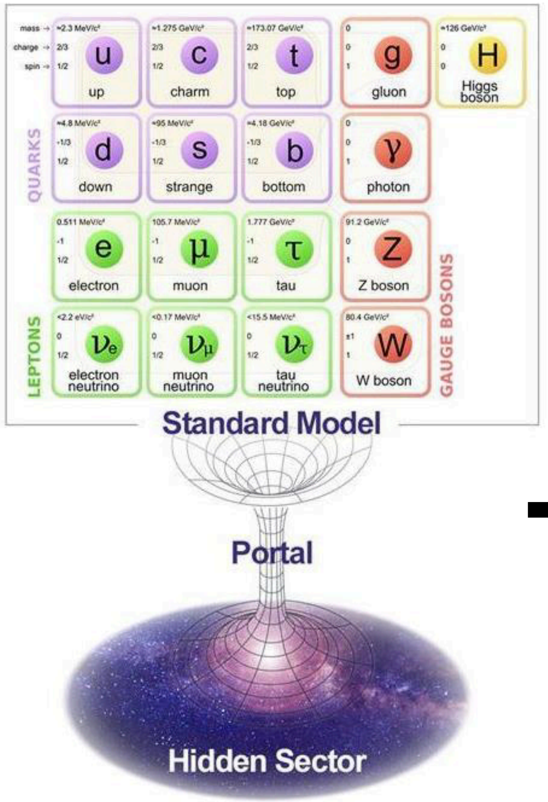
PRL 131, 161802(2023)

Physics BSM must exist!



Dark sector

- A **collection of particles** that are not charged directly under the SM strong, weak, or electromagnetic forces.
  - May interact with SM particle through portal interactions, not through gravitational effect only.

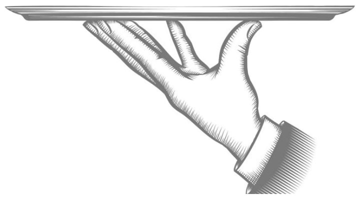


➡ Dark sector particles

- **New invisible particles**
- **New particle decay to SM particles**
- …..

The main of this talk

- **Invisible decay of K_S^0**
  arXiv: 2501.06426 accepted by JHEP
- $\Sigma^+ \to p+$**invisible**
  Phys.Lett.B 852 (2024) 138614
- **Muonphilic particle in $J/\psi \to \mu^+\mu^-$X**
  Phys.Rev.D 109 (2024) 3, L031102
- **(Massless) Dark photon in $D^0 \to \omega\gamma', \gamma\gamma'$**
  Phys.Rev.D 111 (2025) 1, L011103



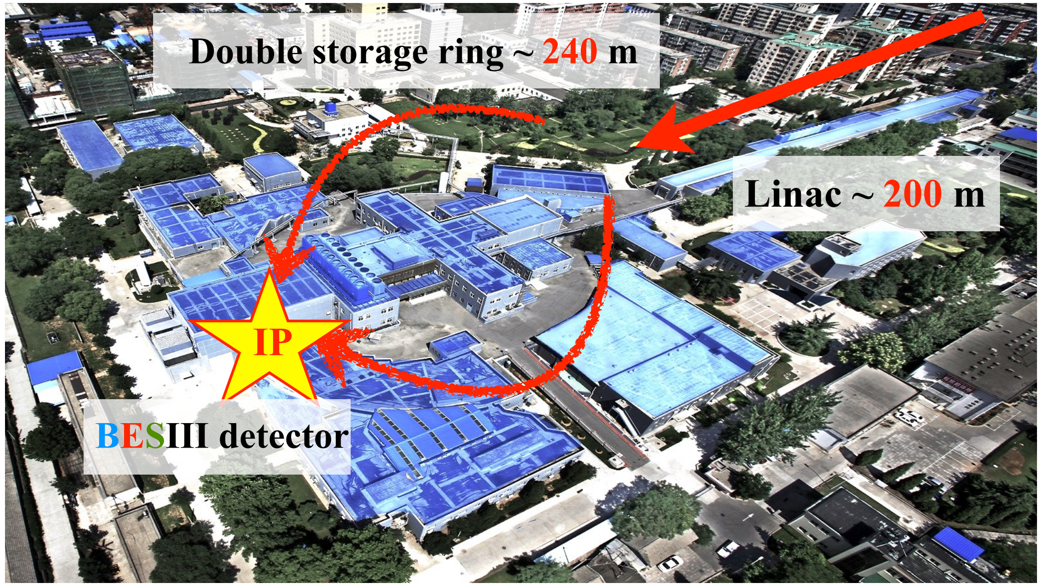
BEPCII

- A **symmetric** e^-e^+ collider running at **tau-charm region** $E_{CM} = 1.84 \sim 4.95$ GeV
  - BEPCII: Electron–positron colliders: accelerate the e^+, e^-

✓ **Beijing Electron Positron Collider II**

BEijing Spectrometer III

*Can't do B physics



- Double rings
- $E_{CM} = 1.84 \sim 4.95$ GeV
- Peak luminosity @Ecm=3.77 GeV $\mathscr{L}_{peak} = 1.1 \times 10^{33} \mathrm{cm}^{-2} \cdot \mathrm{s}^{1}$
- 2009~today: BESIII physics runs;

END 12 KM START

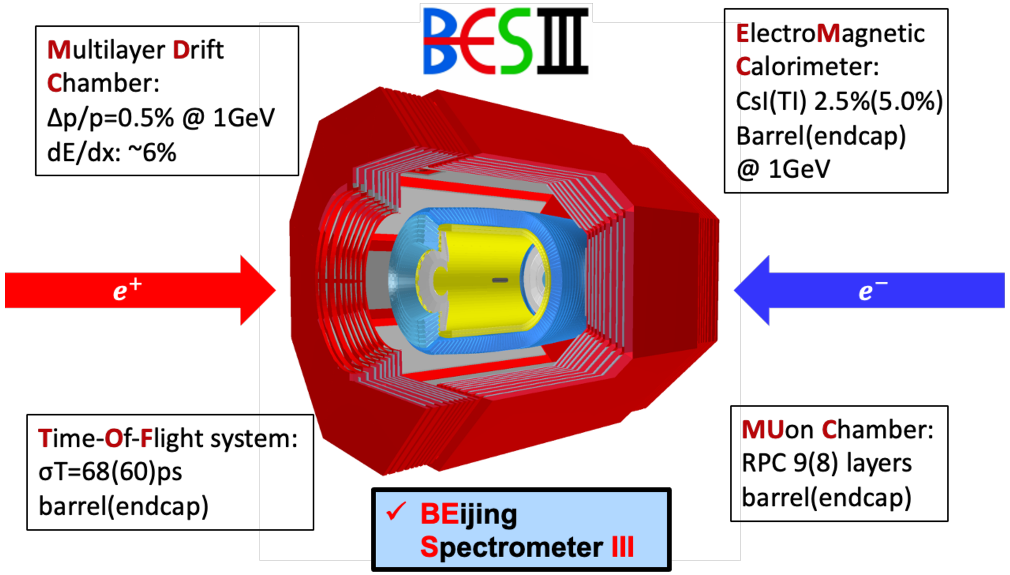
BESIII detector

Merits of BSM search at BESIII:

Also mentioned by Enrico Graziani

- High statistic of data
- Clean background environment
- Angular coverage is almost 4π
- Data collected at the **threshold**

Sensitive to invisible signal!



BESIII has collected large data samples in τ-c energy region! which can benefit the search for the LDM in the **MeV-GeV** range

$$E_{CM} = 1.84 \sim 4.95\ \text{GeV}$$

Invisible decay of K_S^0

Invisible decay of K_S^0

arXiv: 2501.06426 (Accepted by JHEP)

K_S^0

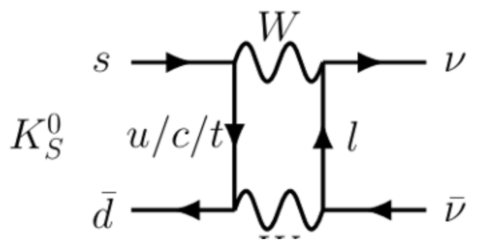
Invisible

SM decay

$K_S^0 \to \nu\bar{\nu}$

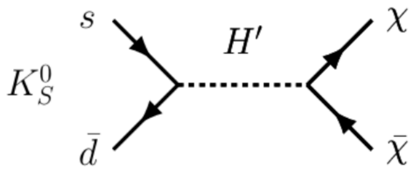
Phys.Rev.D 91 (2015) 1, 015004

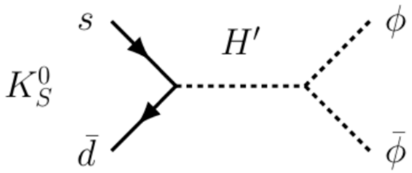
FCNC && helicity suppression, BF < 10^{-16}



Decay to DM

$K_S^0 \to \chi\bar{\chi}$





2HDM model

BF$\sim\mathcal{O}(10^{-6})$

Natural Sci.Rev. 1 (2024) 5

Ordinary-mirror particle oscillations

$K_S^0 \dashrightarrow K_S^{0\prime}$

Mirror matter model

BF$\sim\mathcal{O}(10^{-6})$

arXiv: 2006.10746

Input for CPT test

Bell-Steinberger relation **connects CPTV** to the amplitudes of all decay channels of neutral kaons. BUT currently assumes no invisible modes

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K_S^0

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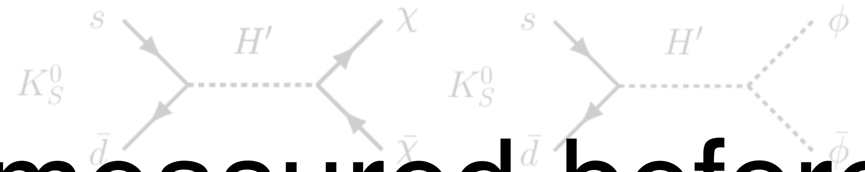

2HDM model
BF~$\mathcal{O}(10^{-6})$

Natural Sci.Rev. 1 (2024) 5

Never been measured before!

Ordinary-mirror particle oscillations

$K_S^0 \dashrightarrow K_S^{0\prime}$

Mirror matter model
BF~$\mathcal{O}(10^{-6})$

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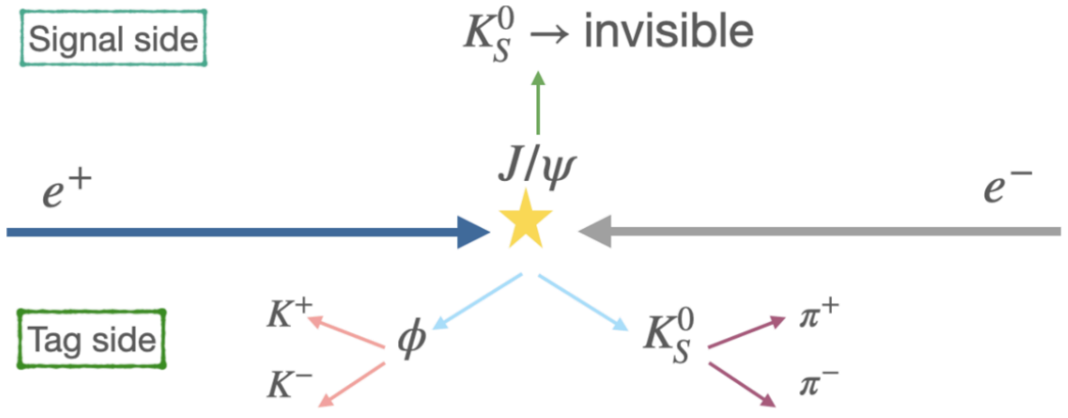
Phys.Rev.D 91 (2015) 1, 015004

Analysis strategy

$\boxed{K_S^0 \text{ source}}$

- $J/\psi \to \phi K_S^0(\text{tag}) K_S^0$, $K_S^0(\text{tag}) \to \pi^+\pi^-$ from **10Billion** J/ψ events



Why this channel?

Analysis strategy

K_S^0 source

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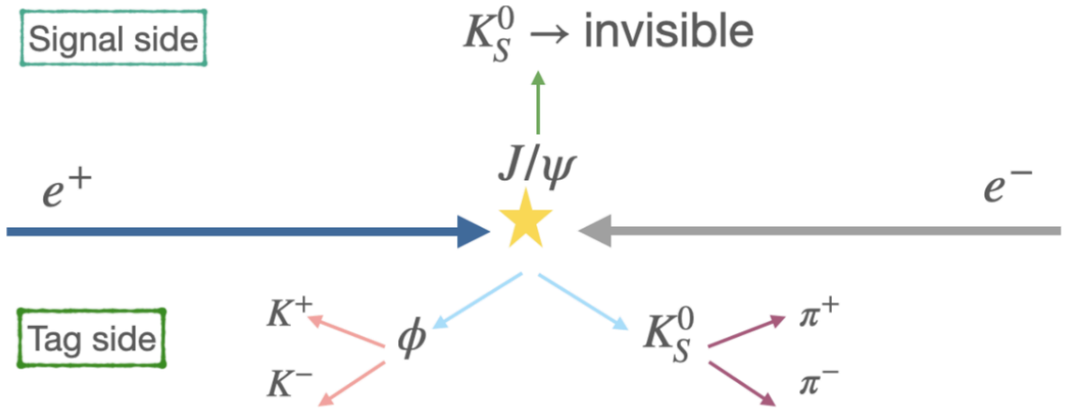
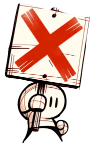


K_L^0

Long life, mostly fly through the detector

Rarely interact with the detector

Can mimic the fake signal!



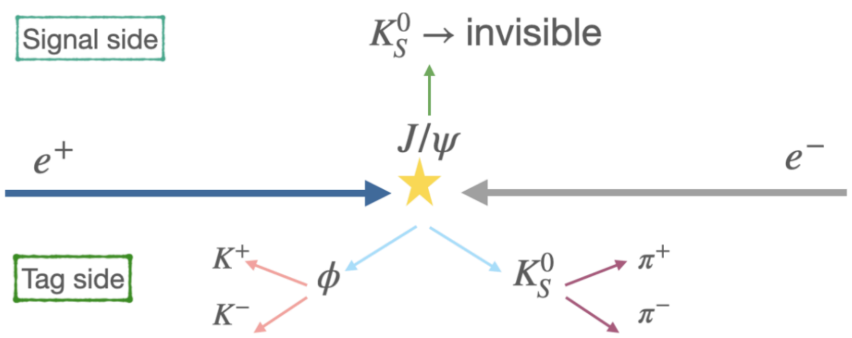
Tag a clean K_S^0 sample:

- One of the dominant K_L^0 backgrounds, $J/\psi \to \phi K_S^0 K_L^0$ is **forbidden** by C-parity conservation
- But still have $J/\psi \to K^+K^-K_S^0K_L^0$

Analysis strategy

Tag a clean K_S^0 sample:

- $J/\psi \to \phi K_S^0(\text{tag}) K_S^0$, $K_S^0(\text{tag}) \to \pi^+\pi^-$ from 10Billion J/ψ events

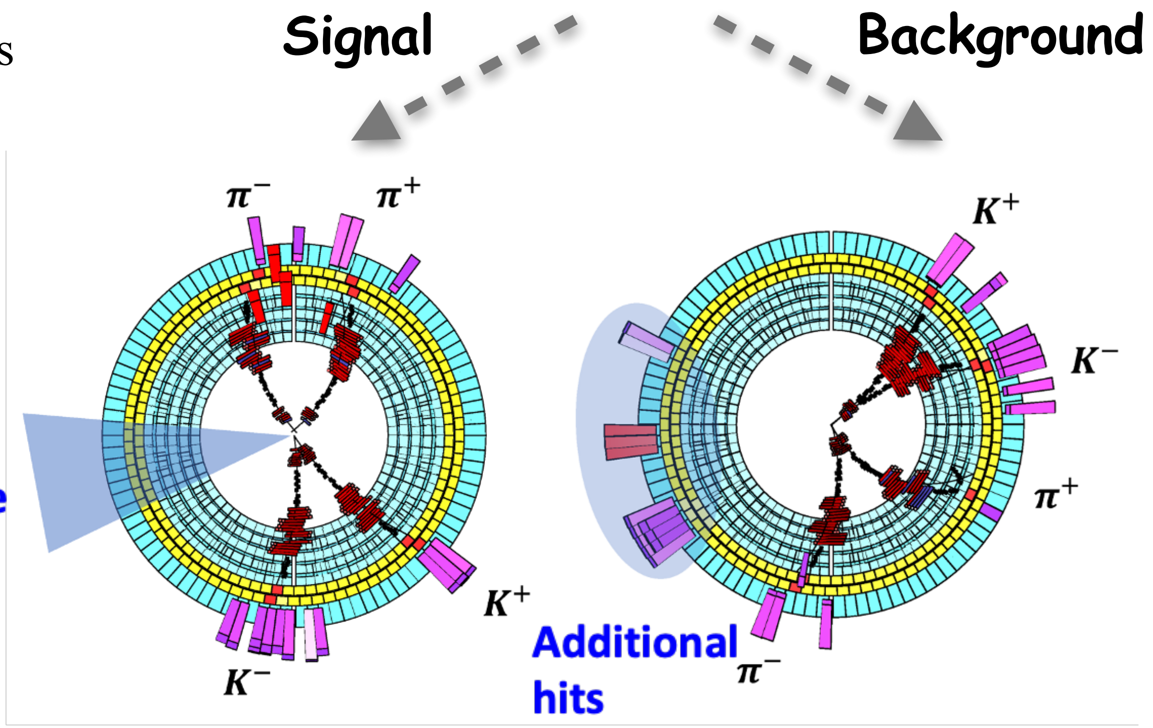


- $J/\psi \to \phi K_S^0 K_L^0$ is forbidden by C-parity conservation,

lower background

- But still have $J/\psi \to K^+K^-K_S^0K_L^0$

Signal feature

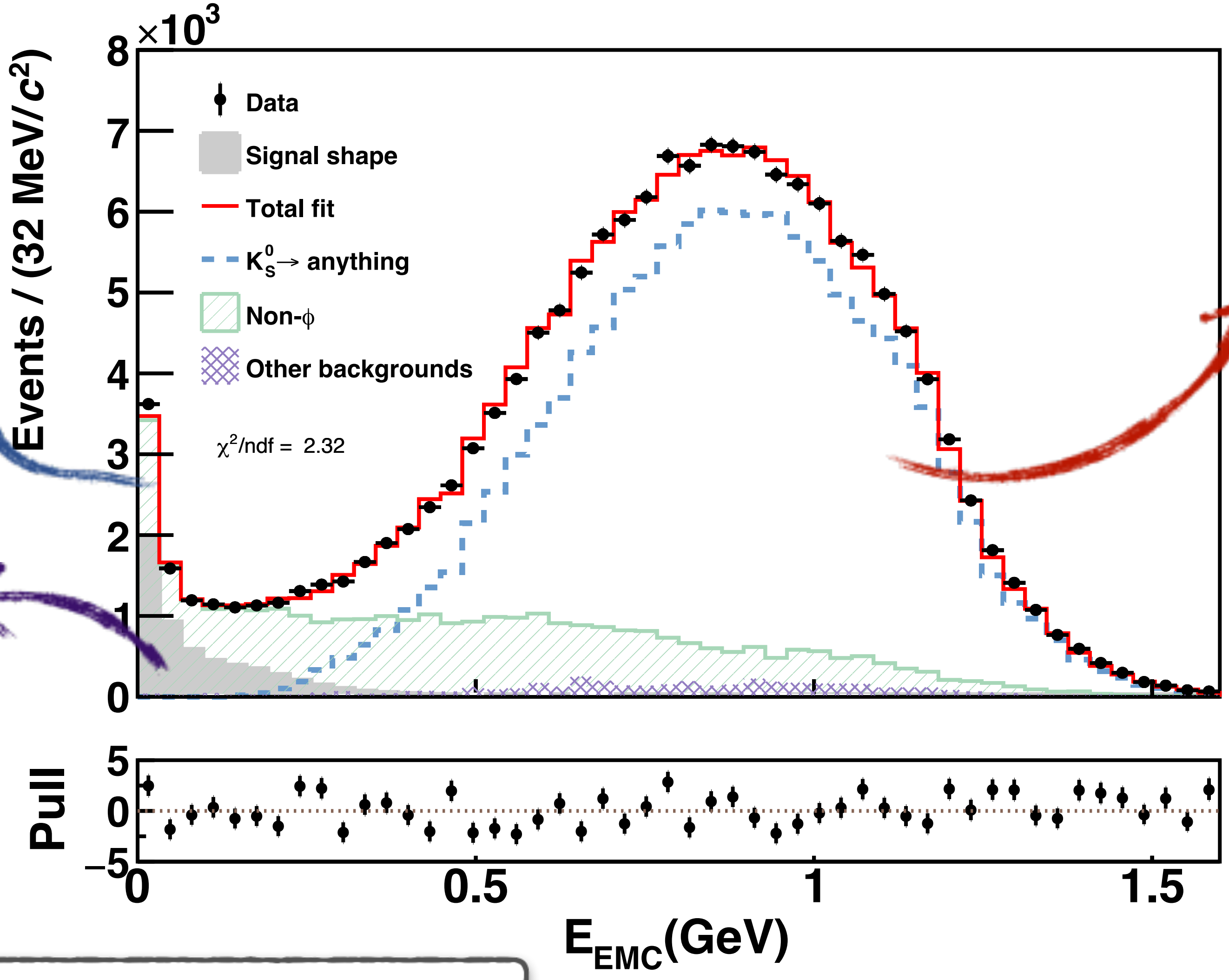


Using the deposited energy in **EMC**(energy calorimeter) to identify the invisible signal

Signal extraction

Peaking background from non-ϕ processes, $J/\psi \to K^+K^-K_S^0K_L^0$, Shape from ϕ sideband

Invisible Signal peaks around zero



Other background modeled with **MC simulation**, such as $K_S^0 \to \pi^0\pi^0$

$N_{\text{invisible}} = 56 \pm 201$,

$\mathscr{B}(K_S^0 \to \text{invisible}) < 8.4 \times 10^{-4}$

(90% C.L)

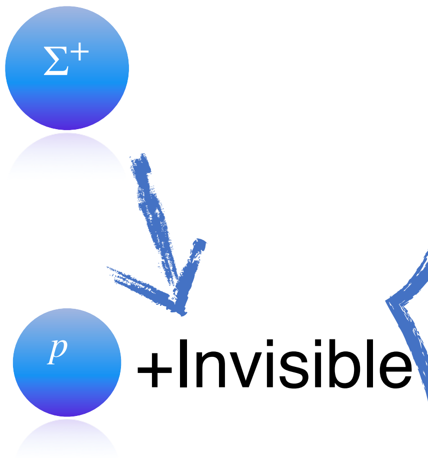
Accepted by JHEP during the LDMA2025

First direct measurement of $K_S^0 \to$ invisible!

the UL still lies above the NP prediction

$\Sigma^+ \to p + \text{invisible}$

$\Sigma^+ \rightarrow p$+invisible



ROPP. 86, 016201 (2023)

Decay to SM

$s \rightarrow d\nu\bar{\nu}$

FCNC && GIM suppression, BF $< 10^{-11}$

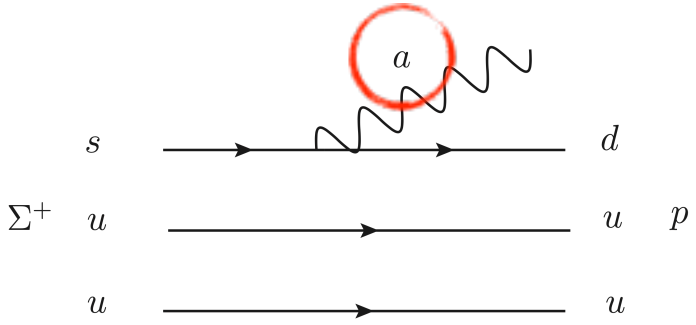
Contributions from BSM can enhance the BF ($\sim 10^{-4}$)

JHEP 04, 104 (2019).

Decay to BSM particle

- **Massless** dark photon γ' && QCD axion, a

$\boxed{m_a \propto 1/f_a \;👉\; m_a \ll 1eV}$



Phys. Rev. D 102, 015023 (2020).

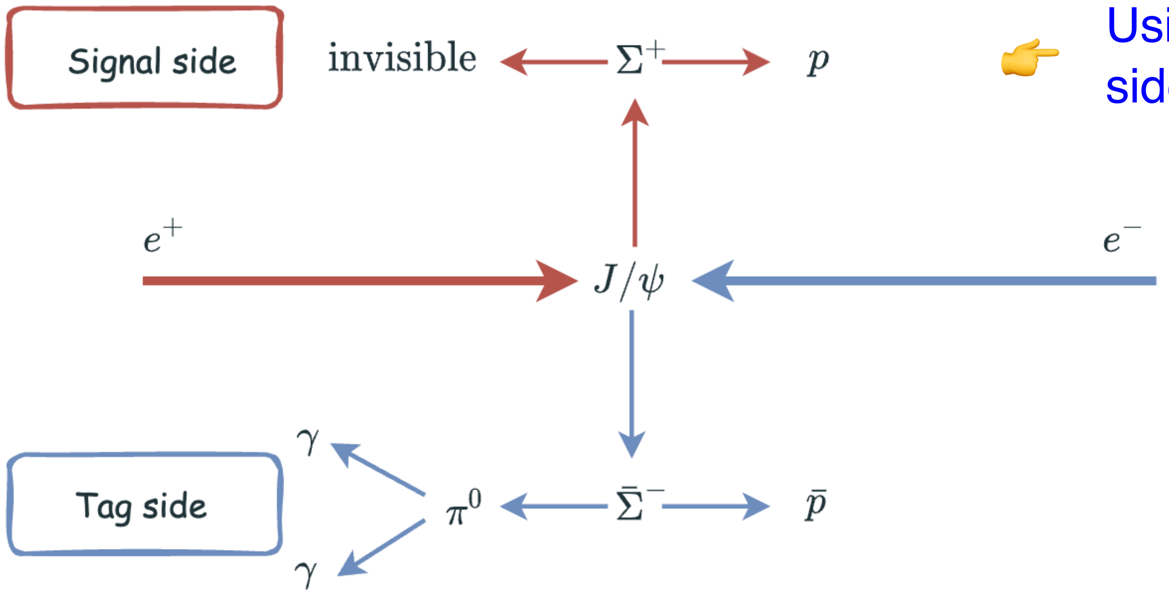
$$\Gamma(\Sigma^+ \rightarrow pa) = \frac{M_{\Sigma^+}^3}{16\pi}\left(1-\frac{M_p^2}{M_{\Sigma^+}^2}\right)^3\left(\frac{(-1)^2}{|F_{sd}^V|^2}+\frac{0.34^2}{|F_{sd}^A|^2}\right)$$

Our measurement can set limits on axion-fermion effective decay constants

Analysis strategy

- 10B J/ψ events, $J/\psi \to \Sigma\bar{\Sigma}$ ($\sim 10^7 \Sigma^+ \bar{\Sigma}^-$ pairs), double tag method

Kinematic fit to constraint the invisible axion mass to **zero**

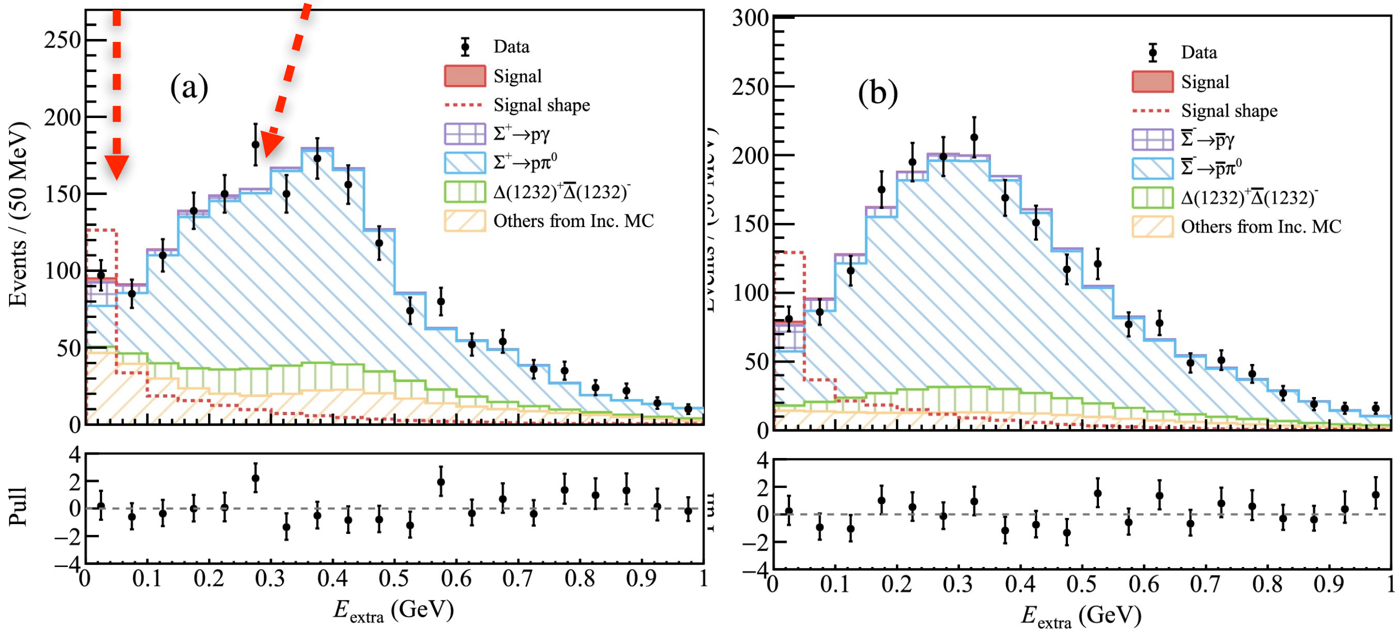


👉 Using the deposited energy except for those from tag side π^0 in EMC to identify the invisible signal

Signal extraction

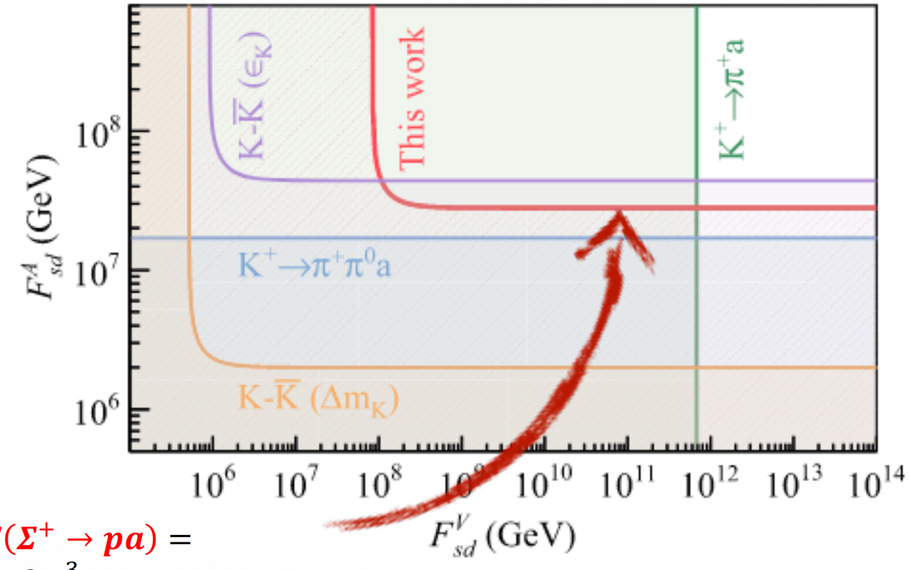
Background modeled with MC simulation, such as $\Sigma^+ \to p\pi^0$

Invisible Signal peaks around zero



BF($\Sigma^+ \to p$+invisible) < 3.2×10^{-5} @ 90% CL.

- Our result lies below the maximum BF allowed for $\Sigma^+ \to p$+invisible in certain scenarios, under the hypothesis of massless γ'
  $\to 3.8 \times 10^{-5}$ Phys. Rev. D 101, 035044 (2020
- Competitive limit on the axial-vectorial part of axion-fermion effective decay constant F^A_{sd} :
  $\to F^A_{sd} > 2.8 \times 10^7$ GeV



$$\Gamma(\Sigma^+ \to pa) = \frac{M^3_{\Sigma^+}}{16\pi}\left(1 - \frac{M_p^2}{M^2_{\Sigma^+}}\right)^3 \left(\frac{(-1)^2}{|F^V_{sd}|^2} + \frac{0.34^2}{|F^A_{sd}|^2}\right)$$

See talks by Anna Marini

Muon-philic particle

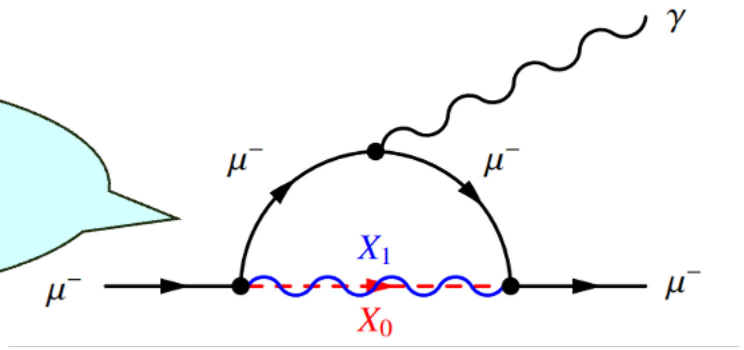
Muon-philic particle

Phys.Rev.D 109 (2024) 3, L031102

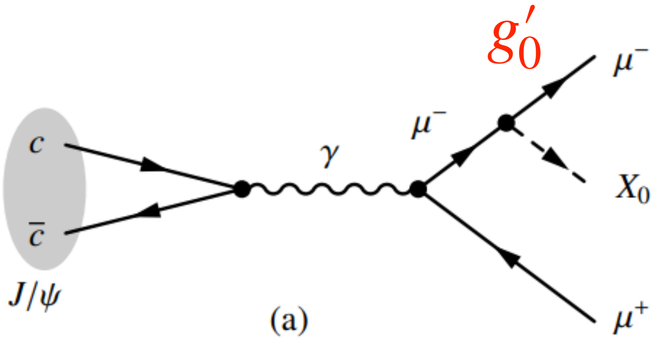
- $U(1)_{L_\mu - L_\tau}$ model : a new massive vector boson X_1 or scalar boson X_0 **only couple to the second or third generations of leptons** $(\mu, \nu_\mu, \tau, \nu_\tau)$ with the coupling strength g_1', g_0'

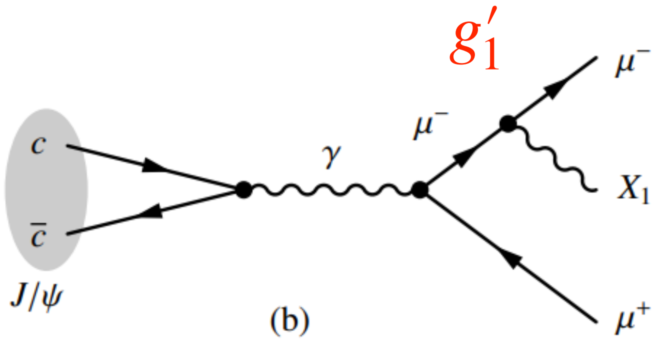
$$\mathcal{L}_\mu^{\text{scalar}} = -g_0\, X_0\, \overline{\mu}\, \mu,$$
$$\mathcal{L}_\mu^{\text{vector}} = -g_1\, X_{1\alpha}\, \overline{\mu}\, \gamma^\alpha\, \mu.$$

explain $(g-2)_\mu$ anomaly



- **The main muon source at BESIII: $J/\psi \to \mu^+\mu^-$**
- **Search for $J/\psi \to \mu^+\mu^- X_{0,1}$** → **Invisible $X_{0,1}$ at this time**

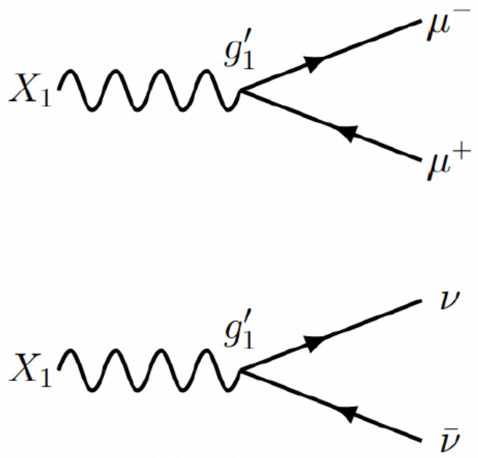




JHEP10(2020)207

Three cases of muon-philic particles

"vanilla" $L_\mu - L_\tau$ model

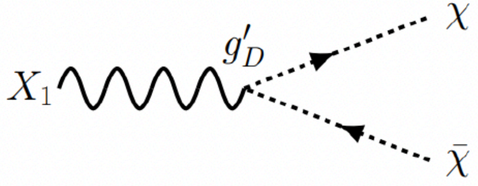


Large mass of dark matter kind:

$m_\chi > m_{\chi_1}/2$

- $\mathscr{B}(X_1 \to \nu\bar{\nu}) = 33 \sim 100\,\%$ with different m_{χ_1}

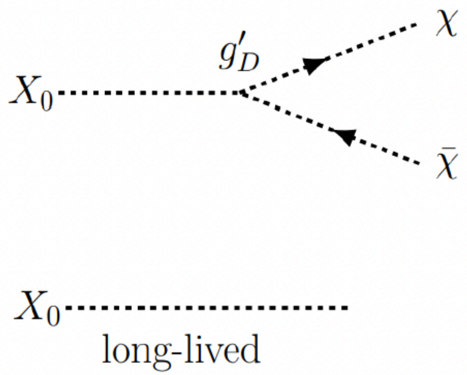
"invisible" $L_\mu - L_\tau$ model



Light dark matter kind $m_\chi < m_{X_1}/2$

- $g_{D'} \gg g_{1'}$
- $\mathscr{B}(X_1 \to \chi\chi) \sim 100\,\%$

"scalar" $U(1)$ model



- Assume the X_0 is long lived or only decay to invisible final states

Search for X_0, X_1 via $J/\psi \to \mu^+\mu^- X_{0,1}$ with $X_{0,1}$ is invisible

Recoil mass spectrum of $J/\psi \to \mu^+\mu^- X_{0,1}$

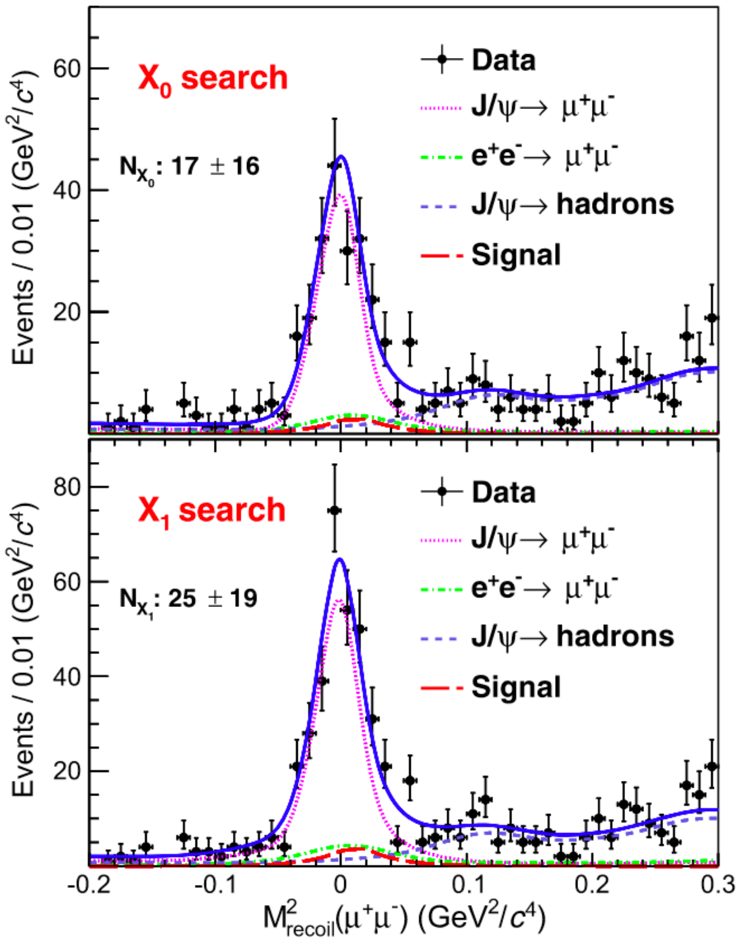
- Data samples: **9B** J/ψ events

58 different $X_{0,1}$ mass values, ranging from 1 to 1000 MeV/c^2, in step of 10~20MeV/c^2

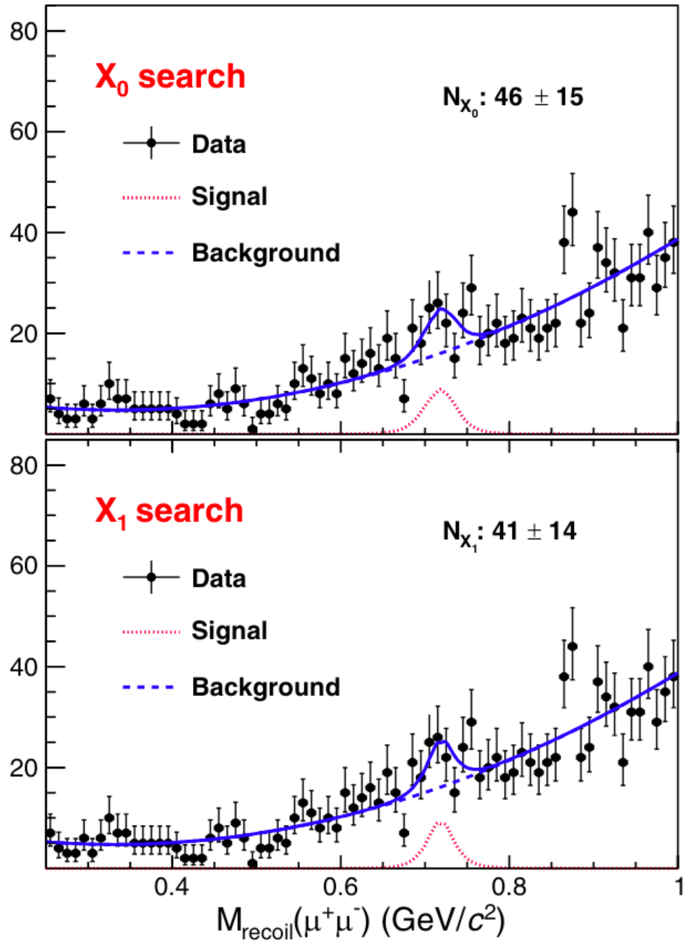
No evidence for $J/\psi \to \mu^+\mu^- + X_{0,1}$ signals

- **The maximum local significance is** 2.5σ at $M(X_{0,1}) = 720\ \mathrm{MeV}/c^2$

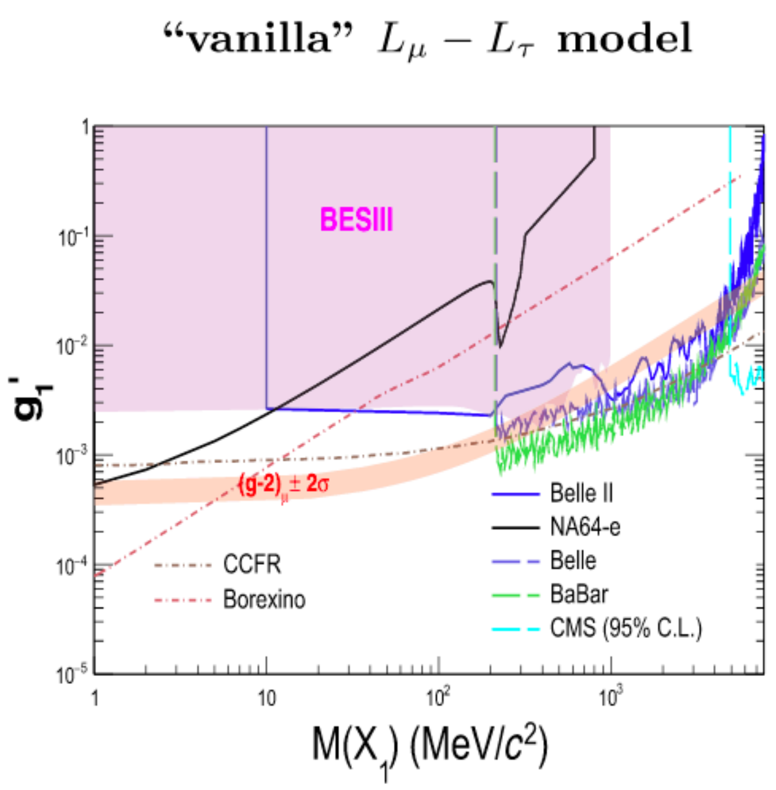
Low mass region, with $M(X_{0,1}) = 120\mathrm{MeV}/c^2$

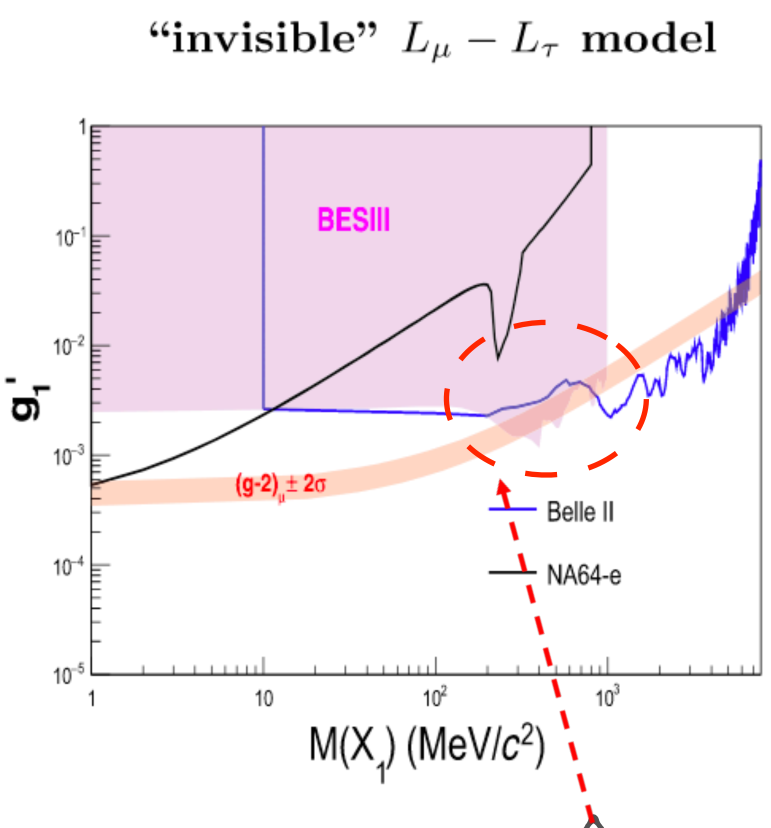


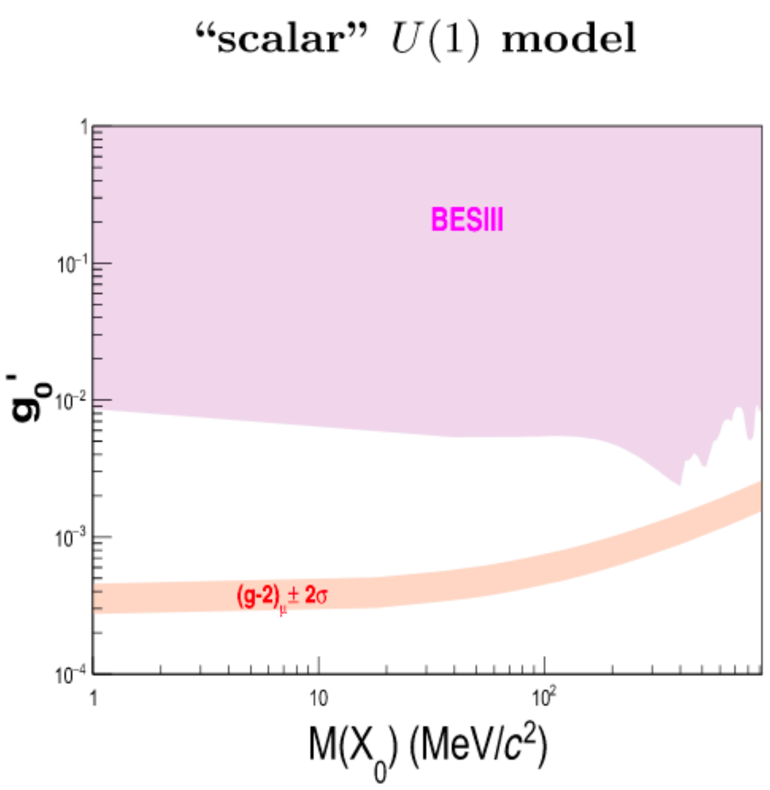
High mass region, with $M(X_{0,1}) = 720\mathrm{MeV}/c^2$



Coupling constraint







BarBar, CMS, Belle : $X_1 \to \mu^+\mu^-$
BelleII and BESIII: $X_1 \to \nu\bar{\nu}$
(Taking $\mathscr{B}(X_1 \to \nu\bar{\nu})$) into account)

Better sensitivity in the range 200–860 MeV$/c^2$ is obtained

First constraint for the "scalar" invisible X_0 case .

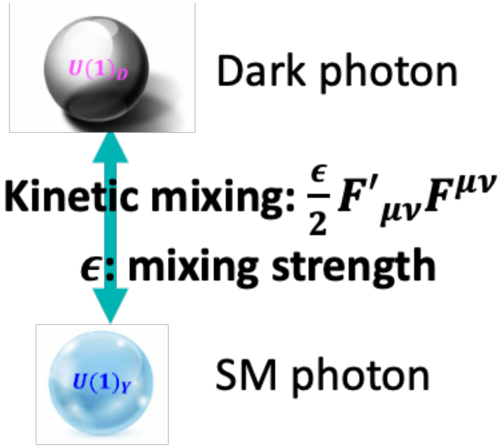
Belle II can also give the constraint

Dark photon in $D^0 \to \omega\gamma', \gamma\gamma'$

Massless Dark photon

See talks by Fernando Arias Aragon

- A minimal extension to SM, $U(1)_D$, causing the associated spin-one boson, the dark photon



- Massive γ', if the symmetry is spontaneously **broken**
- Massless γ', if the symmetry is **unbroken** This work

👉 Only couple to SM particles through operators of higher dimension

PRL 94, 151802 (2005)

Dimension-**six** operator

$$\mathcal{L}_{NP} = \frac{1}{\Lambda_{NP}^2}\left(C_{jk}^{U}\bar{q}_j\sigma^{\mu\nu}u_k\tilde{H} + C_{jk}^{D}\bar{q}_j\sigma^{\mu\nu}d_k H + C_{jk}^{L}\bar{l}_j\sigma^{\mu\nu}e_k H + h.c.\right)\bar{F}_{\mu\nu}$$

Up type quarks coupling | Down type quarks coupling | Charged leptons coupling | Massless dark photon

Experimental search:
- $H \to \gamma\gamma'$
- $\mu \to e\gamma'$
- $\Lambda_c^+ \to p\gamma'$

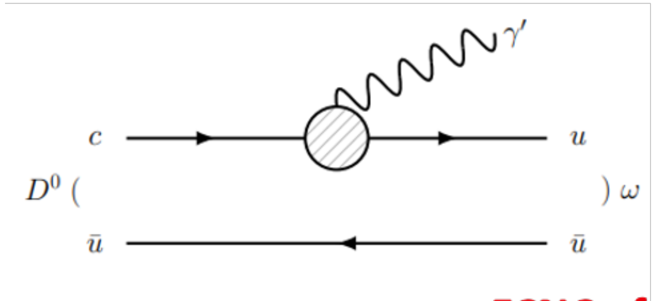
•No signal observed

Slides from Zhijun Li @Hadron2025

Search for $D^0 \to \omega\gamma'$ and $D^0 \to \gamma\gamma'$

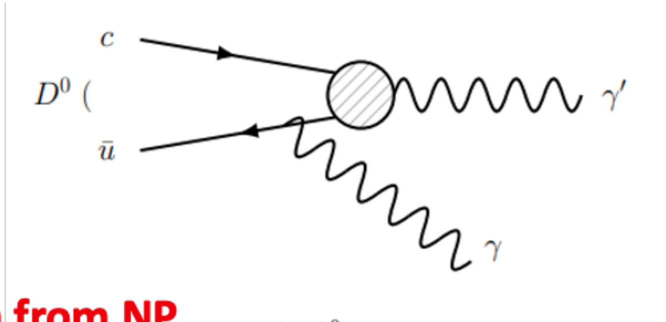
Phys.Rev.D 111 (2025) 1, L011103

- Double tag method: $\sim 6 \times 10^6$ $D^0(\bar{D}^0)$ are tagged with 7.9fb^{-1}data @3.77 GeV
- The massless dark photon is invisible

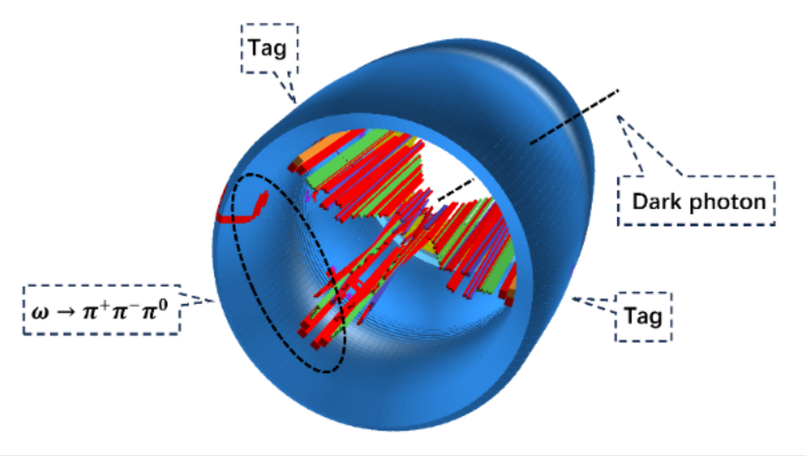


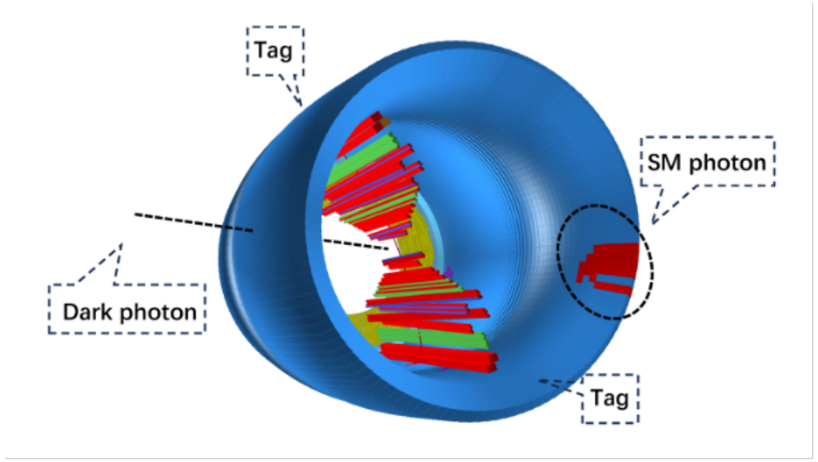
(a) $D^0 \to \omega\gamma'$

FCNC of charm from NP

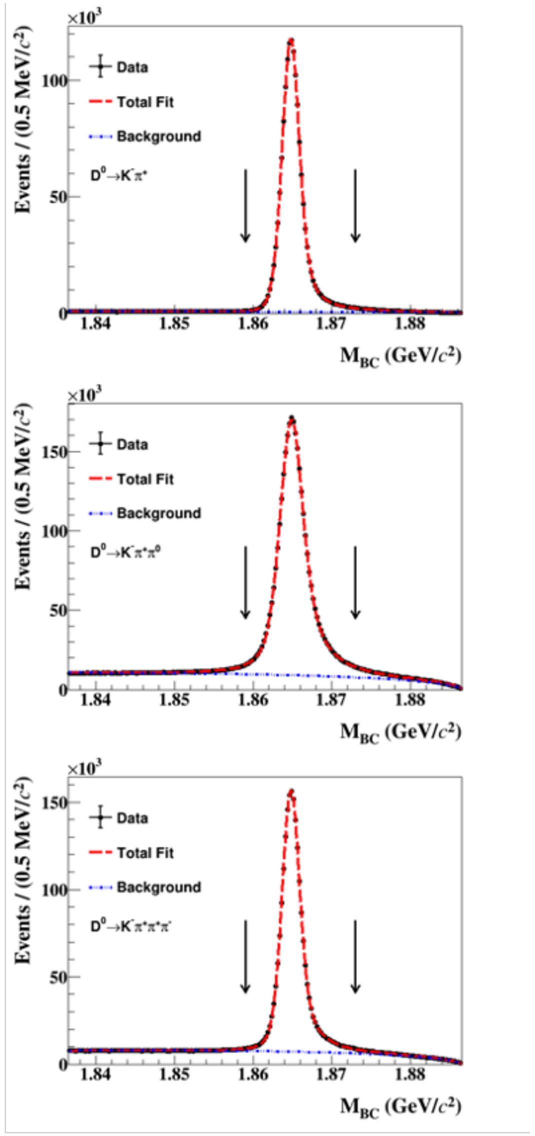


(b) $D^0 \to \gamma\gamma'$



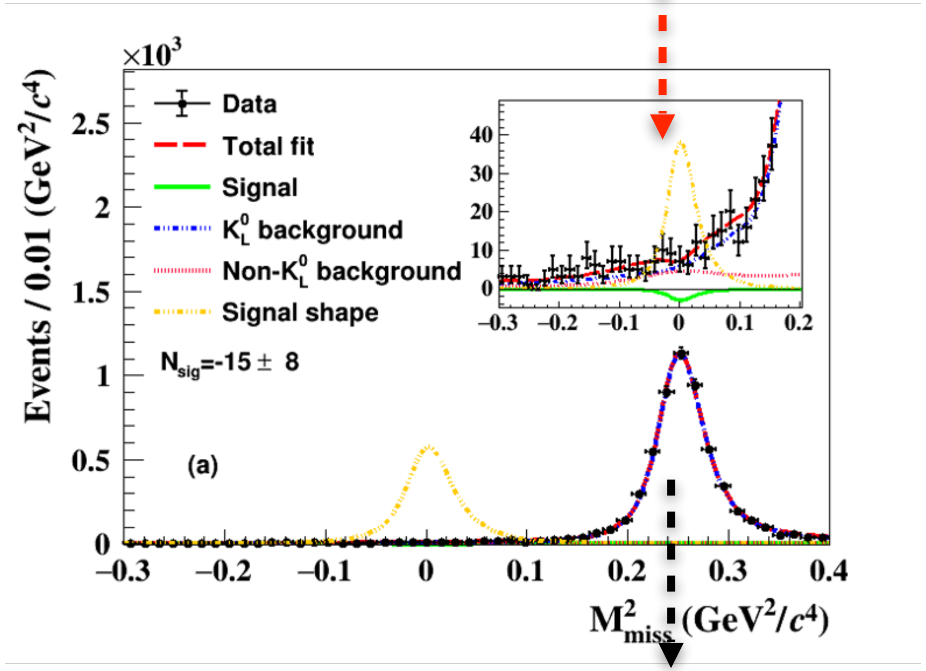


Tag



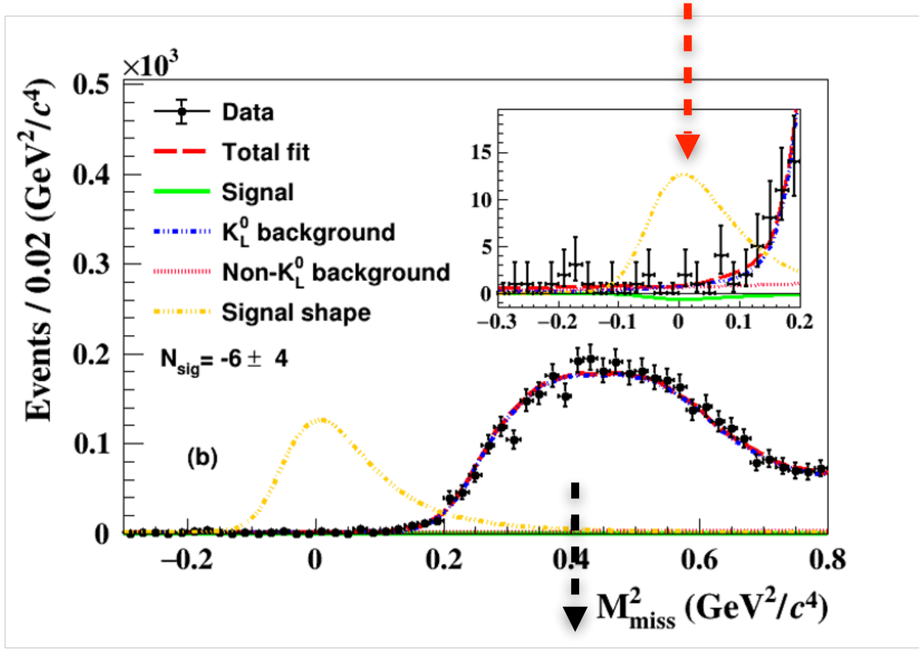
Signal extraction

Signal peaks around zero



$D^0 \to \omega K_L^0$ background

Signal peaks around zero



$D^0 \to \pi^0 K_L^0$ background

Signal extraction of $D^0 \to \omega\gamma'$

Signal extraction of $D^0 \to \gamma\gamma'$

Coupling constraint

This work

$$\mathcal{B}(D \to V\gamma') = \frac{\tau_D f_{DV}^2 (m_D^2 - m_V^2)^3}{2\pi m_D^3}(|\mathbb{C}|^2 + |\mathbb{C}_5|^2)$$

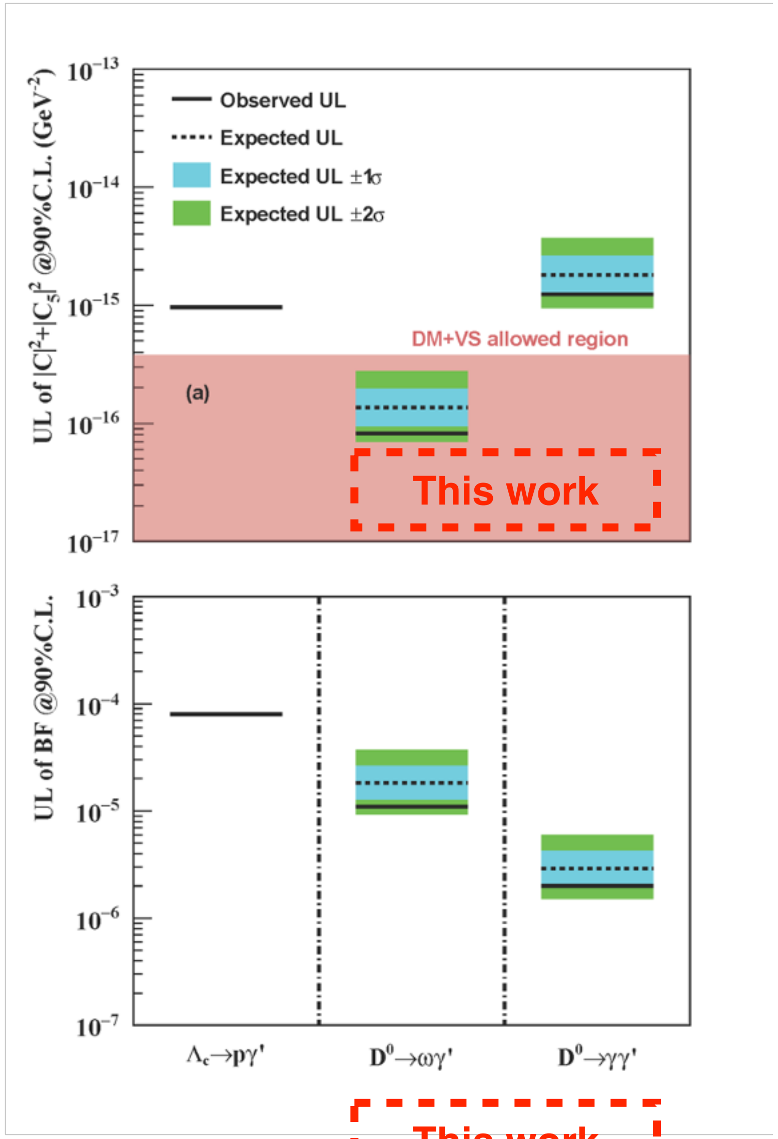
$$\mathcal{B}(D \to \gamma\gamma') = \frac{\alpha_e}{2}\tau_D f_{D\gamma}^2 m_D^3(|\mathbb{C}|^2 + |\mathbb{C}_5|^2)$$

Previous BESIII work

$$\mathcal{B}(\Lambda_c \to p\gamma') = \frac{\tau_{\Lambda_c} f_{\Lambda_c p}^2 (m_{\Lambda_c}^2 - m_p^2)^3}{2\pi m_{\Lambda_c}^3}(|\mathbb{C}|^2 + |\mathbb{C}_5|^2)$$

- $\mathbb{C} = \Lambda_{NP}^{-2}(C_{12}^U + C_{21}^{U*})v/\sqrt{8}$
- $\mathbb{C}_5 = \Lambda_{NP}^{-2}(C_{12}^U - C_{21}^{U*})v/\sqrt{8}$

The constraint from $D^0 \to \omega\gamma'$ goes into the dark matter (DM) and vacuum stability (VS) allowed region for the first time, **improved by more than 1 order**



This work

More recent results on LDM search…

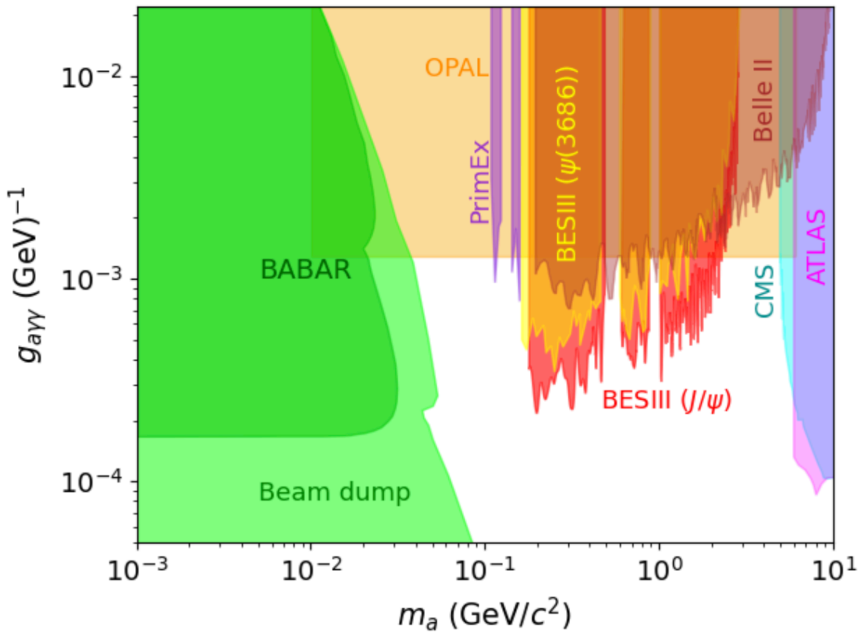
- **ALP** in $J/\psi \to \gamma a, a \to \gamma\gamma$

✓ Using 2.7B $\psi(3686)$ data — PLB 838 137698 (2023)

✓ Using 10B J/ψ data — PRD.110.L 031101 (2024)

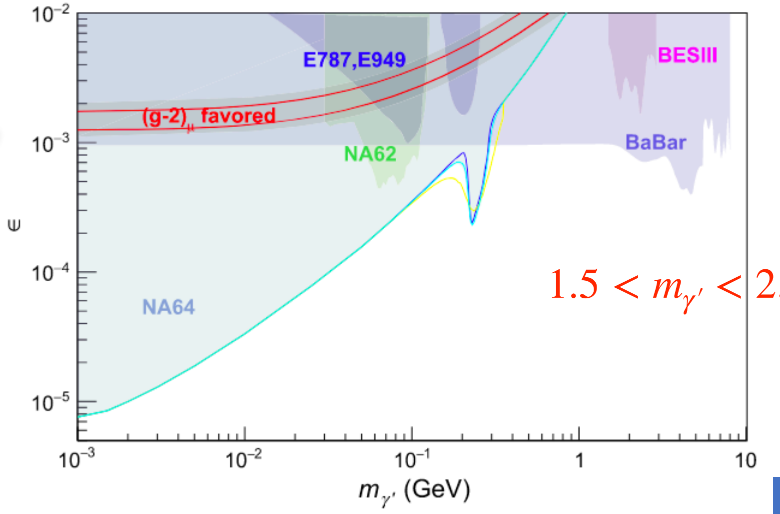
Most stringent constraints to date for $0.18 < m_a < 2.85\ \mathrm{GeV}/c^2$

ALPs-photon Coupling



- Search for **massive dark photon** with $e^+e^- \to \gamma\gamma'$

PLB 839 (2023) 137785



$1.5 < m_{\gamma'} < 2.9\mathrm{GeV}$

Summary

➡New results of K_S^0 (Σ^+) **invisible decay, muonphilic particle, dark photon, ALP** at BESIII

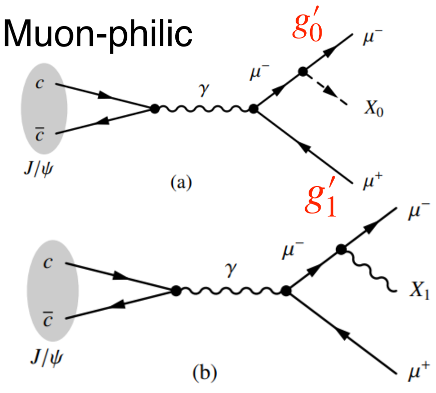
➡No evidence and more stringent constraint on NP

➡BESIII has collected $10^{10} J/\psi$, $2.7 \times 10^9 \psi$, $20\ \mathrm{fb}^{-1} \psi(3770)$ and more

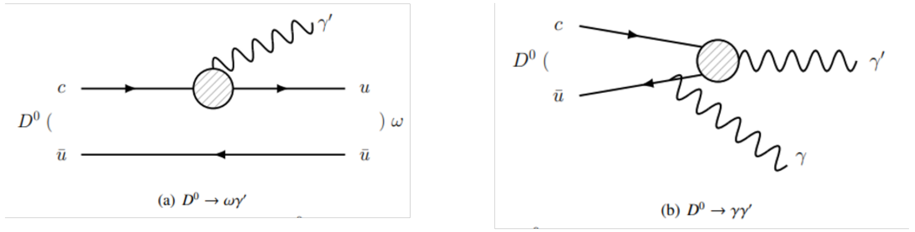
➡More & better results are coming soon

Thanks you!

Muon-philic



massless-γ'

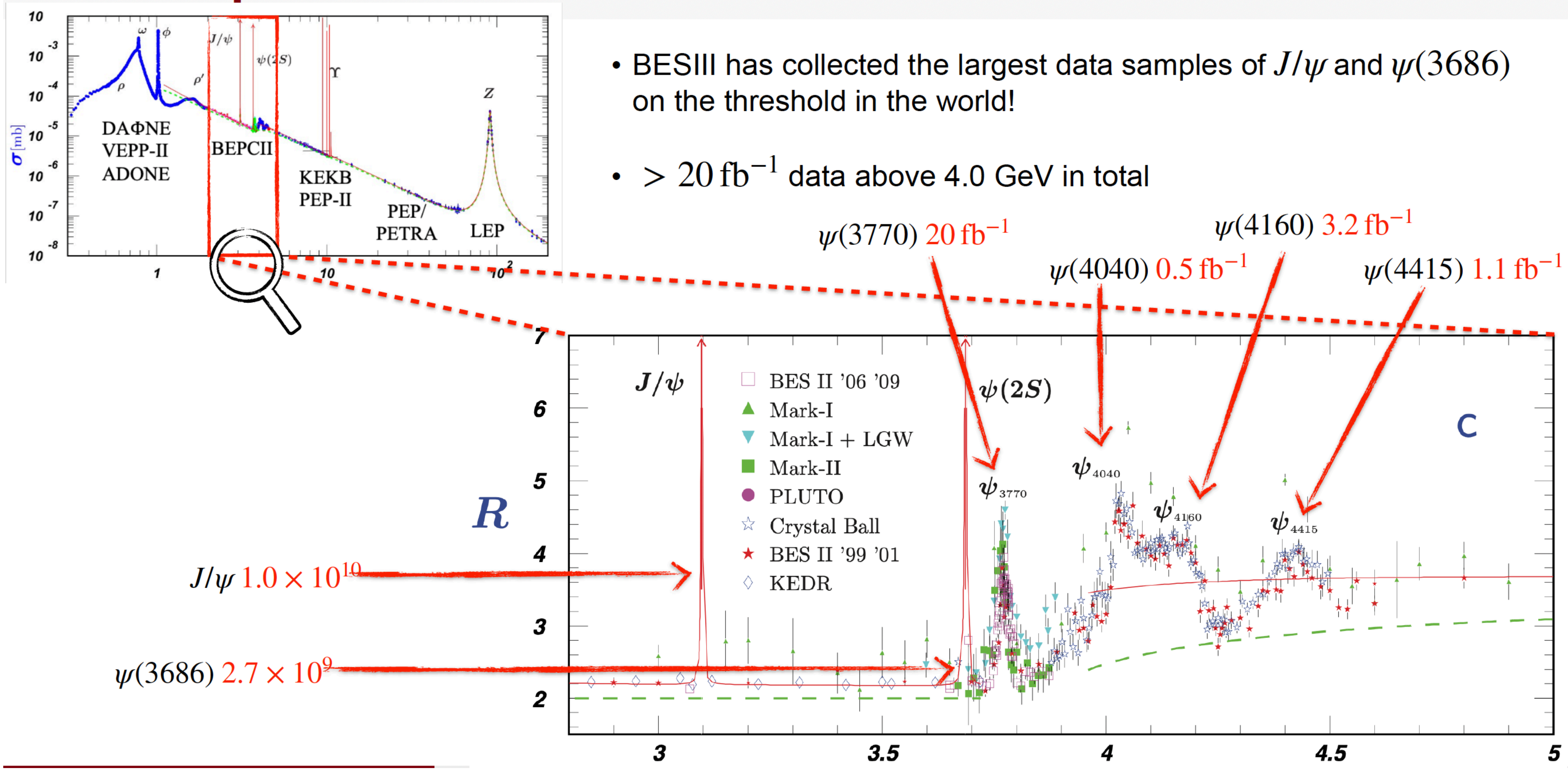


Thanks for your attention!

Back UP

Data samples at BESIII

- BESIII has collected the largest data samples of J/ψ and $\psi(3686)$ on the threshold in the world!
- $> 20\ \mathrm{fb}^{-1}$ data above 4.0 GeV in total



Massless dark photon

Massive dark photon

Symmetry broken spontaneously

Dark photon

Kinetic mixing: $\frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}$

ϵ: mixing strength

SM photon

Massless dark photon

Symmetry remains unbroken

PRL 94, 151802 (2005)

$$A^{\mu} \to A^{\mu} + \epsilon A'^{\mu}$$

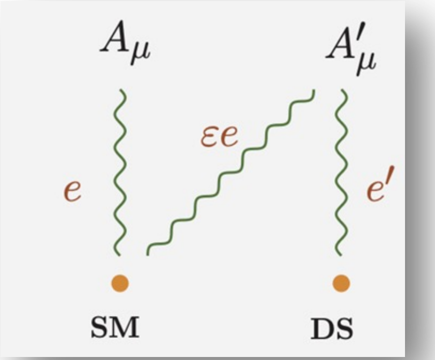
$$\mathcal{L} = eJ_{\mu}A^{\mu} + \underline{e\epsilon J_{\mu}A'^{\mu}} + e'J'_{\mu}A'^{\mu}$$

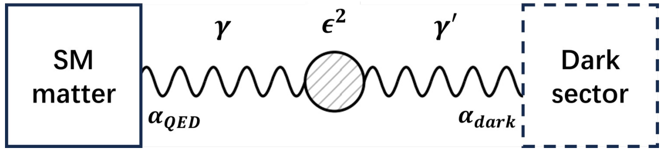
- **Dark photon couples to the SM matter**

$$A'^{\mu} \to A'^{\mu} + \epsilon A^{\mu}$$

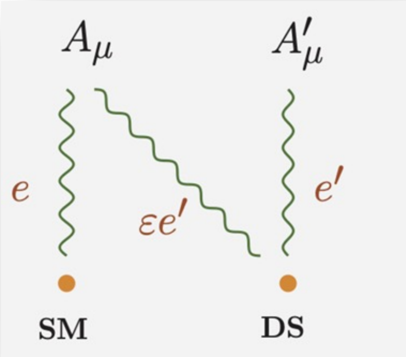
$$\mathcal{L} = eJ_{\mu}A^{\mu} + \underline{e'\epsilon J'_{\mu}A^{\mu}} + e'J'_{\mu}A'^{\mu}$$

- **SM photon couples to the dark sector particles**





A portal to connect the SM matter and the dark sector



Massless dark photon has no interaction with the SM matter in the dimension-4 operator

arXiv:2005.01515

The interaction of γ'

$\boldsymbol{\mathcal{L} = eJ_\mu A^\mu + e'\epsilon J'_\mu A^\mu + e'J'_\mu A'^\mu}$ (no interaction between γ' and SM matter)

PRL 94, 151802 (2005)

$$\mathcal{L}_{NP} = \frac{1}{\Lambda_{NP}^2}\left(C_{jk}^U \bar{q}_j \sigma^{\mu\nu} u_k \tilde{H} + C_{jk}^D \bar{q}_j \sigma^{\mu\nu} d_k H + C_{jk}^L \bar{l}_j \sigma^{\mu\nu} e_k H + h.c.\right)\bar{F}_{\mu\nu}$$

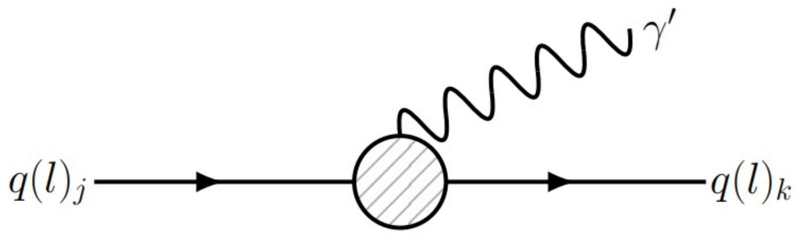
Dimension-six operator

Up type quarks coupling

Down type quarks coupling

Charged leptons coupling

Massless dark photon



Experimental search:

- $H \to \gamma\gamma'$
- $\mu \to e\gamma'$
- $\Lambda_c^+ \to p\gamma'$

- **No signal observed**
- **The sensitivity still lie outside the theoretically predicted allowed region**

Decay width of $J/\psi \to \mu^+\mu^- X$

Probing new physics scenarios of muon g – 2 via J/ψ decay at BESII

J. High Energy Phys. 10 (2020) 207

$$
\begin{aligned}
|\mathcal{M}_{\mu\mu X_0}|^2 = \left(\frac{2}{3}e^2\, g_0\, \frac{f_J}{m_J}\right)^2 \frac{-8}{3\, m_J^2(m_J - 2\, E_-)^2(-2\, E_- - 2\, E_X + m_J)^2}\Big(&- 4\, m_\mu^2\Big(4\, E_-^2 \left(m_X^2 - 2\, E_X\, m_J\right) \\
+E_- \left(-8\, E_X^2\, m_J + 4\, E_X \left(m_X^2 + 2\, m_J^2\right) - 4\, m_X^2\, m_J\right) - E_X^2 \left(m_X^2 - 6\, m_J^2\right) - 2\, E_X\, m_J \left(m_X^2 + m_J^2\right) + m_X^2 m_J^2\Big) & \\
+4\, E_-^2\Big(2\, E_X^2\, m_J^2 + m_X^2\, m_J(m_J - 2\, E_X) + m_X^4\Big) & \\
+4\, E_-\Big(2\, E_X^3\, m_J^2 - 2\, E_X^2\, m_J \left(m_X^2 + m_J^2\right) + E_X \left(m_X^4 + 3\, m_X^2\, m_J^2\right) - m_X^2\, m_J \left(m_X^2 + m_J^2\right)\Big) & \\
-16\, E_X^2\, m_\mu^4 + m_J\Big(- 4\, E_X^3\, m_J^2 + 2\, E_X^2 \left(3\, m_X^2\, m_J + m_J^3\right) - 2\, E_X \left(m_X^4 + 2\, m_X^2\, m_J^2\right) + m_X^2\, m_J \left(m_X^2 + m_J^2\right)\Big)\Big), &
\end{aligned}
$$

where E_-, the energy of μ^- and E_X, the energy of X_0 are measured in the rest frame of J/ψ.

$$
\Gamma_{\mu\mu X_{0,1}} = \int_{E_X^{min}}^{E_X^{max}} \int_{E_-^{min}}^{E_-^{max}} \frac{|\mathcal{M}_{\mu\mu X_{0,1}}|^2}{64\pi^3 m_J} dE_- dE_X,
$$

$$
\begin{aligned}
|\mathcal{M}_{\mu\mu X_1}|^2 = \left(\frac{2}{3}e^2\, g_1\, \frac{f_J}{m_J}\right)^2 \frac{-16}{3\, m_J^2(m_J - 2\, E_-)^2(-2\, E_- - 2\, E_X + m_J)^2}\Big(&16\, E_-^4\, m_J^2 + 32\, E_-^3\, m_J^2(E_X - m_J) \\
+2m_\mu^2\Big(4\, E_-^2 \left(m_J(m_J - 2\, E_X) + m_X^2\right) - 4\, E_- \left(2\, E_X^2\, m_J - E_X \left(m_X^2 + 3\, m_J^2\right) + m_J \left(m_X^2 + m_J^2\right)\right) & \\
+2\, E_X^2 \left(m_X^2 + 3\, m_J^2\right) - 2\, E_X\, m_J \left(m_X^2 + 2\, m_J^2\right) + m_J^2 \left(m_X^2 + m_J^2\right)\Big) & \\
+4\, E_-^2 \left(m_J^2 \left(6\, E_X^2 - 14\, E_X\, m_J + 7\, m_J^2\right) + m_X^2\, m_J(3\, m_J - 2\, E_X) + m_X^4\right) & \\
+4\, E_- \left(2\, E_X^3\, m_J^2 - 2\, E_X^2\, m_J \left(m_X^2 + 4\, m_J^2\right) + E_X \left(m_X^4 + 5\, m_X^2\, m_J^2 + 9\, m_J^4\right) - m_J \left(m_X^4 + 3\, m_X^2\, m_J^2 + 3\, m_J^4\right)\right) & \\
+8\, E_X^2\, m_\mu^4 + m_J \left(-4\, E_X^3\, m_J^2 + 2\, E_X^2 \left(3\, m_X^2\, m_J + 5\, m_J^3\right) - 2\, E_X \left(m_X^2 + 2\, m_J^2\right)^2 + m_J \left(m_X^4 + 3\, m_X^2\, m_J^2 + 2\, m_J^4\right)\right)\Big), &
\end{aligned}
$$

where E_-, the energy of μ^- and E_X, the energy of X_0 are measured in the rest frame of J/ψ.

$K_S^0 \to$ invisible: Strategy

Signal sample

- $J/\psi \to \phi K_S^0(\text{tag})K_S^0, \quad K_S^0(\text{tag}) \to \pi^+\pi^-, K_S^0 \to \text{invisible}$

$$N_{\text{signal}} = 2 \times N_{J/\psi\to\phi K_S^0 K_S^0} \times \mathcal{B}(\phi \to K^+K^-) \times \mathcal{B}(K_S^0 \to \pi^+\pi^-) \times \mathcal{B}(K_S^0 \to \text{invisible}) \times \varepsilon_{\text{signal}}, \tag{3.2}$$

Normalization sample

- $J/\psi \to \phi K_S^0(\text{tag})K_S^0, \quad K_S^0(\text{tag}) \to \pi^+\pi^-, K_S^0 \to \text{non}-\pi^+\pi^-$

$$N_{\text{norm.}} = 2 \times N_{J/\psi\to\phi K_S^0 K_S^0} \times \mathcal{B}(\phi \to K^+K^-) \times \mathcal{B}(K_S^0 \to \pi^+\pi^-) \times (1 - \mathcal{B}(K_S^0 \to \pi^+\pi^-)) \times \varepsilon_{\text{norm.}}, \tag{3.1}$$

$$\mathcal{B}(K_S^0 \to \text{invisible}) = \frac{N_{\text{signal}}}{N_{\text{norm.}}\,(\varepsilon_{\text{signal}}/\varepsilon_{\text{norm.}})}(1 - \mathcal{B}(K_S^0 \to \pi^+\pi^-)).$$

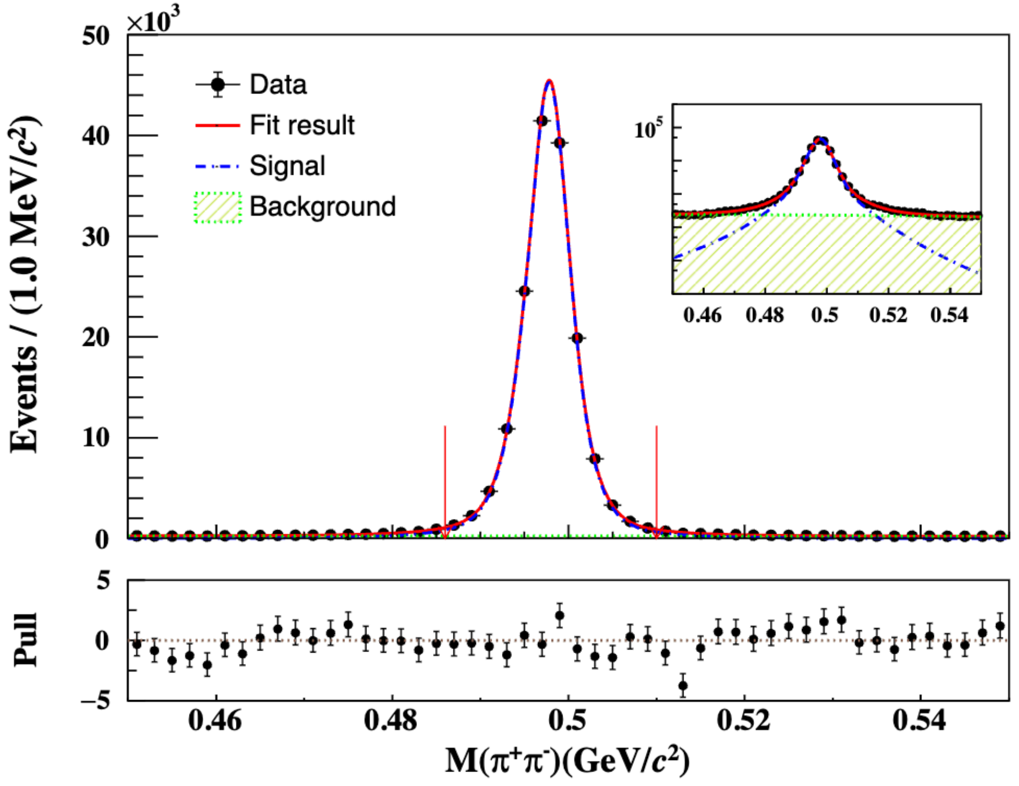
$K_S^0 \to$ invisible: Strategy

Normalization sample

- $J/\psi \to \phi K_S^0(\mathrm{tag})\mathrm{K_S^0}$, $\mathrm{K_S^0}(\mathrm{tag}) \to \pi^+\pi^-$, $K_S^0 \to \mathrm{non} - \pi^+\pi^-$

$$N_{\mathrm{norm.}} = 2 \times N_{J/\psi\to\phi K_S^0 K_S^0} \times \mathcal{B}(\phi \to K^+K^-) \times \mathcal{B}(K_S^0 \to \pi^+\pi^-)$$
$$\times (1 - \mathcal{B}(K_S^0 \to \pi^+\pi^-)) \times \varepsilon_{\mathrm{norm.}},$$

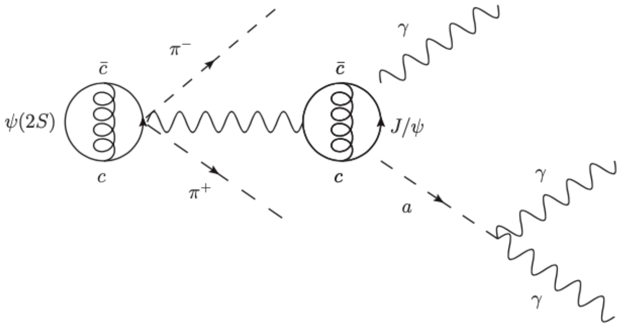
Fit to $M(\pi^+\pi^-)$ to extract the yields for normalization sample



Search for an axion-like particle in radiative J/ψ decays

PLB 838 137698 (2023)

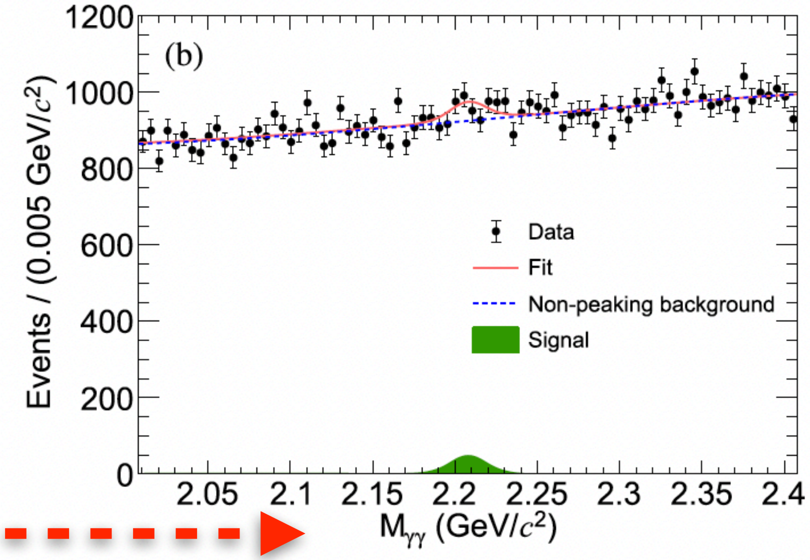
- Data samples: 2.7B $\psi(3686)$ events
- Strategy: Search for $J/\psi \to \gamma a, a \to \gamma\gamma$ with J/ψ sample obtained from $\psi(3686) \to \pi^+\pi^- J/\psi$
  - $\psi(3686)$ decay: avoid the pollution from non-resonant production $e^+e^- \to \gamma\gamma\gamma$



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

- Decay width of $a \to \gamma\gamma$: $\Gamma_a = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}$
- Taking $g_{a\gamma\gamma} \sim 10^{-4}$ GeV^{-1}, $m_a \sim$ GeV, the lifetime of ALP is short in the detector
  ➡ Assume BF($a \to \gamma\gamma$)~100%

- Three $\gamma\gamma$ combinations per event, **extract signal from $M_{\gamma\gamma}$ distribution**
  - 674 mass hypotheses



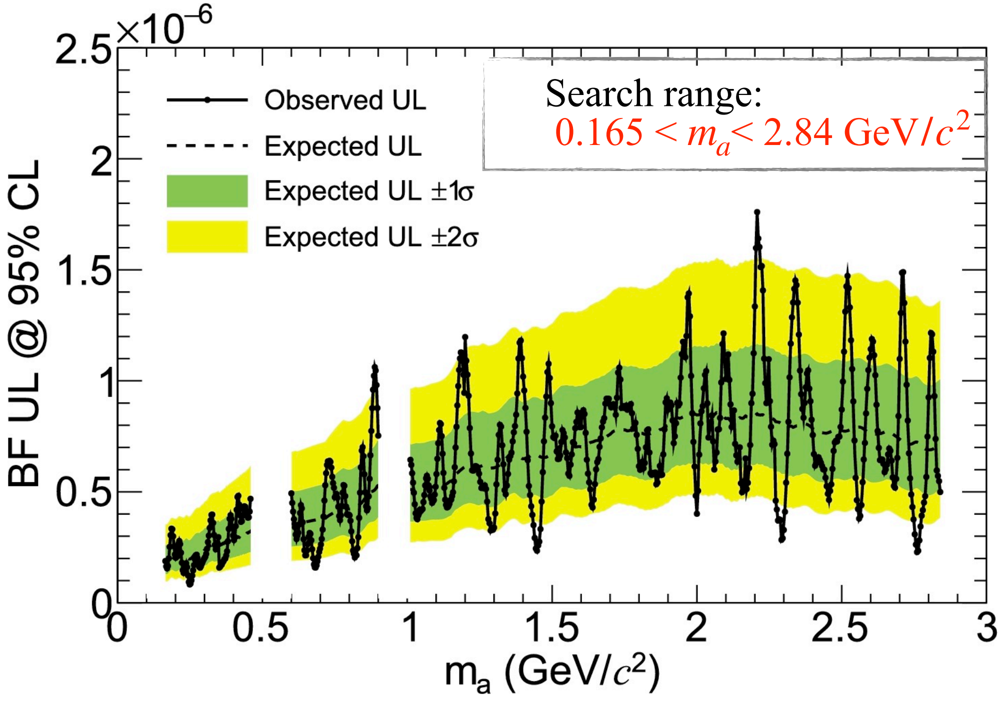
The maximum local significance is 2.6σ at m_a = 2208 MeV/c^2

Search for an axion-like particle in radiative J/ψ decays

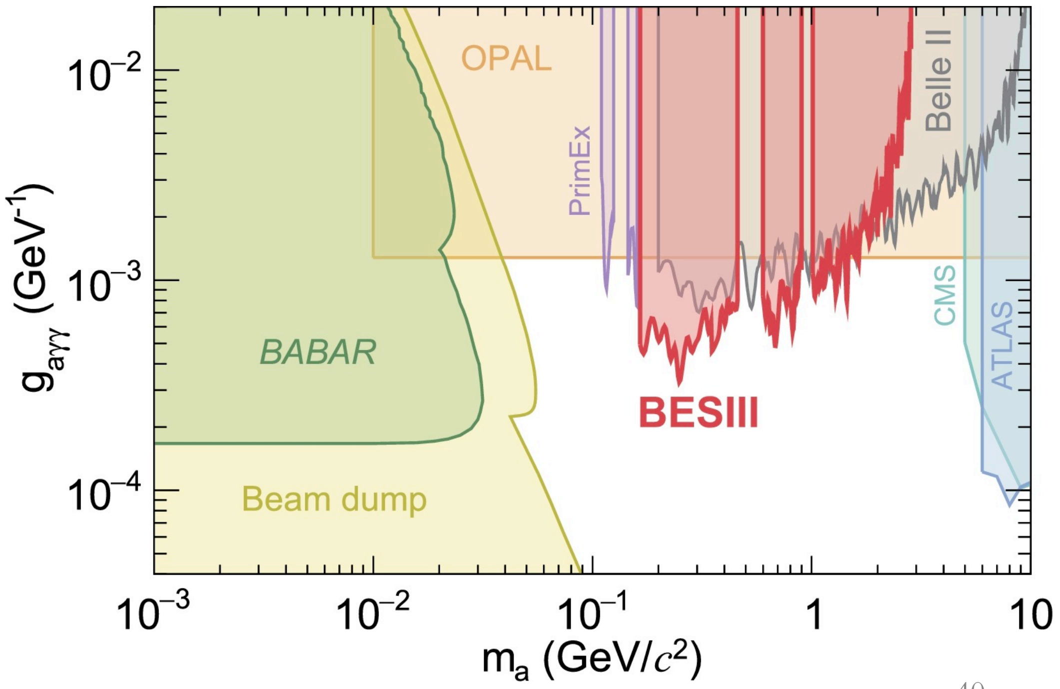
- No significant ALP signal is observed

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

BF @ 95% CL



ALPs-photon Coupling



Search for an axion-like particle in radiative J/ψ decays

arXiv:2404.04640

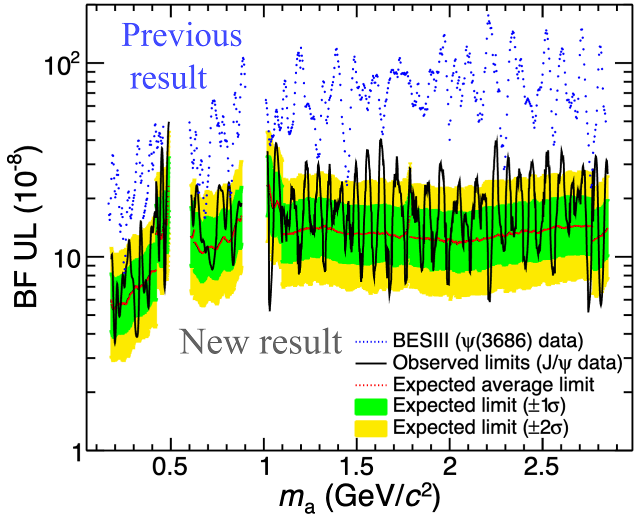
Accepted by Phys. Rev. D (Letter)

- **Data samples**: 10B J/ψ events

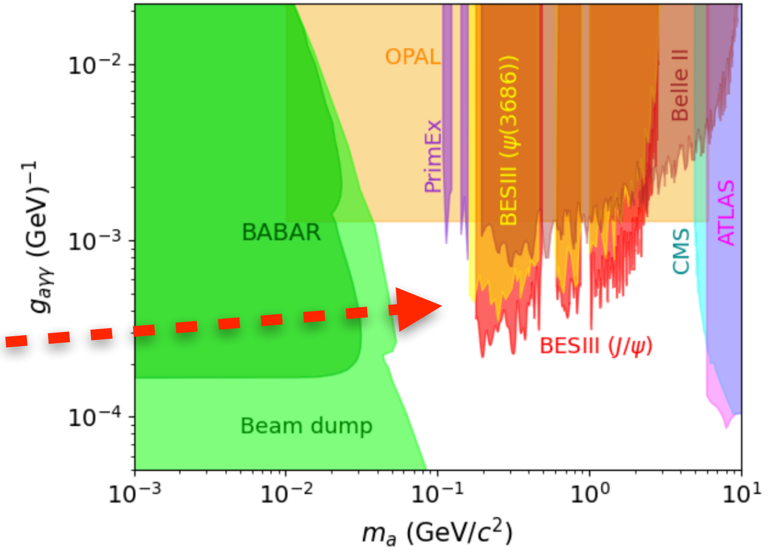
NEWEST RESULT!

- **Strategy:** Search for $J/\psi \to \gamma a, a \to \gamma\gamma$ with J/ψ data on threshold
    - Non-resonant process $e^+e^- \to \gamma a$ is indistinguishable from $J/\psi \to \gamma a$
        - The ratio, $\sigma_{non-res}/\sigma_{res}$ is calculated to be 4.4%
        - The contribution from $e^+e^- \to \gamma a$ is subtracted from the signal yields (interference between $\sigma_{non-res}$, σ_{res} is negligible).

✓ The 95% CL. upper limits of $\mathscr{B}(J/\psi \to \gamma a)$ is set based on 10B data

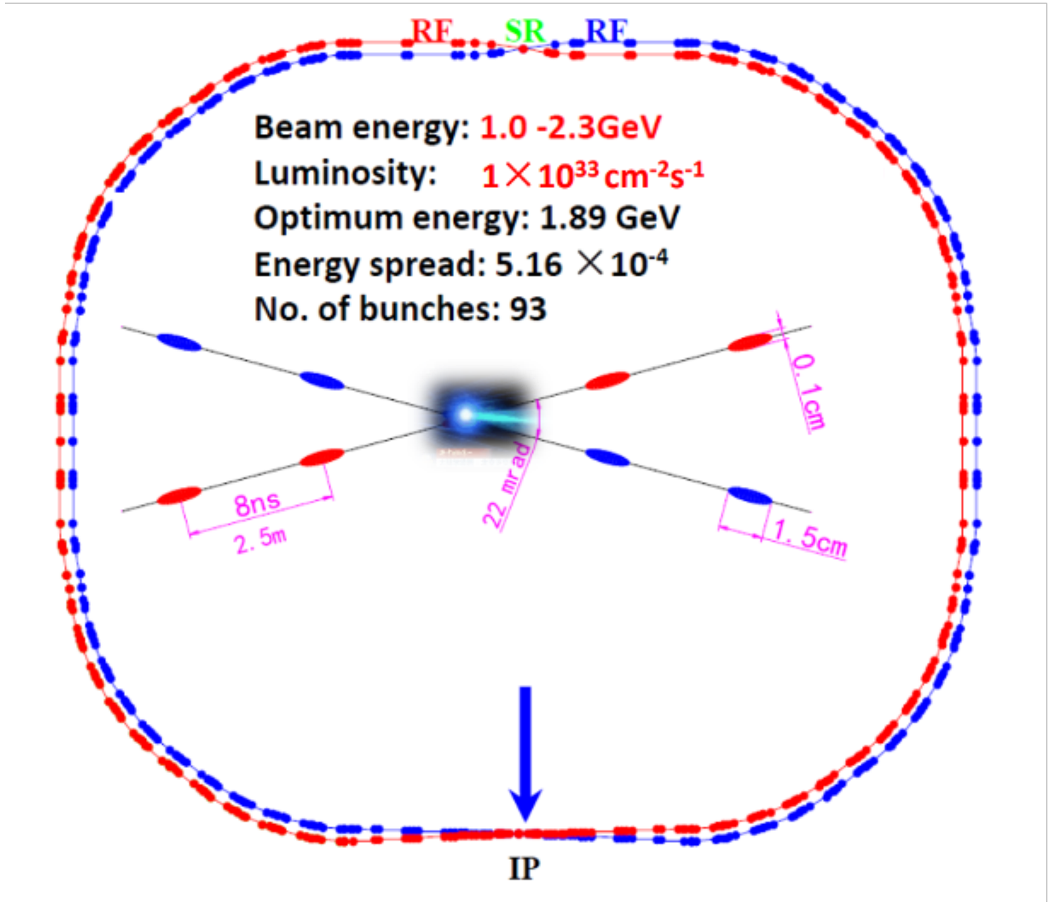


ALPs-photon Coupling



10B J/ψ

Most stringent constraints to date for $0.18 < m_a < 2.85$ GeV


RF
SR
RF
Beam energy: 1.0 -2.3GeV
Luminosity: $1 \times 10^{33}\,cm^{-2}s^{-1}$
Optimum energy: 1.89 GeV
Energy spread: 5.16×10^{-4}
No. of bunches: 93
0.1cm
8ns
2.5m
22 mrad
1.5cm
IP

Invisible decay of K_S^0

K_S^0

Invisible

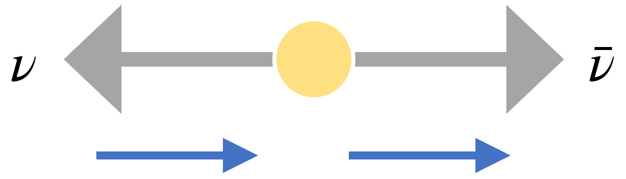
Phys.Rev.D 91 (2015) 1, 015004

SM decay

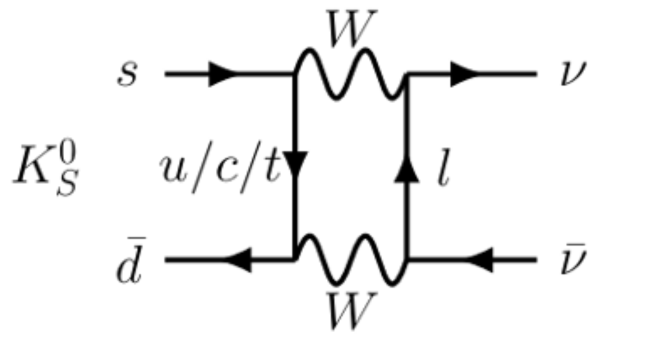
$K_S^0 \to \nu\bar{\nu}$

FCNC && helicity suppression, BF $< 10^{-16}$

$K_S^0 \to \nu\bar{\nu}$

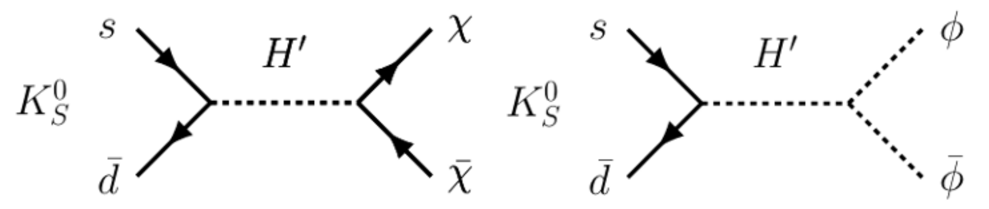


Initial state: S = 0
Final state: S=±1



Decay to DM

$K_S^0 \to \chi\bar{\chi}$



2HDM model
BF$\sim\mathcal{O}(10^{-6})$

Natural Sci.Rev. 1 (2024) 5