Search for dark sector at BESIII

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On behalf of the BESIII Collaboration
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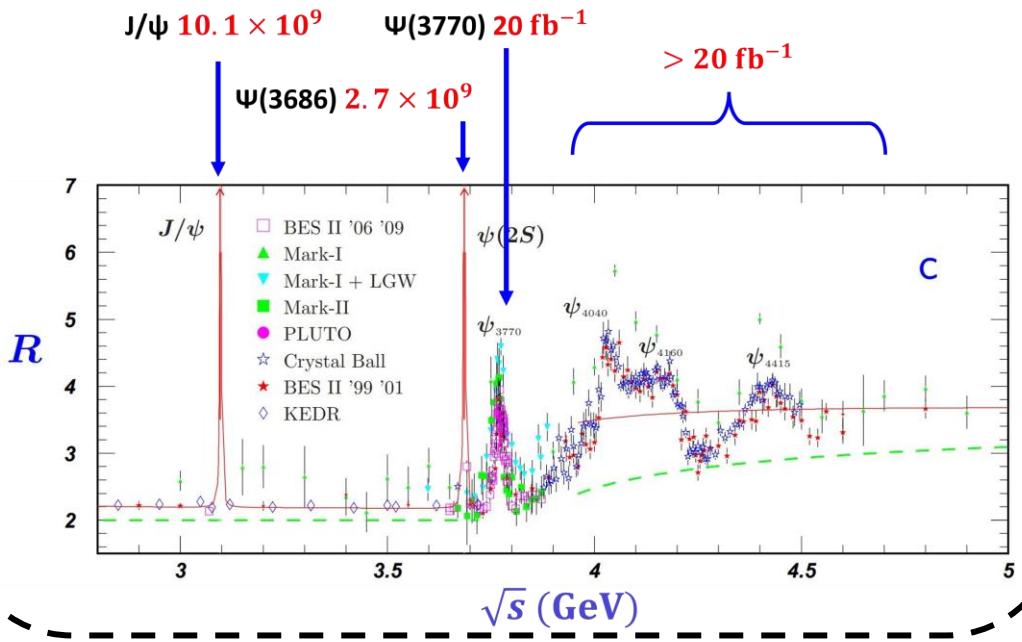
BESIII experiment



■ 10.1×10^9 J/ψ events

- Hyperon
- Light meson

Λ $\bar{\Lambda}$ η η'

$\Sigma^{0,+}$ $\bar{\Sigma}^{0,-}$ ~10^7 ϕ ω ~10^7

$\Xi^{0,-}$ $\bar{\Xi}^{0,+}$ K_S^0

■ 20 fb^{-1} $\psi(3770)$ ■ ……

D^0 $\bar{D}^0$ D^+ D^- ~10^7

- Wide range of physics with clean background
- Beneficial to search for dark sector

Dark sector search at BESIII (in recent years)

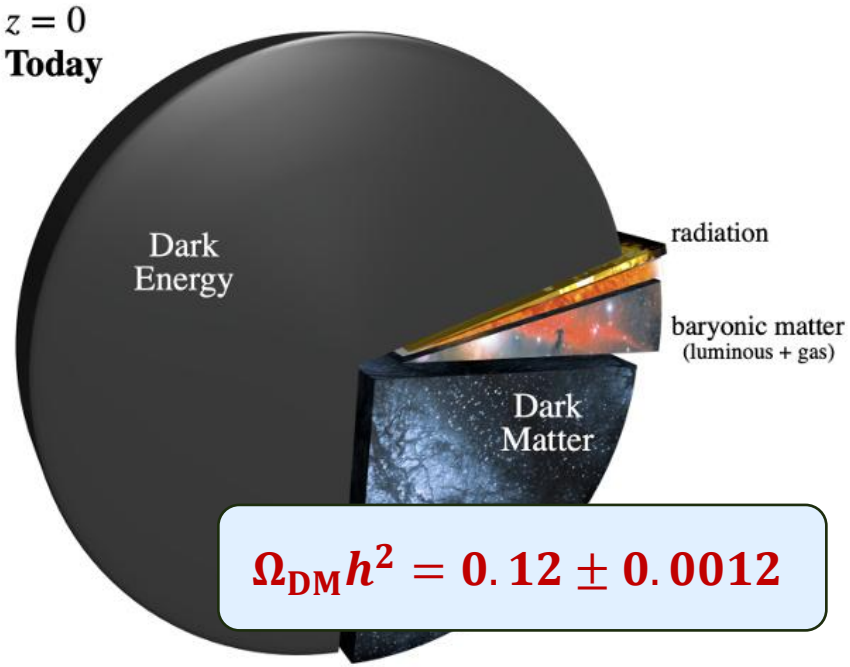
- Search for sub-GeV DM in $\eta \to \pi^0 + \text{invisible}$, **arXiv: 2601.10597** **Very recent result, This talk**

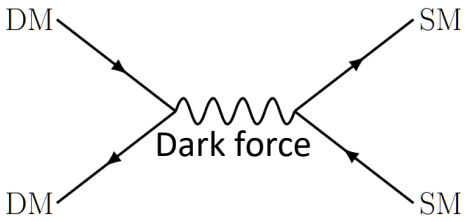
- Search for sub-GeV DM in $J/\psi \to \phi + \text{invisible}$, **Phys.Rev.Lett. 135, 151804 (2025)**
- Search for $K_S^0 \to \text{invisible}$, **JHEP 05 (2025) 092**
- Search for dark baryon in $\Xi^- \to \pi^- + \text{invisible}$, **Phys. Lett. B 872 (2026) 140099**
- Search for QCD axion in $\Sigma^+ \to p + \text{invisible}$, **Phys.Lett.B 852 (2024) 138614**
- Search for QCD axion in $\Xi^0 \to \Lambda + \text{invisible}$, **arXiv:2603.03199**
- Search for massless dark photon in $D^0 \to \omega/\gamma + \text{invisible}$, **Phys.Rev.D 111 (2025) 1, L011103**
- Search for massless dark photon in $\Lambda_c \to p + \text{invisible}$, **Phys.Rev.D 106 (2022) 7, 072008**
- Search for muon-philic particle in $J/\psi \to \mu^+\mu^- + \text{invisible}$, **Phys.Rev.D 109 (2024) 3, L031102**
- Search for dark photon in $e^+e^- \to \gamma + \text{invisible}$, **Phys.Lett.B 839 (2023) 137785**
- Search for axion-like particle in $J/\psi \to \gamma a, a \to \gamma\gamma$, **Phys.Lett.B 838 (2023) 13769**
- Search for axion-like particle in $J/\psi \to \gamma a, a \to \gamma\gamma$, **Phys.Rev.D 110 (2024) 3, L031101**
- Search for light vector boson in $\chi_{cJ} \to J/\psi\, V, V \to e^+e^-$, **Phys.Rev.D 113 (2026) 3, 032009**

Some in backup

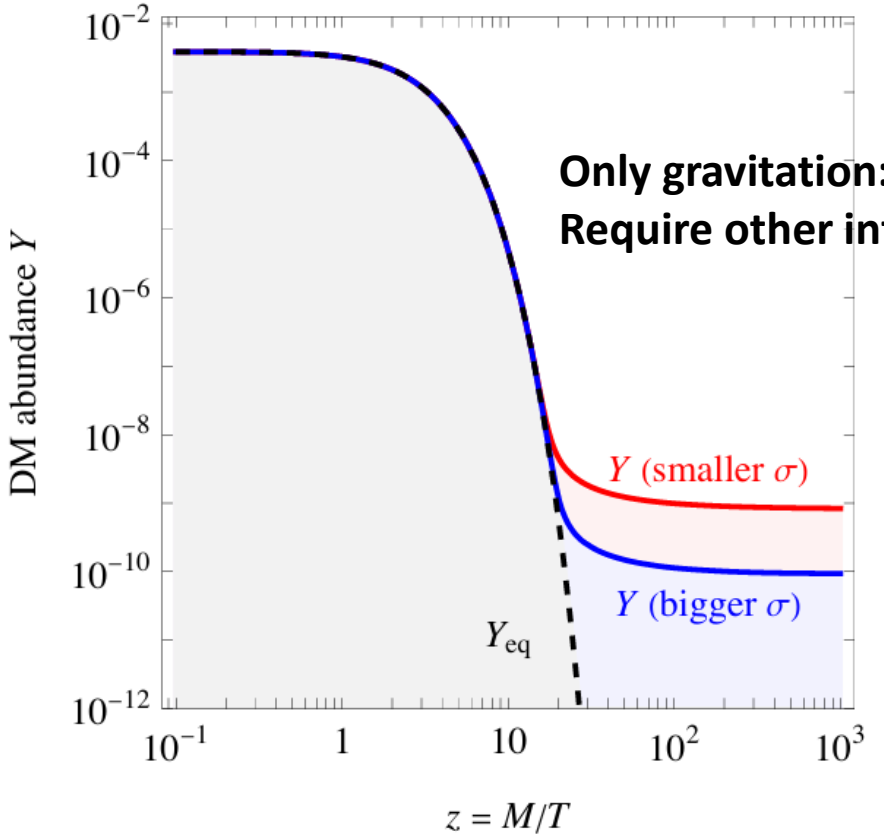
- ……

Dark matter (DM) in cosmology





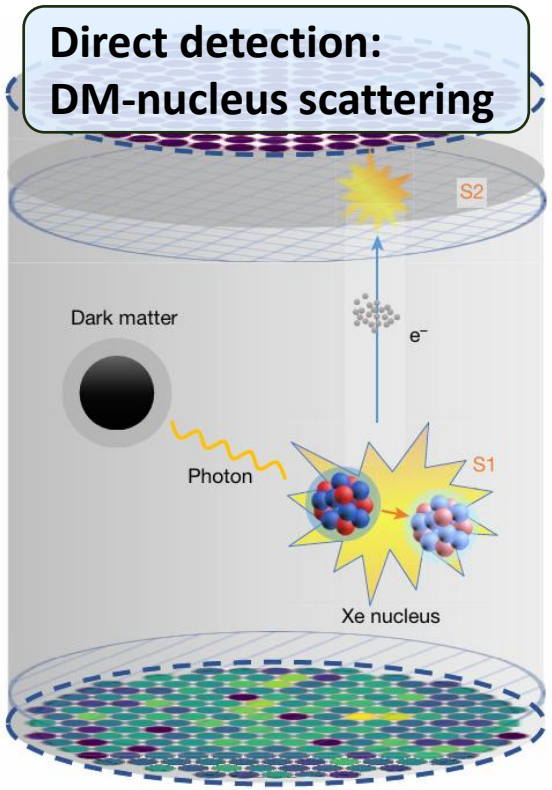
thermal relic by freeze-out

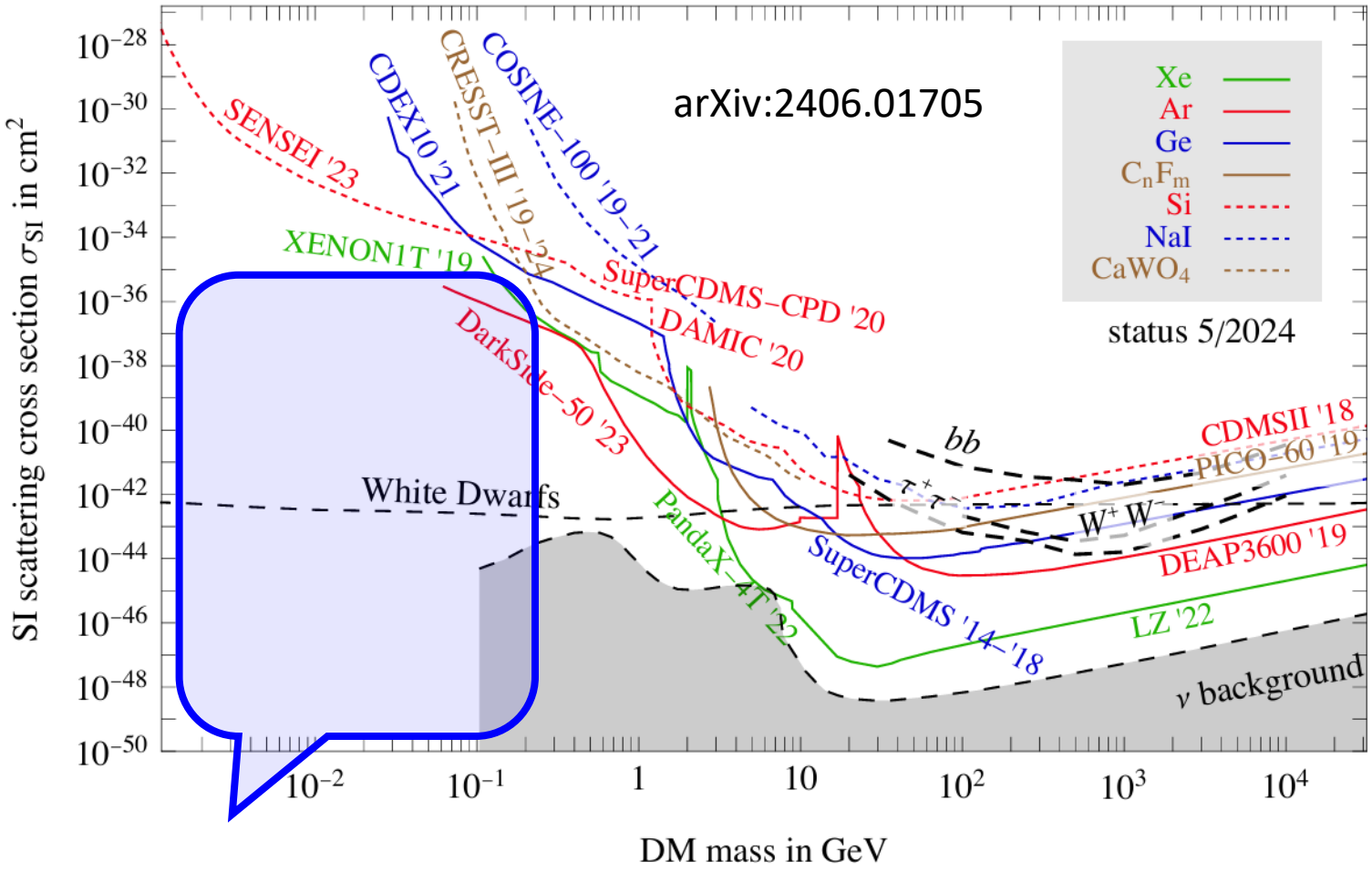


Only gravitation: too weak;
Require other interactions

- For DM≫GeV, coupling~$\mathcal{O}(1)$, eg. WIMP
- **For DM≲GeV, coupling $\ll 1$**

DM search status





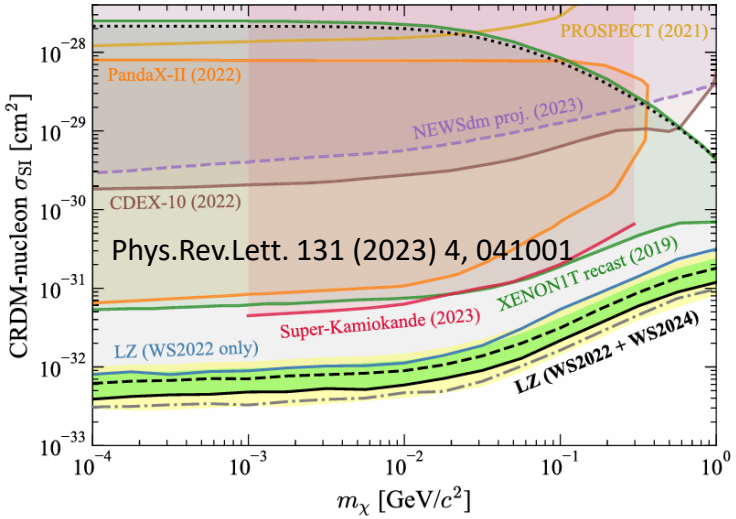
- GeV to TeV scale: strong constraint, not found any WIMP signal
- Sub-GeV: insufficient nuclear recoil energy to be detected, less exploration

Sub-GeV DM search status

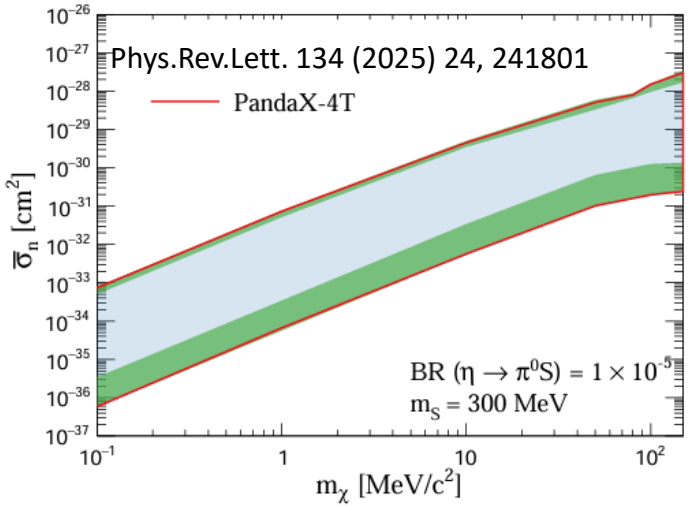
- The challenge of the sub-GeV DM detection

Non-relativistic velocities ✚ Sub-GeV ⇨ Small recoil energy ⇨ Not exceed the detection threshold

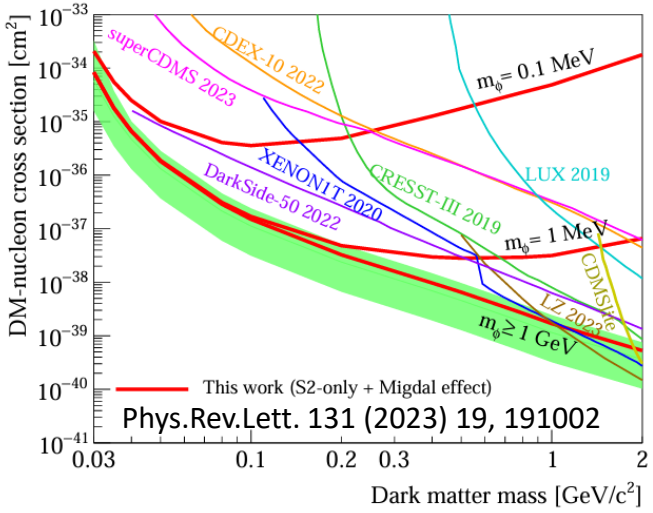
- **Solutions** of the sub-GeV DM detection: **1. boosted DM** **2. low threshold detection**



Cosmic-ray boosted DM



Atmospheric-meson-decay boosted DM

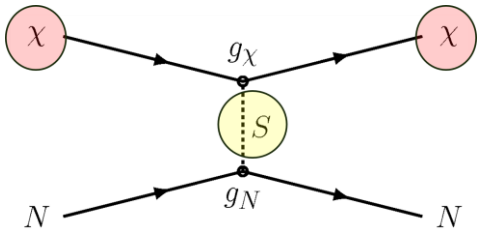


Migdal effect to lower the threshold

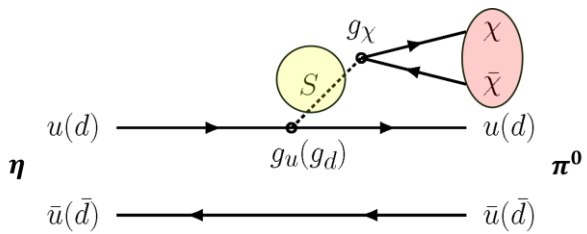
- Hard work but **sensitivity remains limited** due to the reduced DM Flux or reduced detection probability
- **BESIII operates in ~GeV region, can offer a unique opportunity to probe sub-GeV DM from the collider**

arXiv: 2601.10597

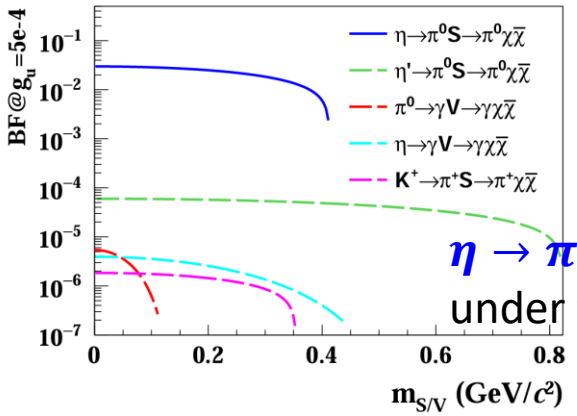
Search for $\eta \to \pi^0 +$ invisible at BESIII



DM-nucleon scattering



$\eta \to \pi^0 S \to \pi^0 \chi\bar{\chi}$ decay



Flavor Conservation
DM decays

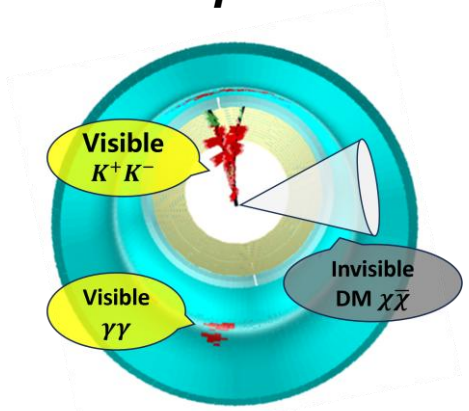
$\eta \to \pi^0 S \to \pi^0 \chi\bar{\chi}$ has the largest BF
under the equal coupling strength

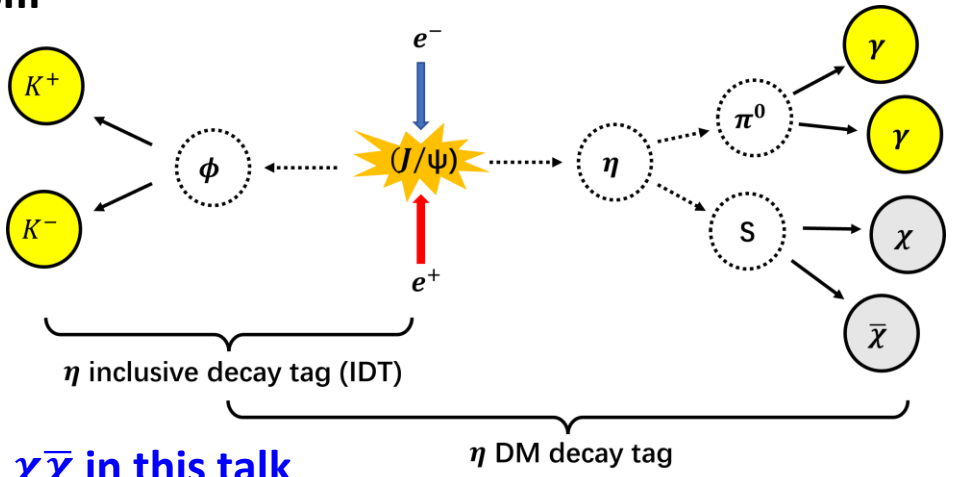
- The two processes involve the same new physics
- S is a dark scalar boson, and χ is the DM

☐ Search for sub-GeV dark particles with $\eta \to \pi^0 S \to \pi^0 \chi\bar{\chi}$ at BESIII

- Data set @ 3.097 GeV
  $(10087 \pm 44) \times 10^6$ J/ψ
- η source: $J/\psi \to K^+K^-\eta$

- **Charged kaons help to tag η and DM**



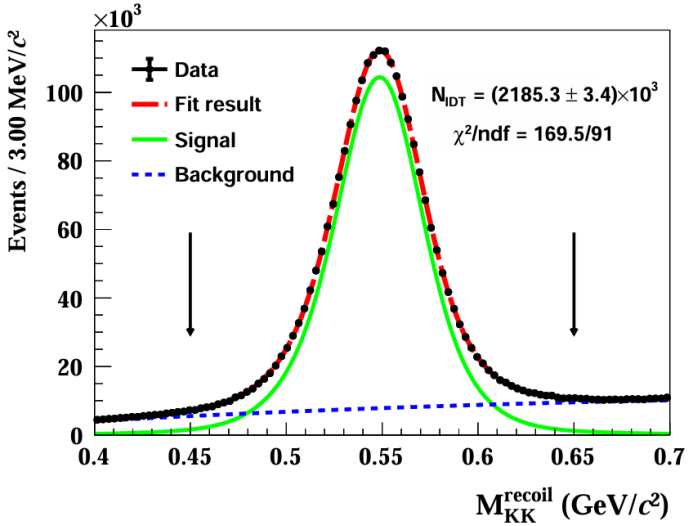


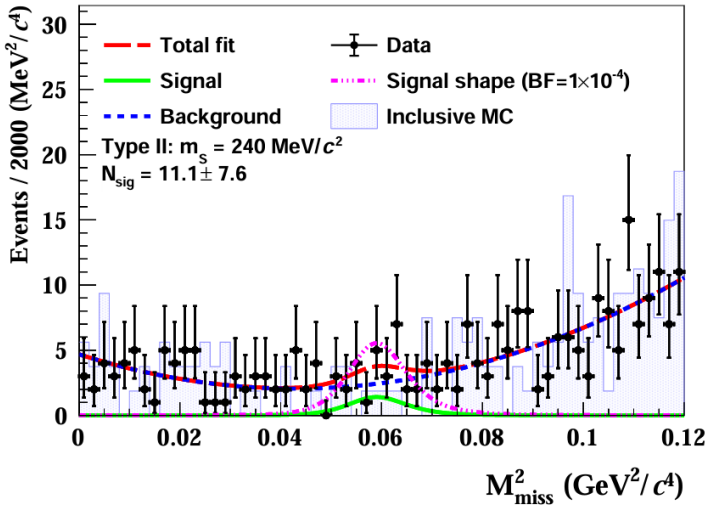
Search for on-shell $S \to \chi\bar{\chi}$ in this talk
The off-shell $S \to \chi\bar{\chi}$ search is ongoing

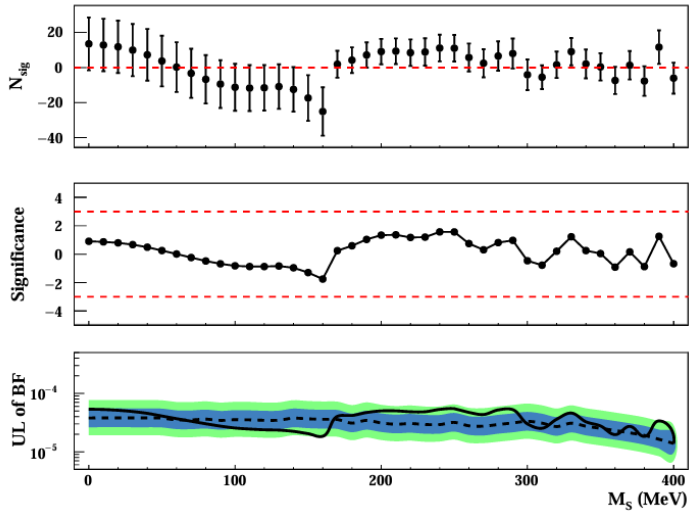
arXiv: 2601.10597

Search for $\eta \to \pi^0 +$ invisible at BESIII

Tag K^+K^- with $\eta \to$ any → **Further tag $\eta \to \pi^0 +$ inv** → **Scan signal with different m_S**







- The recoiling mass of K^+K^-
- **$\sim 2 \times 10^6$ η events are tagged**
- Not the world largest η data set, but may be the cleanest η data

- The recoiling mass square of $K^+K^-\pi^0$
- On-shell $S \to \chi\bar{\chi}$

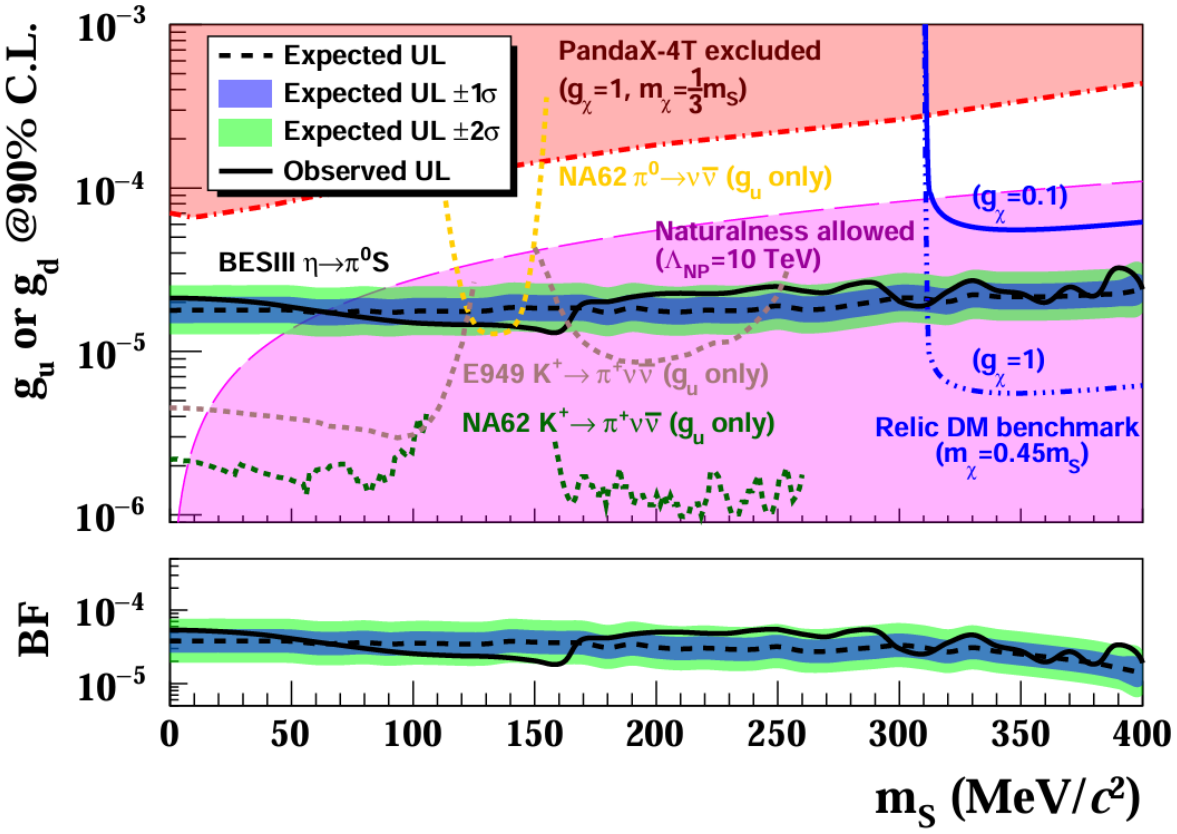
- Signal yield and upper limit (UL)
- S mass from $\sim$0 to 400 MeV
- **UL on $\mathcal{B}(\eta \to \pi^0 S)$ @90% C.L.: $(1.8 \sim 5.5) \times 10^{-5}$**

☐ Advantages of **DM study at BESIII**
- **Clean background, full reconstruction, high efficiency, absolute BF measurement…**

arXiv: 2601.10597

Search for $\eta \to \pi^0 +$ invisible at BESIII

- $\mathcal{L} \supset -g_\chi S \bar{\chi}_L \chi_R - g_u S \bar{u}_L u_R + h.c., \quad g_u \equiv \frac{c_S v}{\sqrt{2}\Lambda_{NP}}$
- The coupling strength g_u not necessarily proportional to the Higgs Yukawa couplings



$$\mathcal{B} \propto g_u^2 \lambda^{\frac{1}{2}}\left(1, \frac{m_S^2}{m_\eta^2}, \frac{m_{\pi^0}^2}{m_\eta^2}\right)$$

- **UL on g_u or g_d @90% C.L.: $(1.3 \sim 3.2) \times 10^{-5}$**
- Better than the result of atmospheric-boosted DM from PandaX-4T

- Constraints from $K^+ \to \pi^+ +$ invisible: only for g_u

- Naturalness bound in EFT, setting $\Lambda_{\mathrm{NP}} = 10$ TeV
- $g_u \leq \frac{16\pi^2}{\sqrt{2}} \frac{m_S v}{\Lambda_{\mathrm{NP}}^2}$

- **Thermal Relic DM** benchmark: Freeze-out by $\chi\bar{\chi} \to \pi\pi$
- **Excluded when $g_\chi = 0.1$**

arXiv: 2601.10597

Search for $\eta \to \pi^0 +$ invisible at BESIII

- $\mathcal{L} \supset -g_\chi S \bar{\chi}_L \chi_R - g_u S \bar{u}_L u_R + h.c., \quad g_u \equiv \frac{c_S v}{\sqrt{2}\Lambda_{NP}}$
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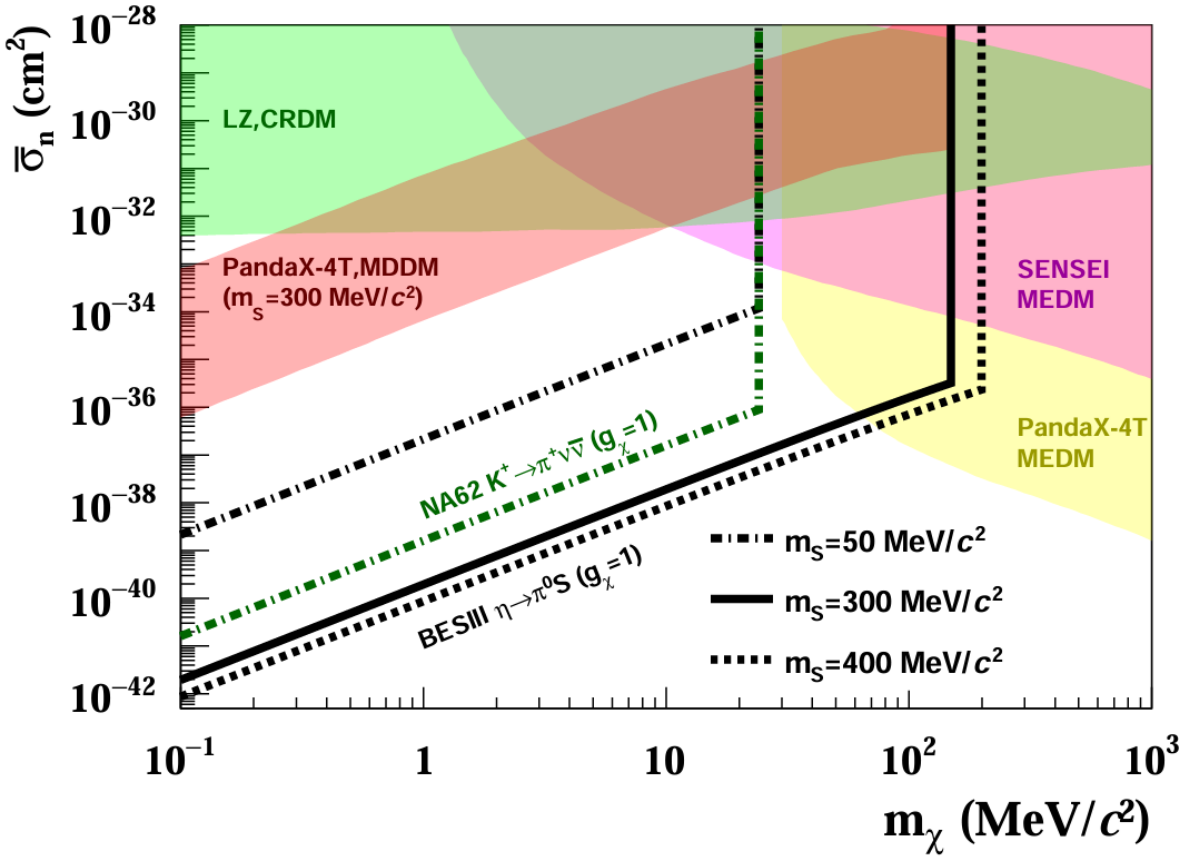


$$\bar{\sigma}_n \propto \frac{g_u^2 g_\chi^2}{m_S^4} \left(\frac{m_\chi m_N}{m_\chi + m_N}\right)^2$$

- Constraint on DM-nucleon cross section ($\bar{\sigma}_n$)
- **Improved by approximately 5 orders** of magnitude over previous DM-nucleon scattering experiments

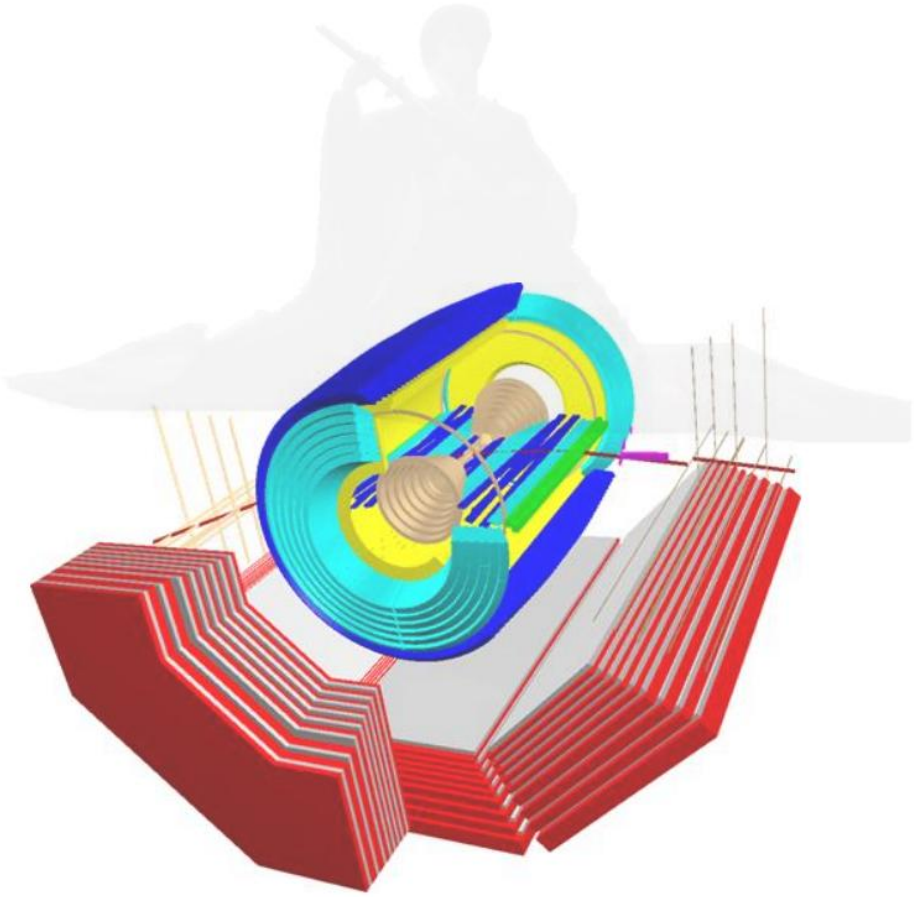
- **Model-dependent constraint**:
- Scattering mediated by on-shell S

- **Ongoing and Future**
- Off-shell S case in $\eta \to \pi^0 \chi \bar{\chi}$
- Larger S mass in $\eta' \to \pi^0 \chi \bar{\chi}$
- Pseudo-scalar case in $\eta \to \pi^+ \pi^- \chi \bar{\chi}$
- Vector case in $\pi^0/\eta \to \gamma \chi \bar{\chi}$
- ……

Summary

- **New result of sub-GeV dark sector at BESIII**
  - $\eta \to \pi^0 +$ invisible
  - **Unique stringent constraints on the sub-GeV DM**

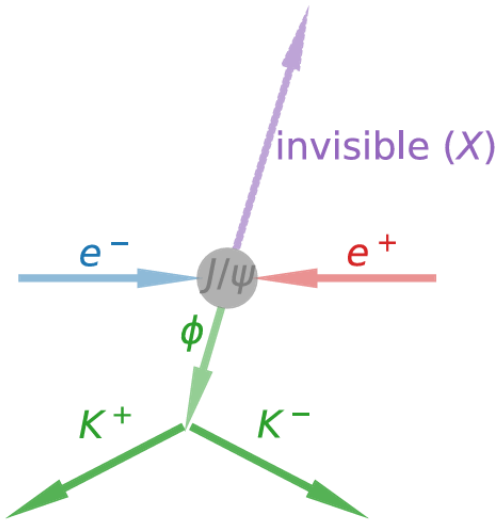
- **BESIII has collected 10^{10} J/ψ , 2.7×10^9 ψ',**
  20 fb^{-1} @ 3.77 GeV data ($D\bar{D}$) and more…
- **More & better results are coming soon**



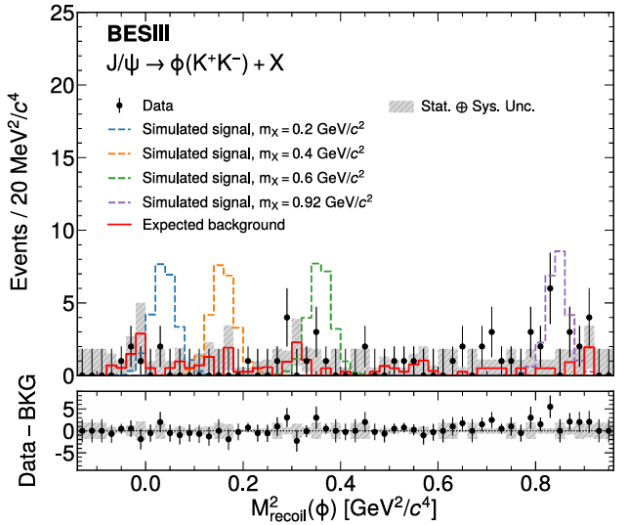
Phys.Rev.Lett. 135, 151804 (2025)

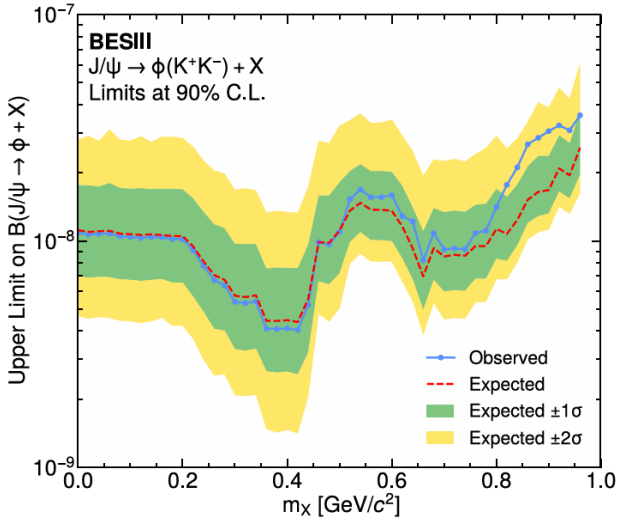
Search for $J/\psi \to \phi +$ invisible at BESIII

- Motivation **similar to the previous $\eta \to \pi^0 +$ invisible**
- Using $(8774.0 \pm 39.4) \times 10^6$ J/ψ events to search for sub-GeV particles in $J/\psi \to \phi +$ invisible



Reconstruct the invisible signal by the K^+K^- recoil





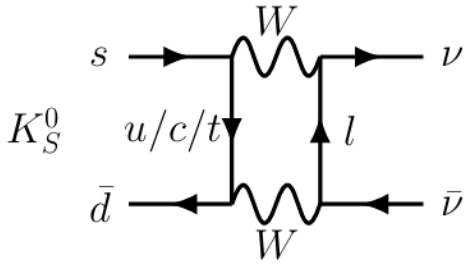
- **UL on $\mathcal{B}(J/\psi \to \phi X)$** with m_X ranging from 0 to 0.96 GeV @90% C.L.
  $4 \times 10^{-9} \sim 4 \times 10^{-8}$
- UL on the inclusive invisible BF of $J/\psi \to \phi X$: 7.0×10^{-8} @90% C.L.
- Taking $X = \eta$, **UL on $\mathcal{B}(\eta \to$ invisible$)$: 2.4×10^{-5}** @90% C.L., improved by more than 4 times

Lacking the theoretical connection to the physical coupling (and DM XS)
More theoretically complex in charm decay, still wait for a calculation…

K_S invisible decay

Invisible decay of K_S^0

- **SM decay**

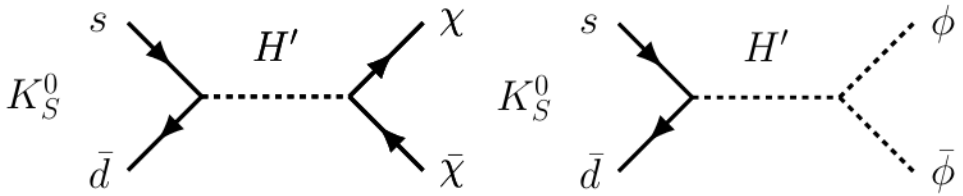


$\mathbf{BF} < \mathbf{10^{-16}}$

FCNC && Helicity suppression

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

- **Decay to DM**



2HDM model

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

Natural Sci.Rev. 1 (2024) 5

- **Ordinary-mirror particle oscillations**

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

Mirror matter model

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

arXiv: 2006.10746

- **Input for CPT test**

Bell-Steinberger relation **connects CPTV** to the amplitudes of all decay channels of neutral kaons.

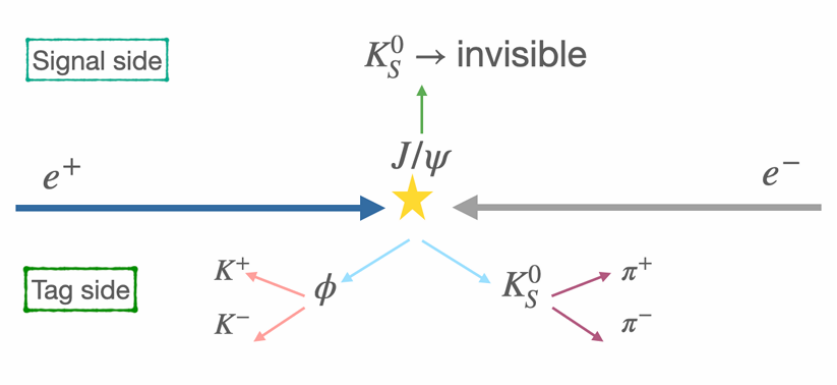
BUT currently assumes no invisible modes

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

Search for K_S^0 invisible decay at BESIII

K_S^0 source

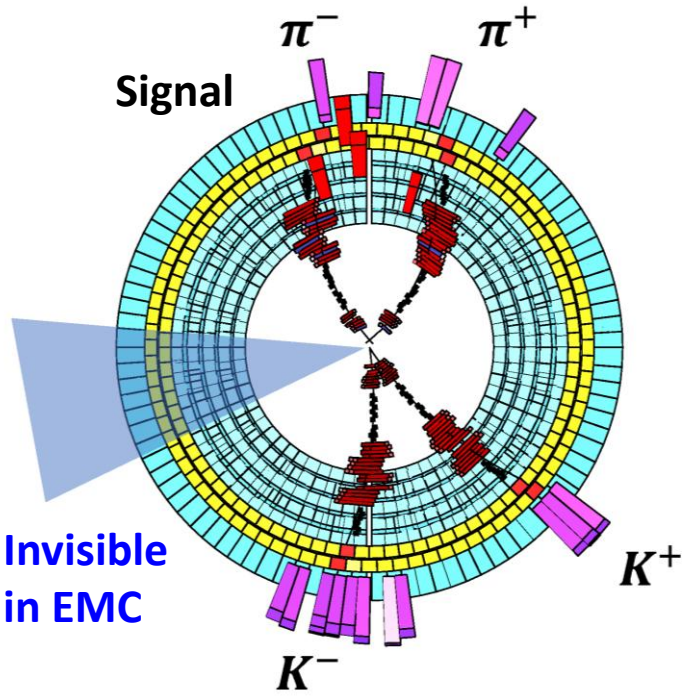
$J/\psi \to \phi K_S^0 K_S^0$ from $(10087 \pm 44) \times 10^6$ J/ψ

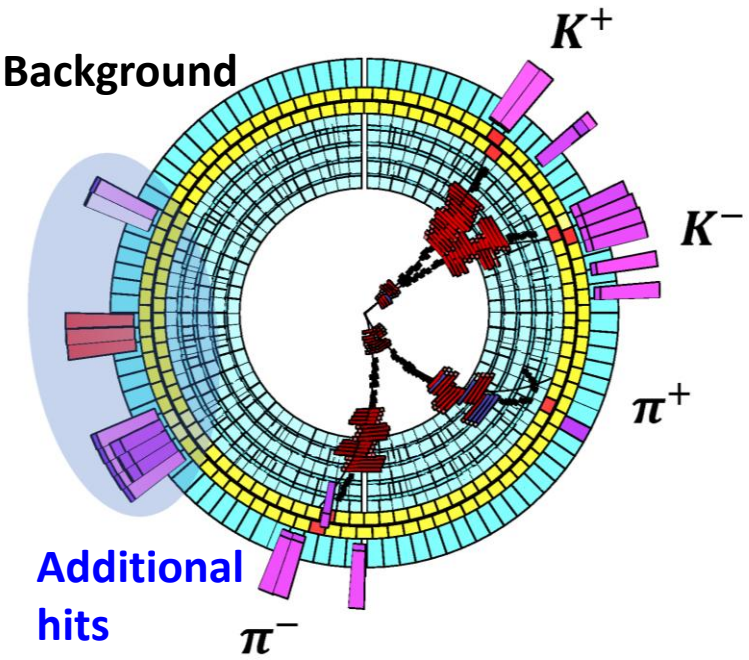


Why this channel?

- $J/\psi \to \phi K_S^0 K_L^0$ is forbidden with C Parity conservation, **lower background**
- But still have $J/\psi \to K^+K^-K_S^0K_L^0$

Signal feature

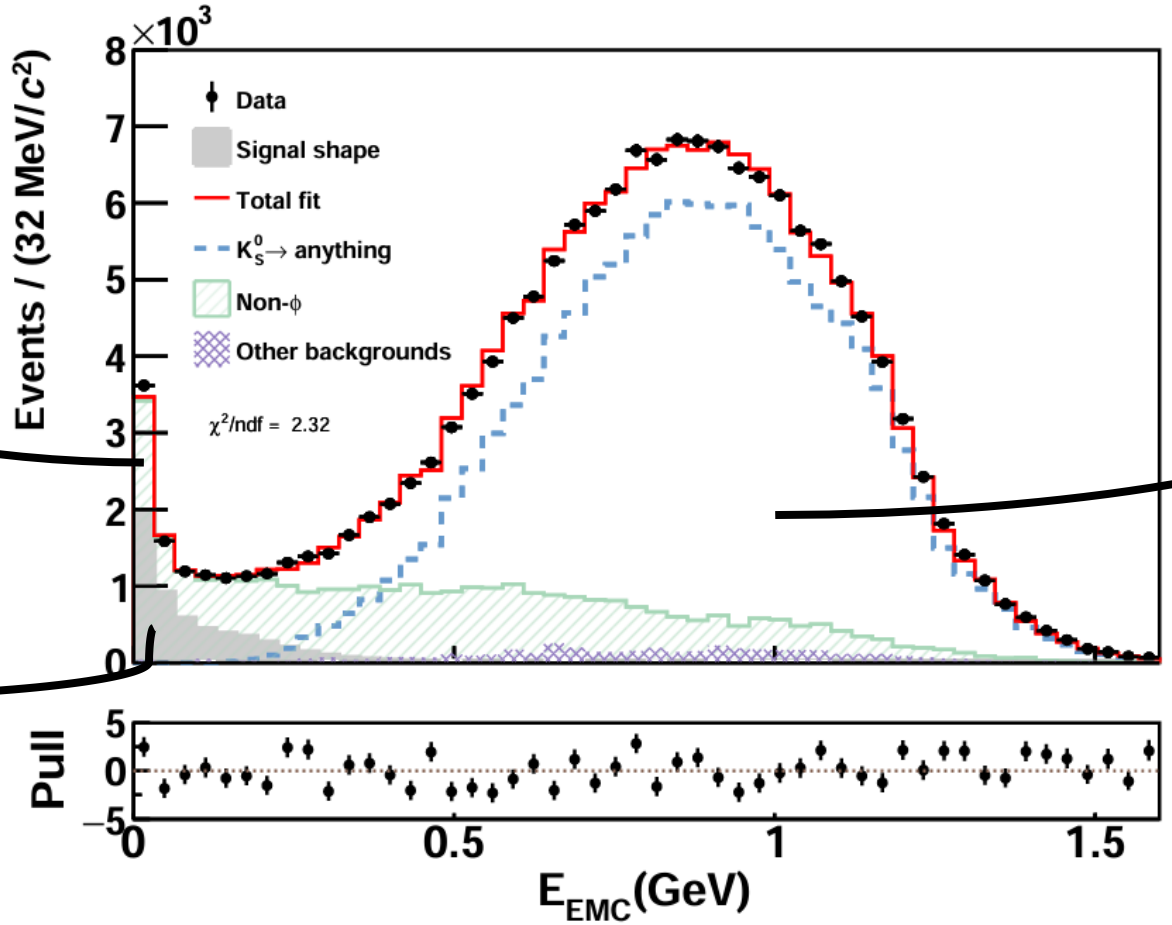




- **Using the deposited energy in EMC to identify the invisible signal**
- **An alternative method for invisible signal search at BESIIII**

Search for K_S^0 invisible decay at BESIII

$J/\psi \to K^+K^-K_S^0K_L^0$ peaking background shape from ϕ sideband



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

Invisible Signal peaks around zero

$N_{\rm sig} = 56 \pm 201$

$\mathcal{B}(K_S^0 \to \text{invisible}) < 8.4 \times 10^{-4}$ (90% C.L.)

arXiv: 2501.06426

First direct measurement of $K_S^0 \to$ invisible; the UL still lies above the NP prediction

Dark baryon

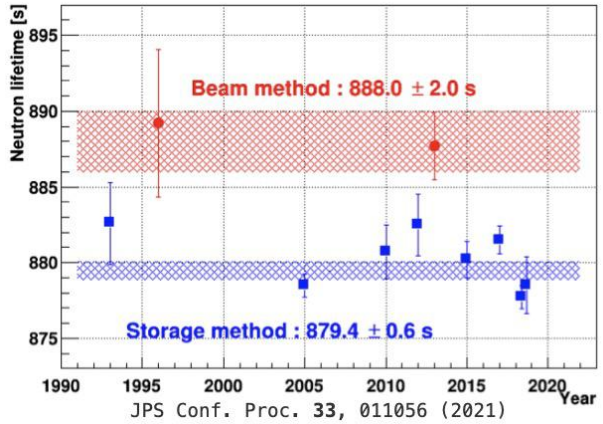
Coincidence problem

The baryon and dark matter energy densities are fairly similar

$\Omega_{DM}/\Omega_b \cong 5.36 \pm 0.06$

- Potential connection between their origins
- **DM may carry non-zero baryon number**

Neutron lifetime puzzle



$$\tau_n^{\text{beam}} = \frac{\tau_n^{\text{bottle}}}{\text{Br}(n \to p + \text{ anything })} \qquad \mathcal{B}(n \to \text{dark}) \sim 1\%$$

- **Motivates the existence of dark baryon**

B-Mesogenesis mechanism

CP asymmetry in $B \to$ baryon + dark baryon

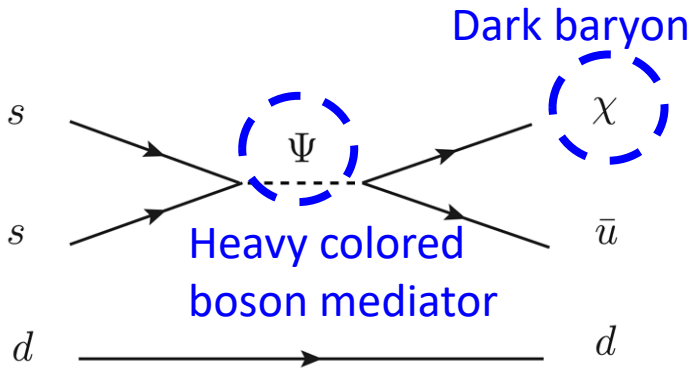
1. **Explain matter anti-matter asymmetry**
2. **The origin of the dark matter**

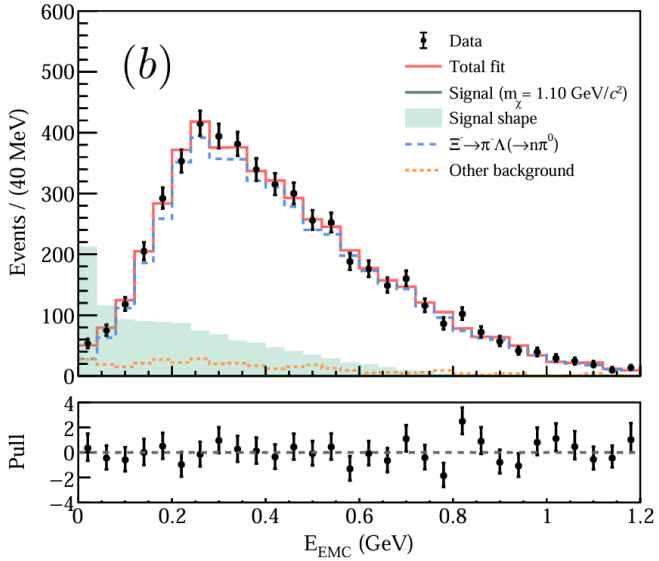
Naturally, dark baryon interacts with all SM quark flavor

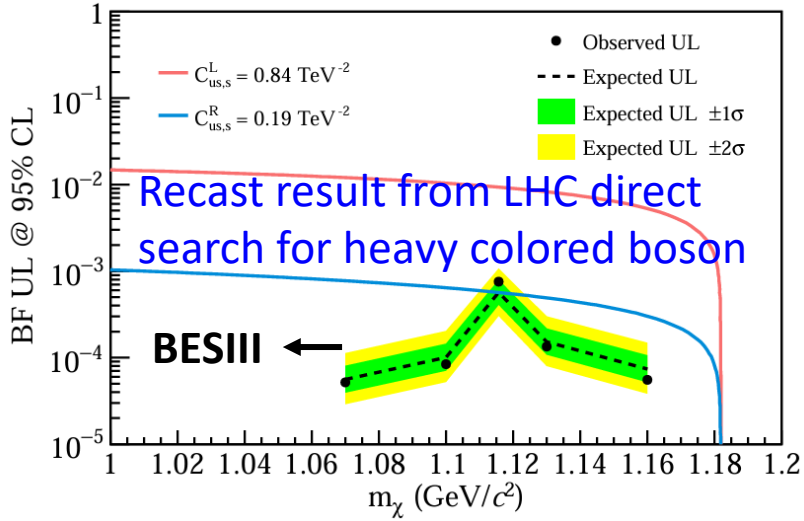
$\Longrightarrow$ **Search for dark baryon in hyperon decay at BESIII**

Phys. Lett. B 872 (2026) 140099

Search for $\Xi^- \to \pi^- +$ invisible at BESIII



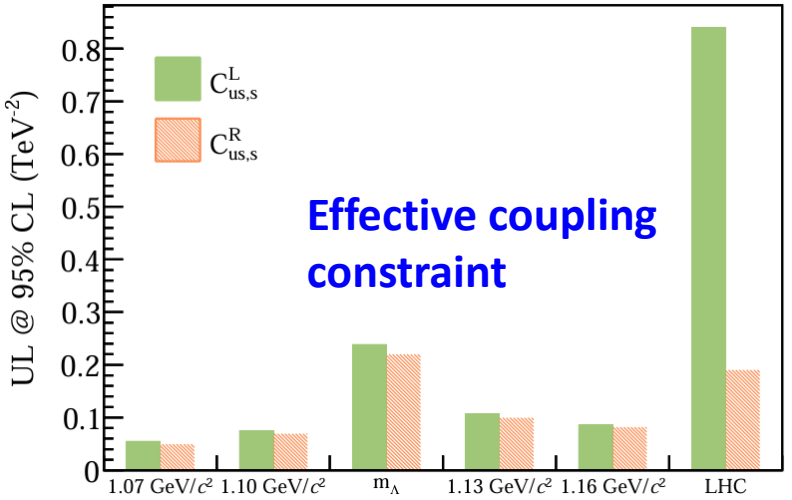




- $\bar{\Xi}^+ \to$ SM, $\Xi^- \to \pi^- \chi$
- Dark baryon χ with mass hypothesis of 1.07, 1.10, m_Λ, 1.13, 1.16 GeV

- Deposited energy in EMC used to identify the invisible signal

➢ $J/\psi \to \bar{\Xi}^+\Xi^-$ from 10^{10} J/ψ

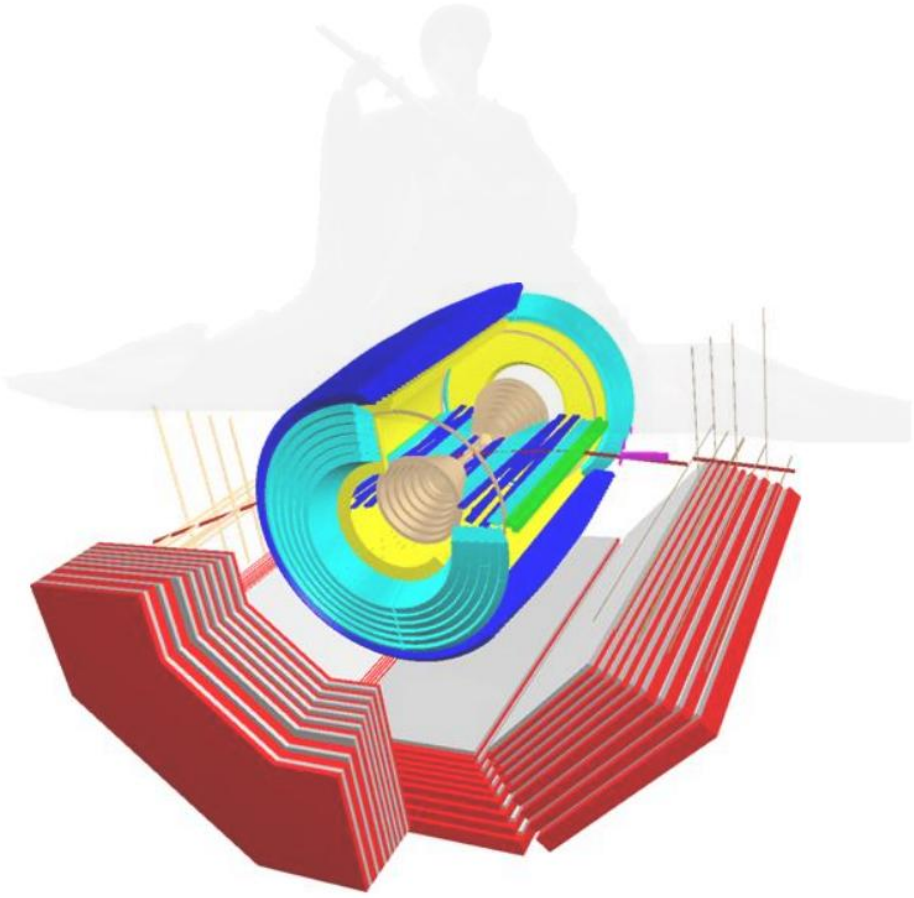


Better effective coupling constraints

Summary

➢ **New results of sub-GeV dark sector at BESIII**

- $\eta \to \pi^0 + \text{invisible}, J/\psi \to \phi + \text{invisible}$
- $K_S^0 \to \text{invisible}, \eta \to \text{invisible}$
- $\Xi^- \to \pi^- + \text{invisible}$
- **Unique stringent constraints on the sub-GeV DM**



➢ **BESIII has collected 10^{10} J/ψ , 2.7×10^9 ψ',**

20 fb^{-1} @ 3.77 GeV data ($D\bar{D}$) and more…

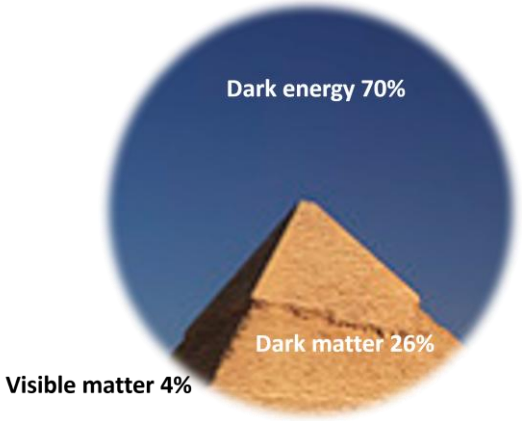
➢ **More & better results are coming soon**

Appendix

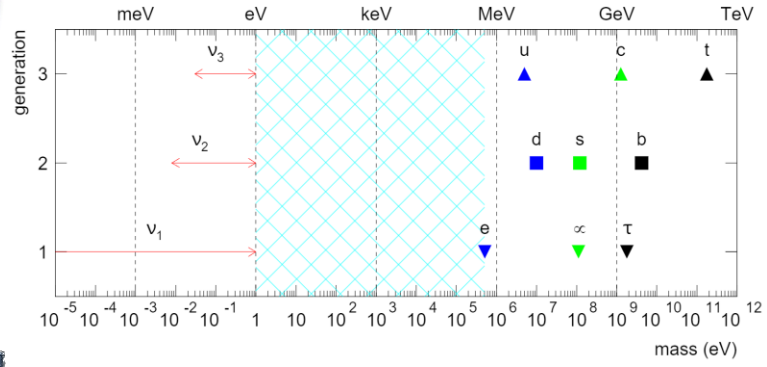
Standard model and Puzzles

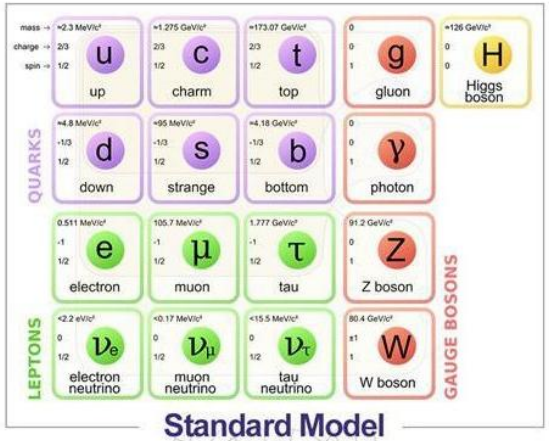
Dark Matter
Dark Energy

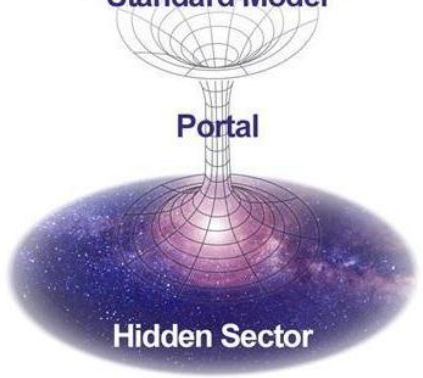
- SM explains most facts but not all
- More than two dark clouds



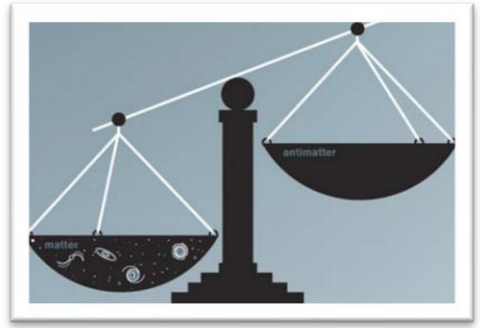
Fermion Mass Hierarchy



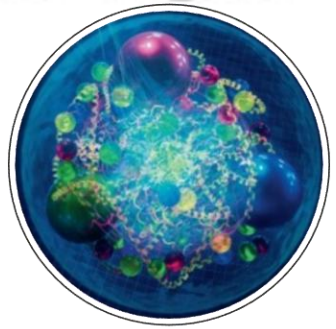


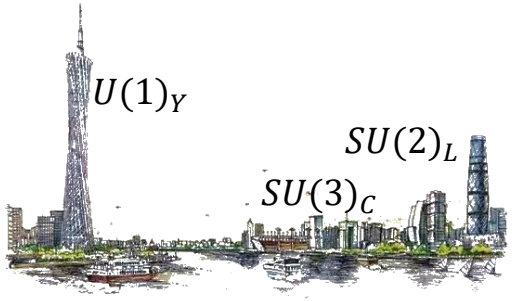


Matter Anti-matter Asymmetry



Strong CP Problem



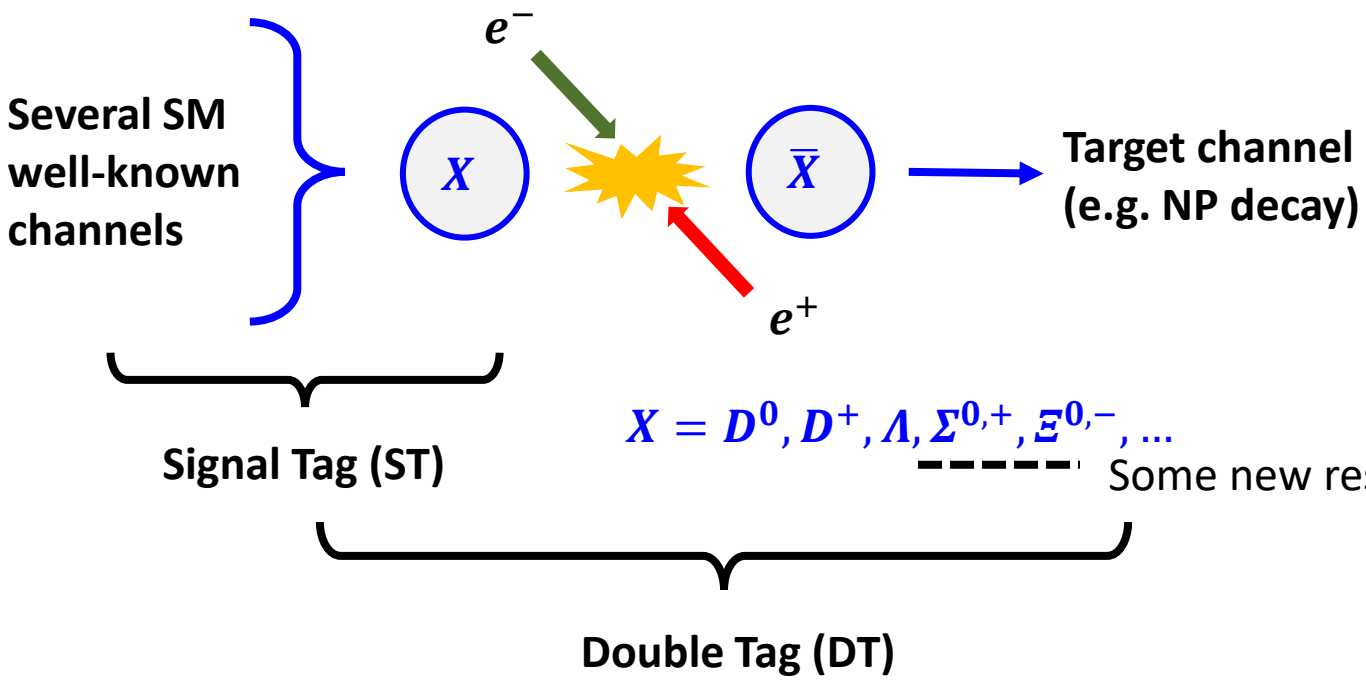


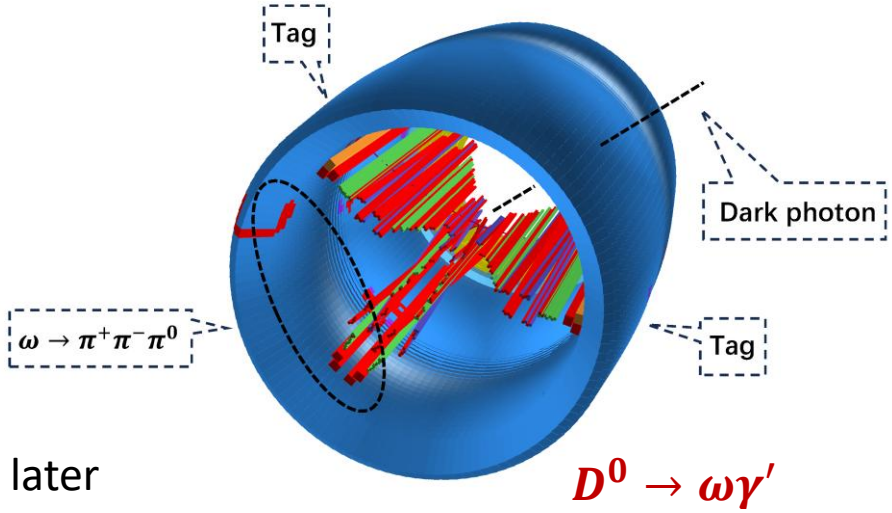
More . . .

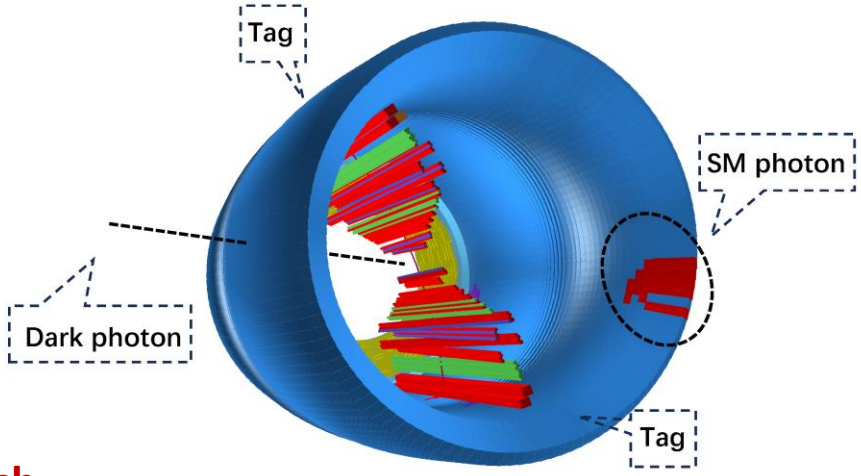
Potentials to find new physics

This talk: New dark sector result at BESIII

Double tag analysis at BESIII





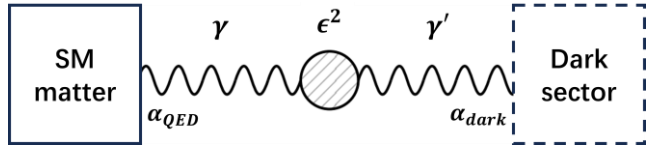


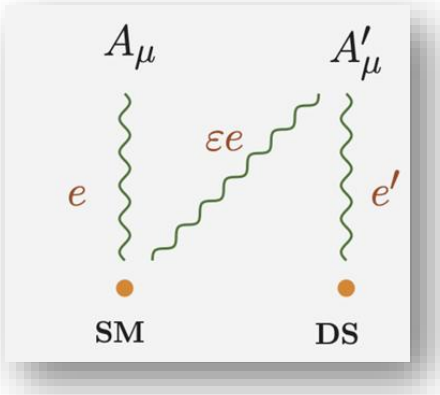
- Measure absolute branching fraction, $\mathcal{B} = \frac{N_{DT}/\epsilon_{DT}}{N_{ST}/\epsilon_{ST}}$
- Clean background
- Recoil missing particle, such as invisible particle
- Cancel systematic uncertainty

Active in dark sector search

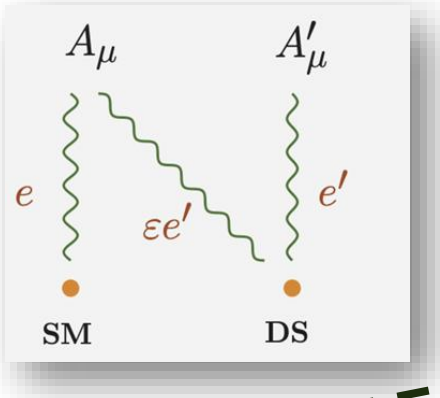
Massless dark photon

Simplest extension of the SM ⟹ An extra Abelian gauge group, $U(1)_D$ ⟹ dark photon





- **Massive dark photon**
- Coupling with SM fermion
- Strong constraint



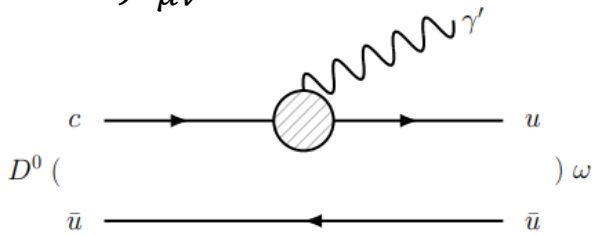
- **Massless dark photon**
- No direct coupling with SM fermion
- Less constraint
- Also important role in dark sector

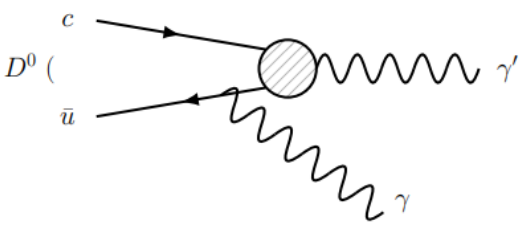
Searching for the massless case can only be in the higher dimension operator:

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

PRL 94, 151802 (2005)

- **Naturally allow the FCNC coupling**
- Less background and higher sensitivity



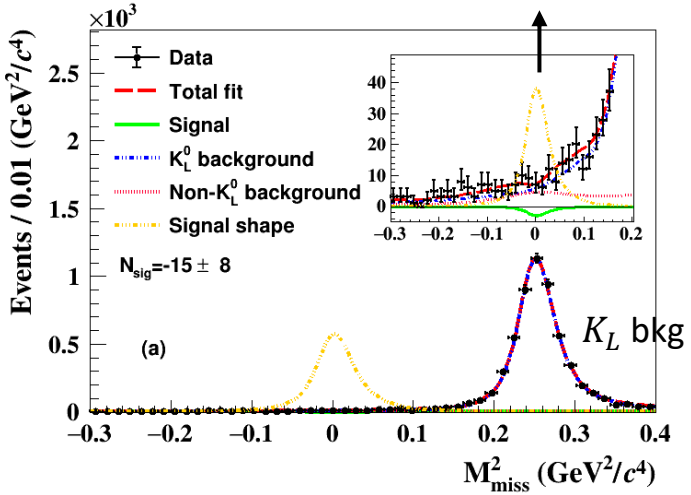


New searches at BESIII: through $cu\gamma'$ coupling in $D^0 \to \omega\gamma'$ and $D^0 \to \gamma\gamma'$

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

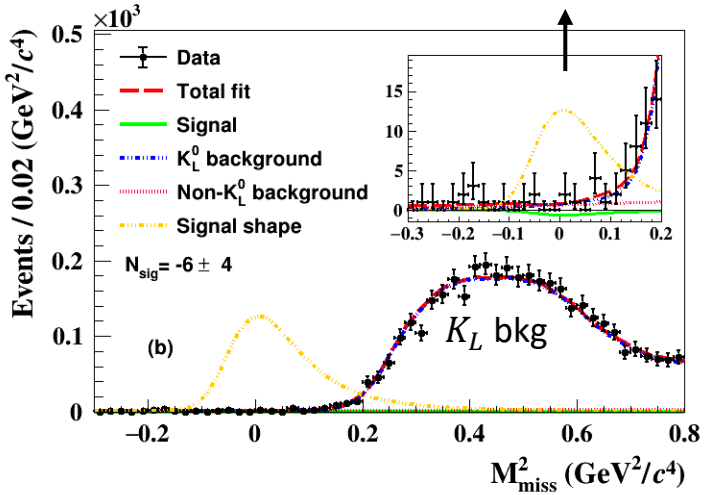
Search for $D^0 \to \omega\gamma'$ and $D^0 \to \gamma\gamma'$ at BESIII

Signal should peak at zero



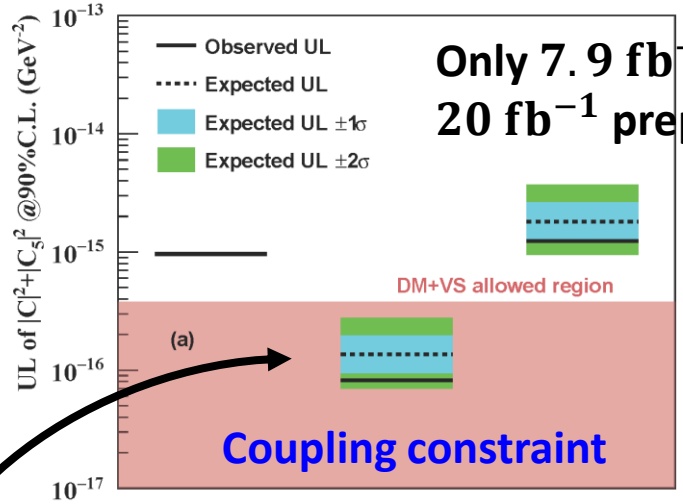
Signal extraction of $D^0 \to \omega\gamma'$

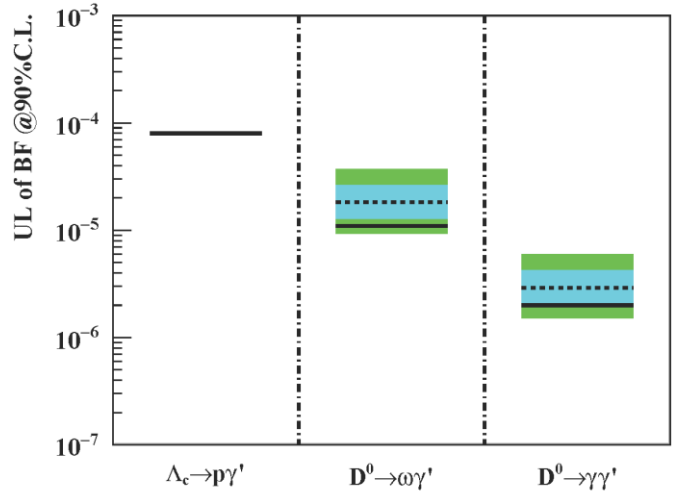
Signal should peak at zero



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

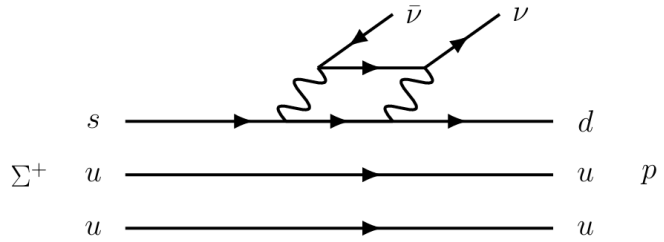
- **First search** for massless dark photon in D meson decay
- The constraint from $D^0 \to \omega\gamma'$ goes into the dark matter (DM) and vacuum stability (VS) allowed region for the first time, **improved by more than 1 order**





$\Sigma^+ \to p +$ invisible and QCD axion

SM decay



- $s \to d\nu\bar{\nu}$, **FCNC && GIM suppression**
- **BF** $< 10^{-11}$

Phys.Rev.D 94 (2016) 11, 115013

Decay to BSM particles

- **Solution to strong CP problem**
- An excellent **dark matter**
- $m_a \sim g \sim \frac{1}{F_a} \Longrightarrow m_a \ll 1$ **eV**;

g: coupling strength;
F_a: decay constant

➢ Naturally allow the FCNC coupling

$$\mathcal{L}_{a-f} = \partial_\mu a \bar{f}_i \gamma^\mu \left(\frac{1}{F_{ij}^V} + \frac{\gamma^5}{F_{ij}^A} \right) f_j$$

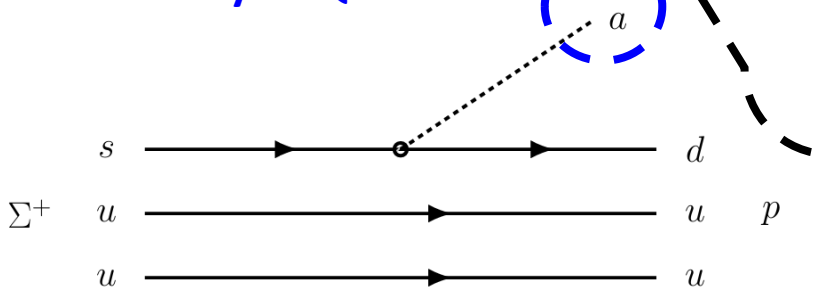
Vector coupling **Axial coupling**

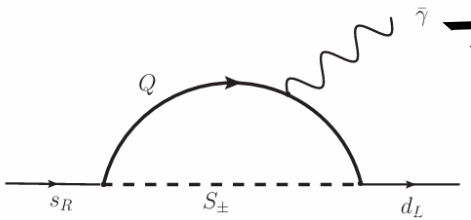
sensitive $K^+ \to \pi^+ a$

Both sensitive

Hyperon decay

Decay to QCD axion





- Can also **Decay to massless dark photon**
- Maximum allowed BF $\sim 3.8 \times 10^{-5}$

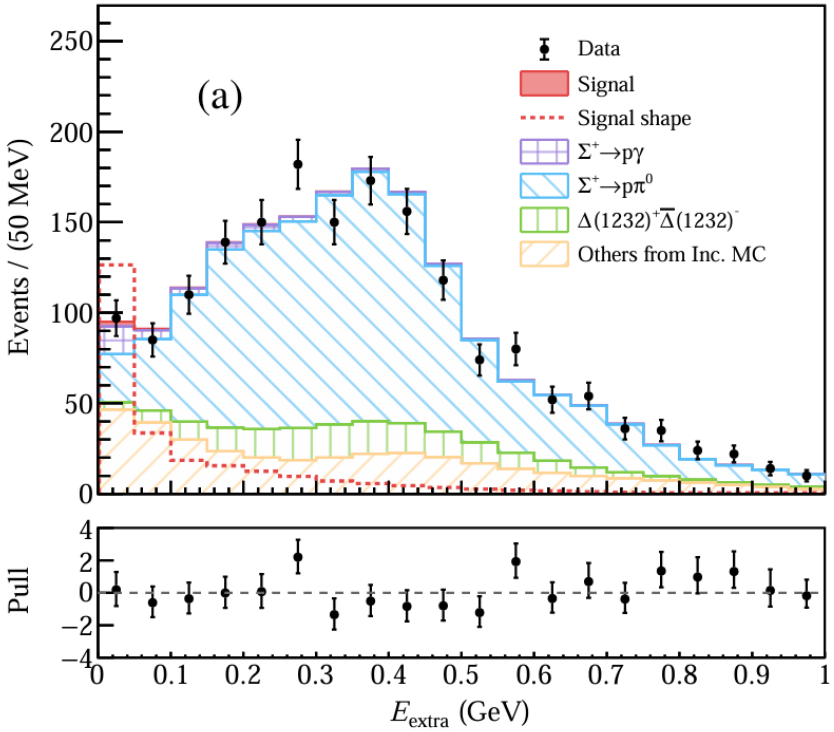
Phys.Rev.D 102 (2020) 1, 015023

Phys.Lett.B 852 (2024) 138614

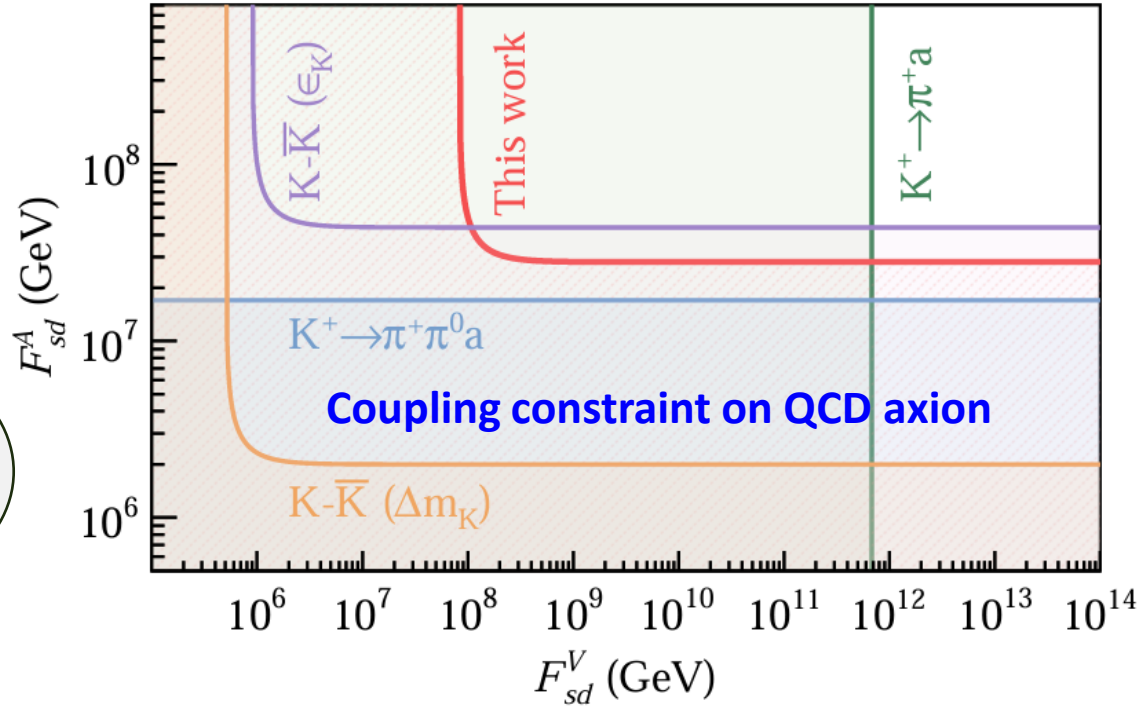
Search for $\Sigma^+ \to p +$ invisible at BESIII

- $J/\psi \to \Sigma^+\bar{\Sigma}^-$ from 10^{10} J/ψ
- Double tag method

- Invisible particle with mass hypothesis of zero
- Deposited energy in EMC used to extract the signal



$\mathcal{B}(\Sigma^+ \to pa) < 3.2 \times 10^{-5}$ @90% C.L.

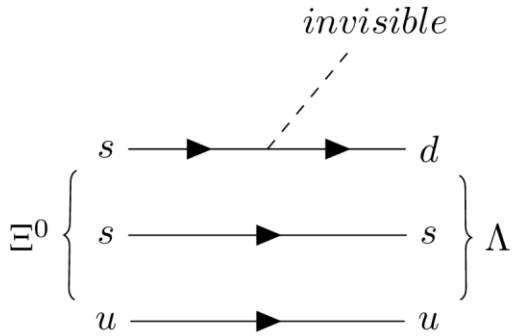


- Competitive constraint on the axial coupling temp F^A_{sd} of QCD axion
- The BF UL lies below the maximum allowed BF of massless dark photon decay (3.8×10^{-5})

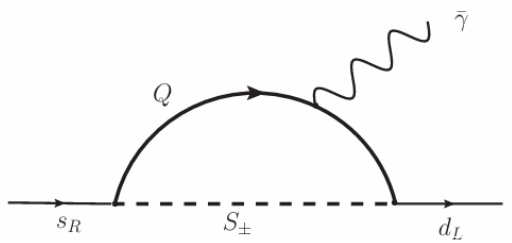
arXiv:2603.03199

Search for $\Xi^0 \to \Lambda +$ invisible at BESIII

- SM decay: $s \to d\nu\bar{\nu}$, FCNC && GIM suppression; BF $< 10^{-11}$
- **Decay to BSM particles** (with FCNC coupling)



QCD axion a



Massless dark photon γ'

$$\mathcal{L}_{a-f} = \partial_\mu a \bar{f}_i \gamma^\mu \left(\frac{1}{F_{ij}^V} + \frac{\gamma^5}{F_{ij}^A} \right) f_j$$

Phys.Rev.D 94 (2016) 11, 115013

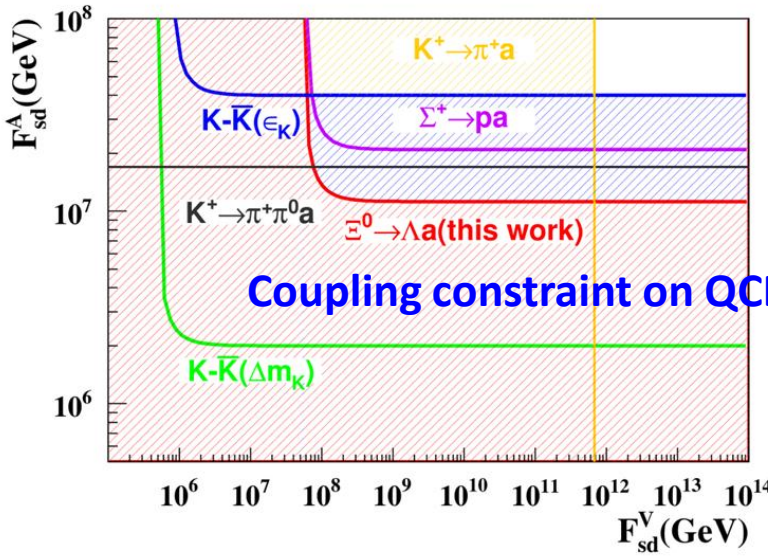
$m_a \ll 1$ eV motivated by $m_a \propto \frac{1}{F_a}$ with $F_a \gg$ PeV

$$\mathcal{L}_{\rm NP} = \frac{1}{\Lambda_{\rm NP}^2} C_{jk}^D \bar{q}_j \sigma^{\mu\nu} d_k H \bar{F}_{\mu\nu}$$

Allowed BF: 1.2×10^{-4}

Phys.Rev.D 102 (2020) 1, 015023

- $J/\psi \to \bar{\Xi}^0 \Xi^0$ from 10^{10} J/ψ events
- $\bar{\Xi}^0 \to$ SM, $\Xi^0 \to \Lambda a/\gamma'$
- Deposited energy in EMC used to extract the invisible signal
- $\mathcal{B}(\Xi^0 \to \Lambda a/\gamma') < 2.3 \times 10^{-4}$ @90% C.L.



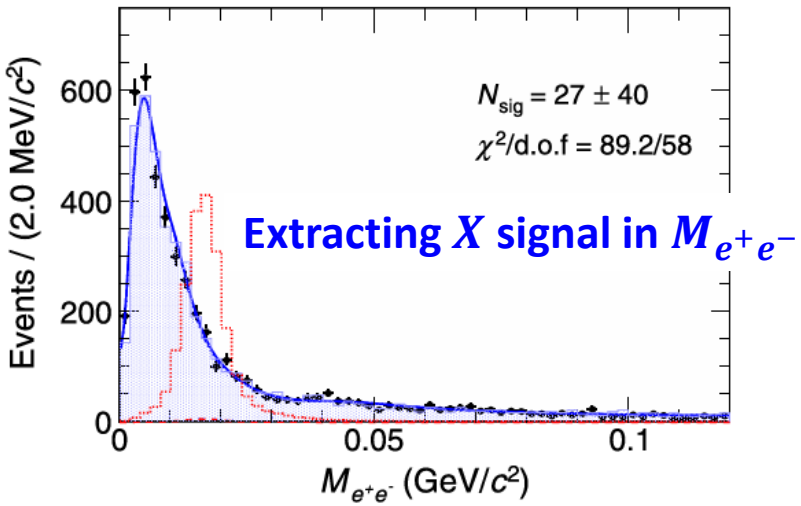
Coupling constraint on QCD axion

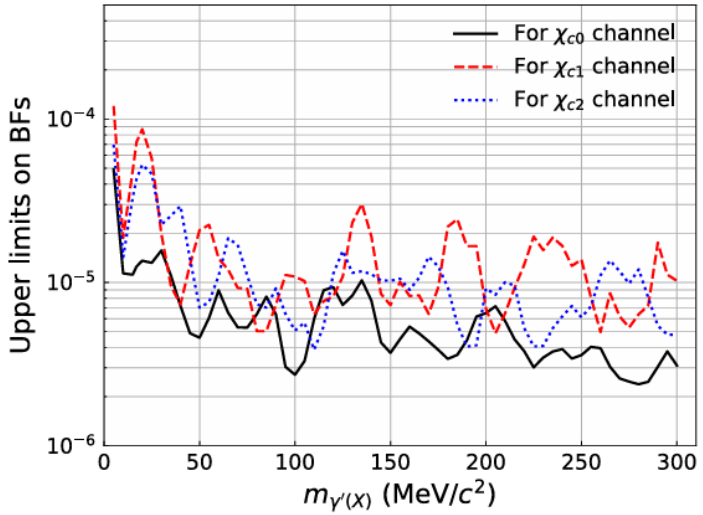
Competitive constraint on the axial coupling temp F_{sd}^A

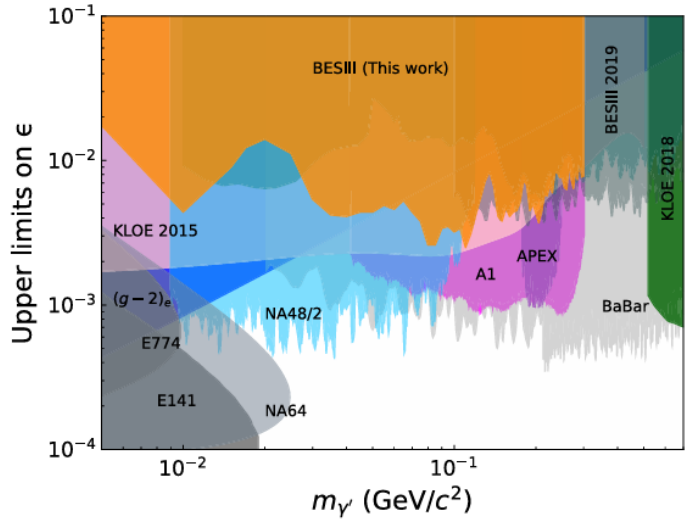
Phys.Rev.D 113 (2026) 3, 032009

Search for $\chi_{cJ} \to J/\psi\, X, X \to e^+e^-$ at BESIII

- Search for a **light vector boson X**: $\mathcal{L} \supset \sum_f e q_f \epsilon_f X^\mu \bar{\psi}_f \gamma_\mu \psi_f$
  - If there is no dark sector lighter than X, can only $X \to f\bar{f}$
- Data set: 2.7×10^9 **$\psi(2S)$**
  - χ_{cJ} from $\psi(2S) \to \gamma\chi_{cJ}$



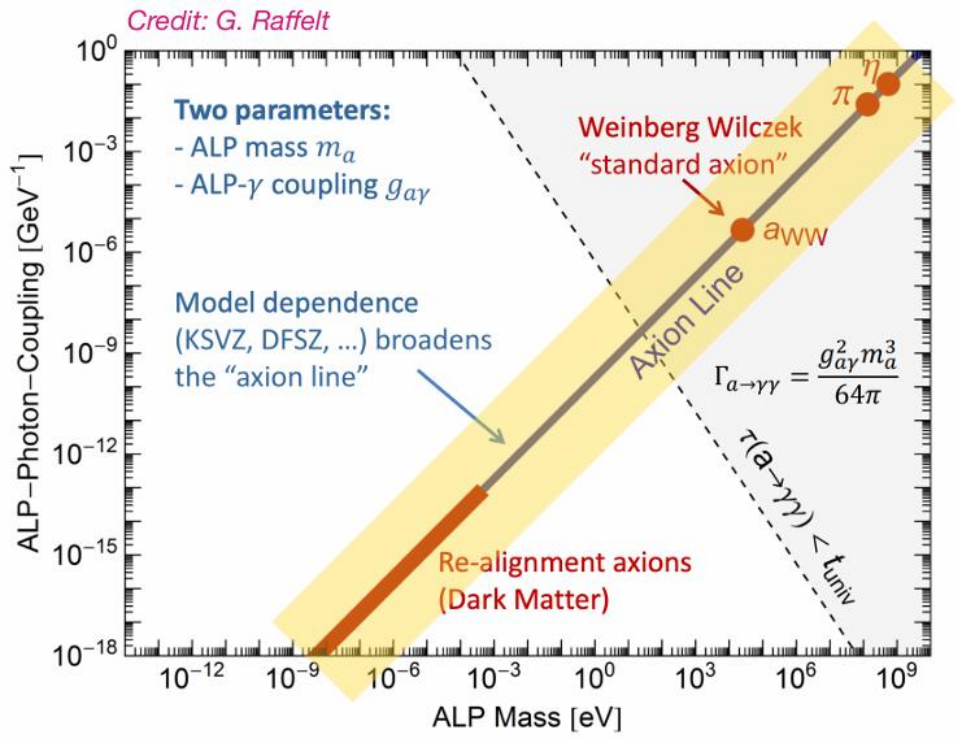




- UL on $\mathcal{B}(\chi_{cJ} \to J/\psi\, X) \times \mathcal{B}(X \to e^+e^-)$ @90% C.L.: $2 \times 10^{-6} \sim 10^{-4}$ for X mass ranging from 5 to 300 MeV
- **Coupling strength with charm quark** @90% C.L.: $(2.5 \sim 17.5) \times 10^{-3}$ (in unit of eq_c)

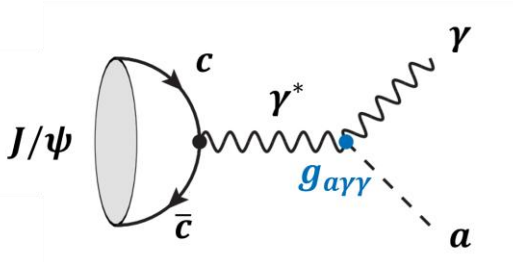
- In dark photon model, X shares a universal ϵ_f for different fermion
  - This work has no advantage in dark photon model,
    but provides **unique probe on coupling with charm** in some un-universal coupling models

Axion-like particle



➢ **Axion-like particle (ALP)**
- Similar to QCD axion
- **arbitrary masses and couplings**

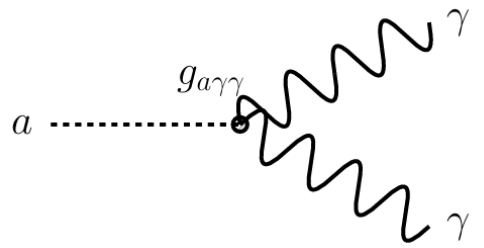
➢ **Considering the ALP-photon interaction**
- $\mathcal{L} \supset -\frac{1}{4} g_{a\gamma\gamma} a F^{\mu\nu} \tilde{F}_{\mu\nu}$ JHEP 06 (2019) 091



- **Produced from heavy photon**

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

$\Longrightarrow$ **BF$\sim g_{a\gamma\gamma}^2$**



- **Decay to di-photons**

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

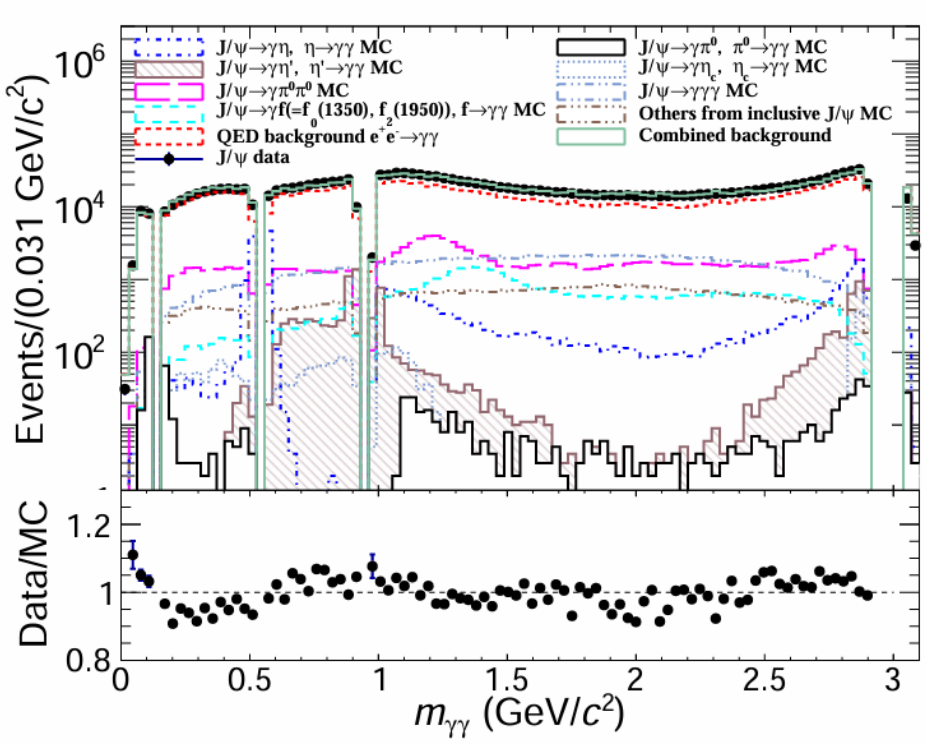
$g_{a\gamma\gamma}\sim 10^{-4}$ GeV^{-1}, $m_a\sim$GeV

$\Longrightarrow$ **short-lived**

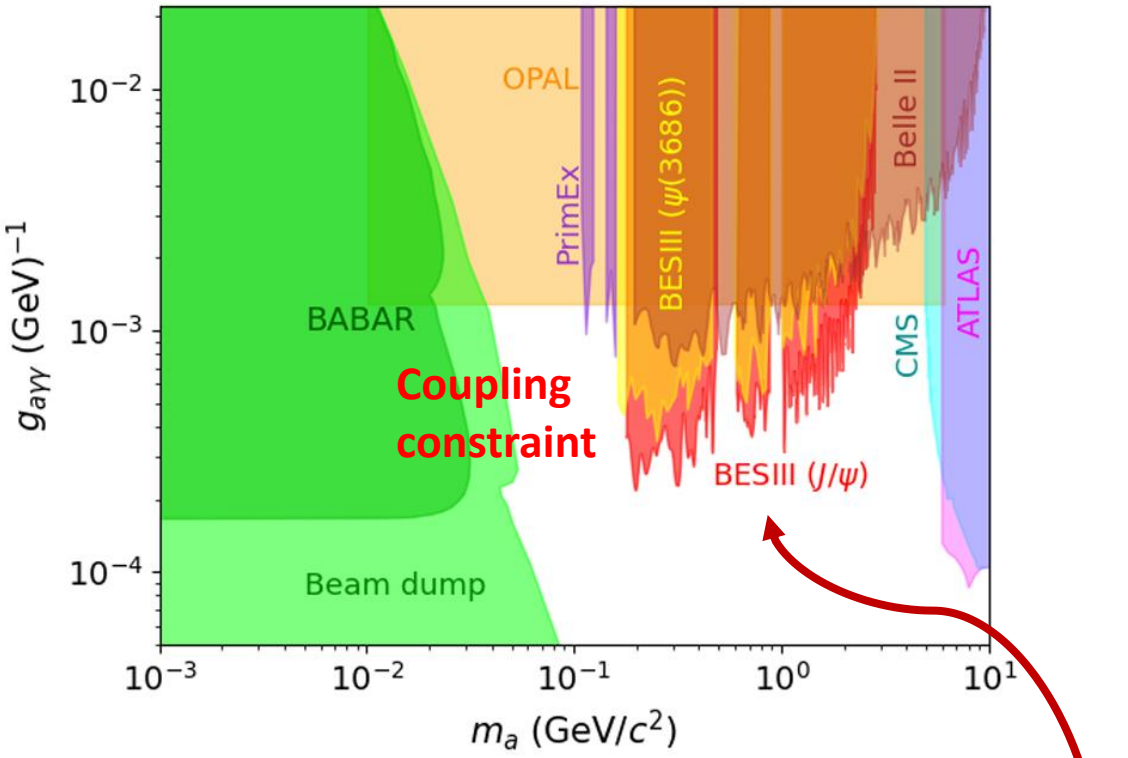
New searches for ALP at BESIII: $J/\psi \to \gamma a, a \to \gamma\gamma$

Phys.Rev.D 110 (2024) 3, L031101

Search for $J/\psi \to \gamma a_{\gamma\gamma}$ at BESIII



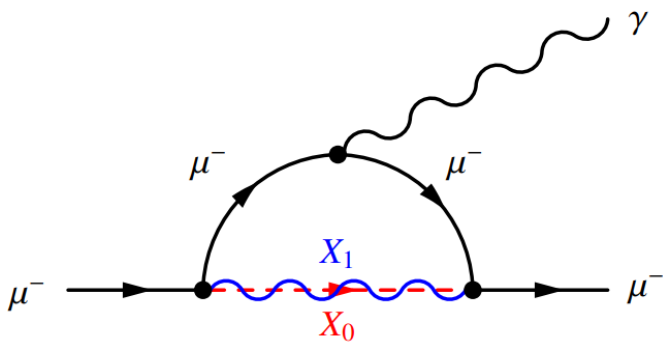
- 10^{10} J/ψ events
- Extract signal from $M_{\gamma\gamma}$ distribution
- Maximum signal significance: $< 3\sigma$



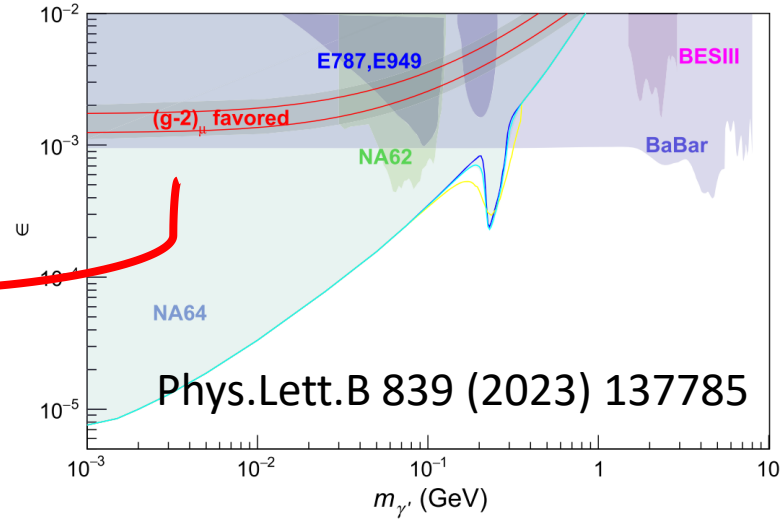
- UL on the BF of $\mathcal{B}(J/\psi \to \gamma a) \times \mathcal{B}(a \to \gamma\gamma)$ $(3.6 \sim 53.1) \times 10^{-8}$ @ 90% C.L.
- New stringent constraints on ALP-photon coupling for $0.18 \leq m_a \leq 2.85$ GeV

Why we need the muon-philic particle

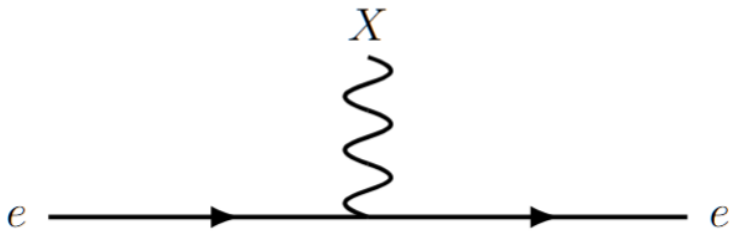
To explain $g_\mu - 2$ anomaly:
Add a new particle X, like dark photon



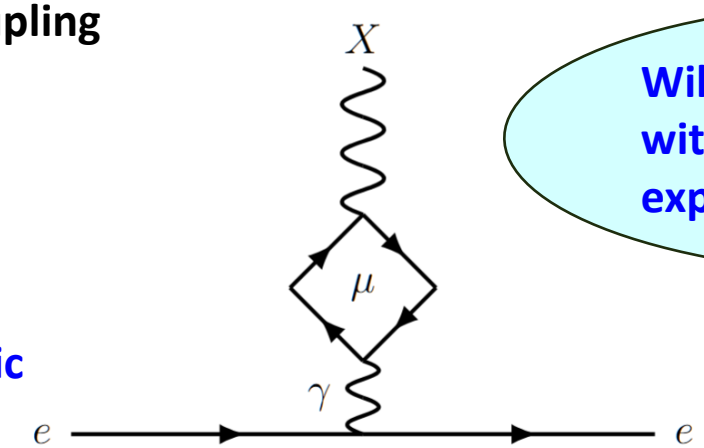
Has been Excluded



But most of the experiments are based on electron coupling or light quark coupling



If X is only muon-philic



Will have worse constraint with electron-coupling experiment

Call for a tree-level muon-coupling experiment

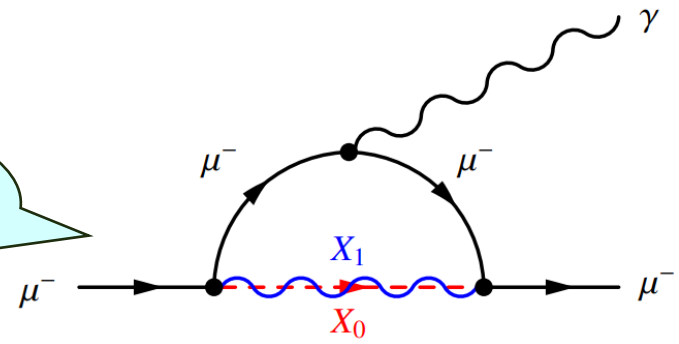
Phys.Rev.D 109 (2024) 3, L031102

Search for $J/\psi \to \mu^+\mu^-$ + invisible at BESIII

- $U(1)_{L\mu-L\tau}$ **model**: A new massive scalar boson X_0 or vector boson X_1 **only couples to the second and third generations** of leptons $(\mu, \nu_\mu, \tau, \nu_\tau)$ with the **coupling strength** $g'_{0,1}$

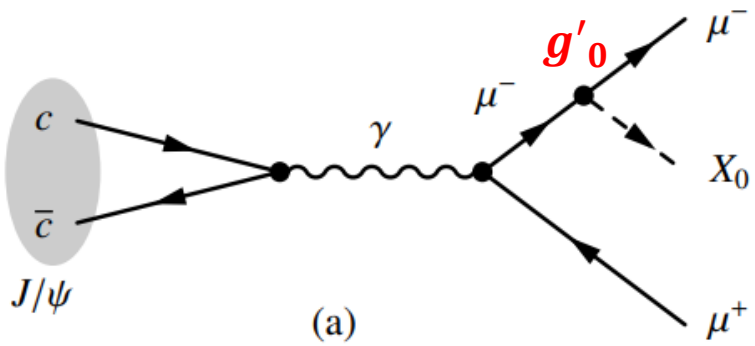
$$\mathcal{L}_\mu^{\text{scalar}} = -g_0\, X_0\, \bar{\mu}\, \mu,$$
$$\mathcal{L}_\mu^{\text{vector}} = -g_1\, X_{1\alpha}\, \bar{\mu}\, \gamma^\alpha\, \mu.$$

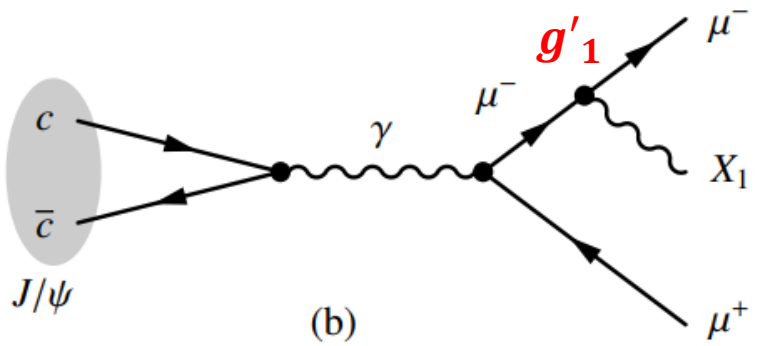
explain $(g-2)_\mu$ anomaly



- ➢ **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

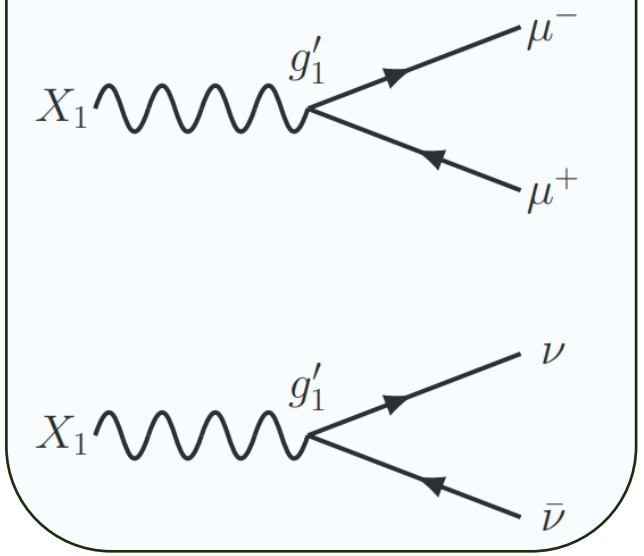




Phys.Rev.D 109 (2024) 3, L031102

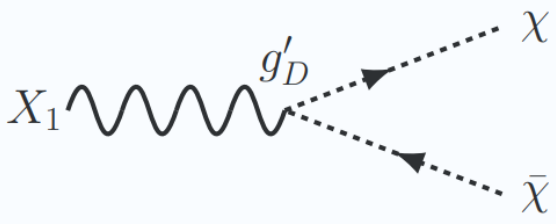
Search for $J/\psi \to \mu^+\mu^- +$ invisible at BESIII

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



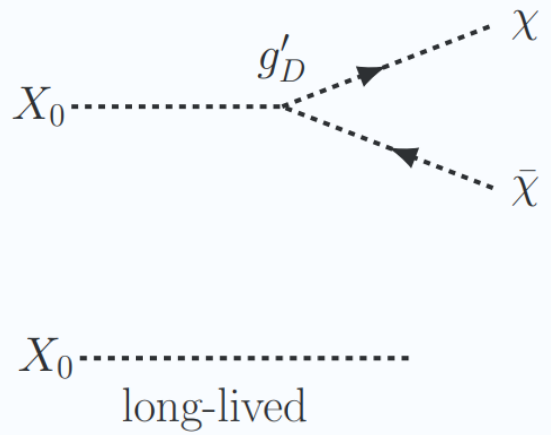
- Large mass of dark matter kind: $m_\chi > m_{X_1}/2$
- $\mathcal{B}(X_1 \to \upsilon\bar{\upsilon}) = 33\% - 100\%$ with different m_{X_1}

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



- Light dark matter kind: $m_\chi < m_{X_1}/2$
- $g'_D \gg g'_1$
- $\mathcal{B}(X_1 \to \chi\bar{\chi})$~100%

"scalar" $U(1)$ model



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

Search for muon-philic scalar X_0 or vector X_1 via $J/\psi \to \mu^+\mu^- X_{0,1}$ with $X_{0,1}$ invisible

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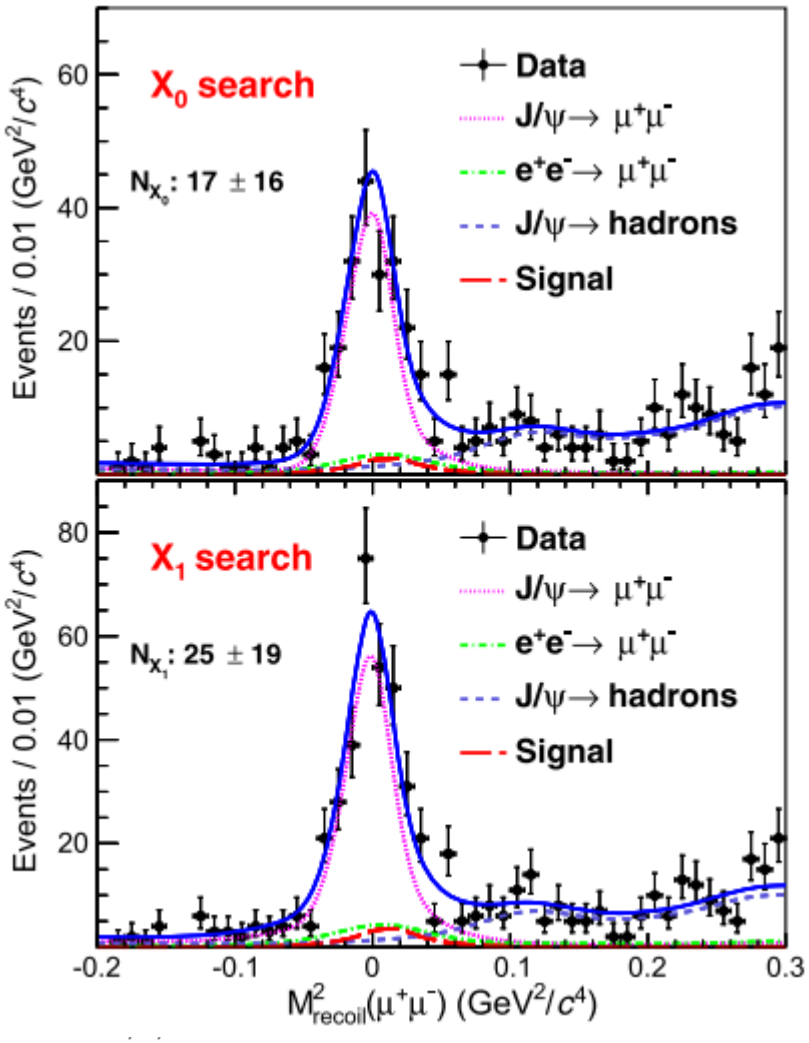
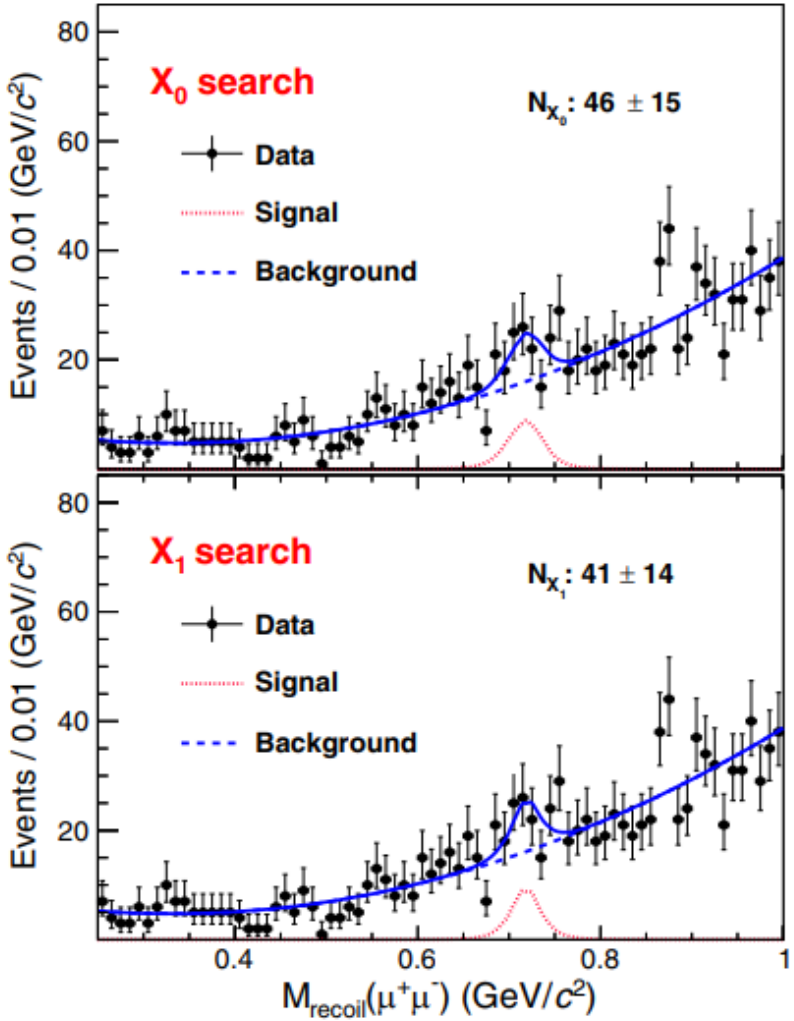
Search for $J/\psi \to \mu^+\mu^- +$ invisible at BESIII

Low mass region



High mass region



- Data samples: $\sim 9 \times 10^9$ J/ψ events
- **No evidence** for invisible $X_{0,1}$

Maximum local signal significance: $\mathbf{2.5\sigma}$ at $\mathrm{M}(X_{0,1}) = 720\ MeV/c^2$

UL on the BF: 10^{-7} to 10^{-9} order

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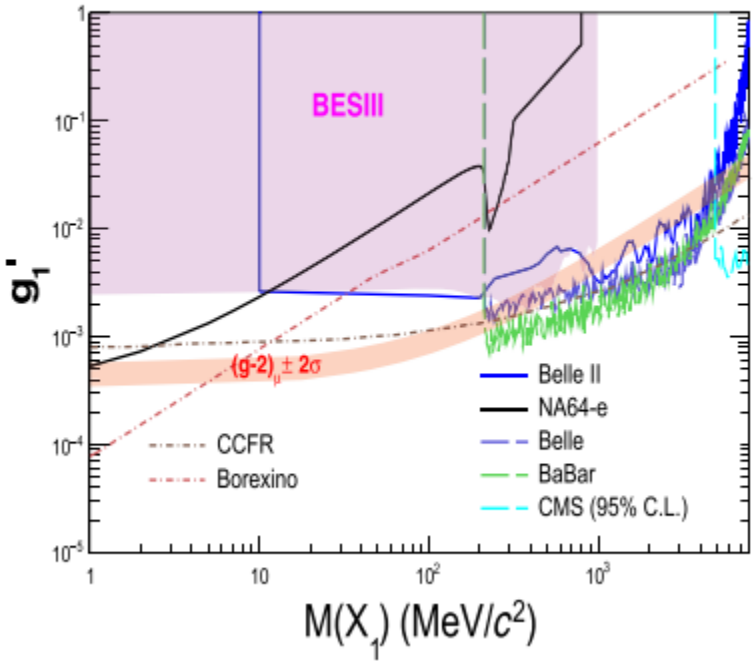
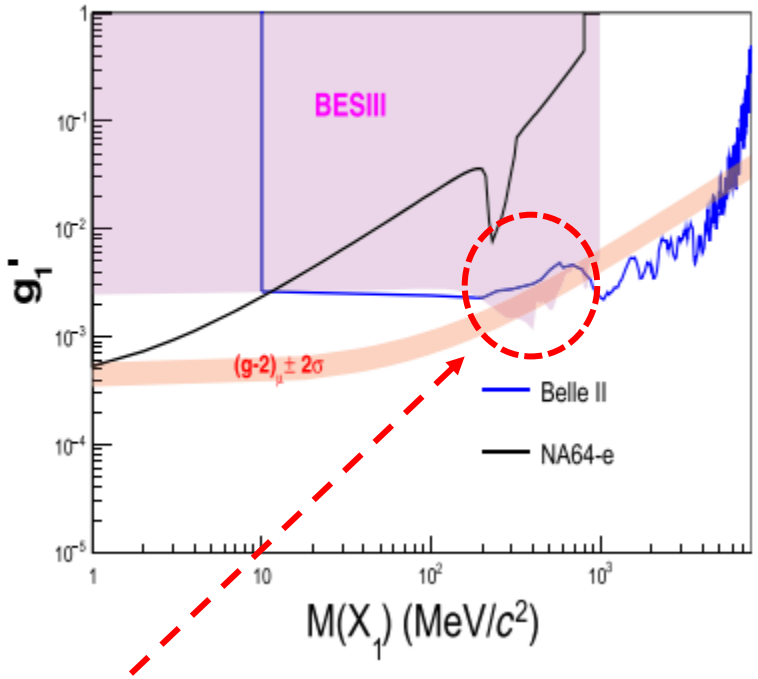
Search for $J/\psi \to \mu^+\mu^- +$ invisible at BESIII

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



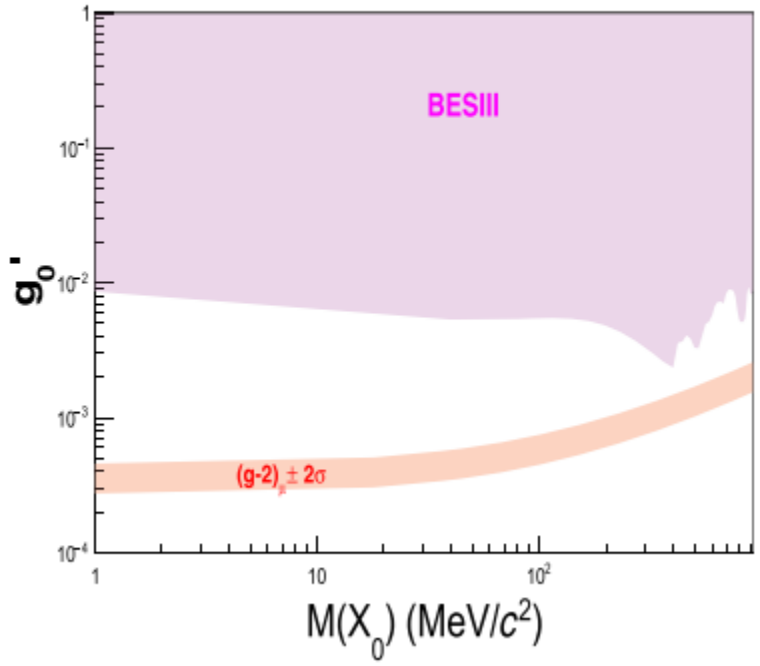
BarBar, CMS, Belle: $X_1 \to \mu^+\mu^-$
Belle II, BESIII: $X_1 \to \nu\bar{\nu}$
(Taking $\mathcal{B}(X_1 \to \nu\bar{\nu})$ into account)

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



Better sensitivity in the range 200-860 MeV/c^2

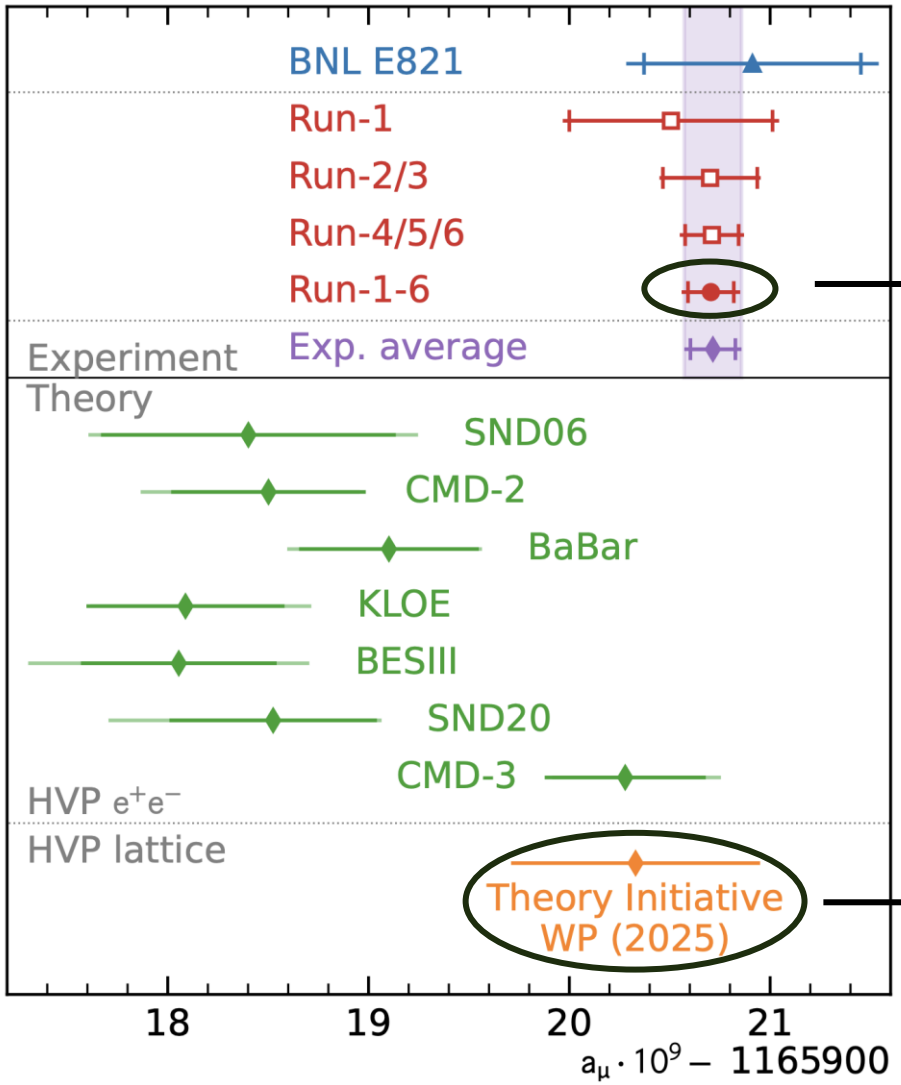
"scalar" $U(1)$ model



First constraint for the "scalar" invisible X_0 case
Belle II can also give the constraint

"Significant Room Remaining for $g_\mu - 2$ Anomaly; Big Potential!" —— from my talk in 2025.3

Newest state of $(g-2)_\mu$



New exp. value
arXiv:2506.03069

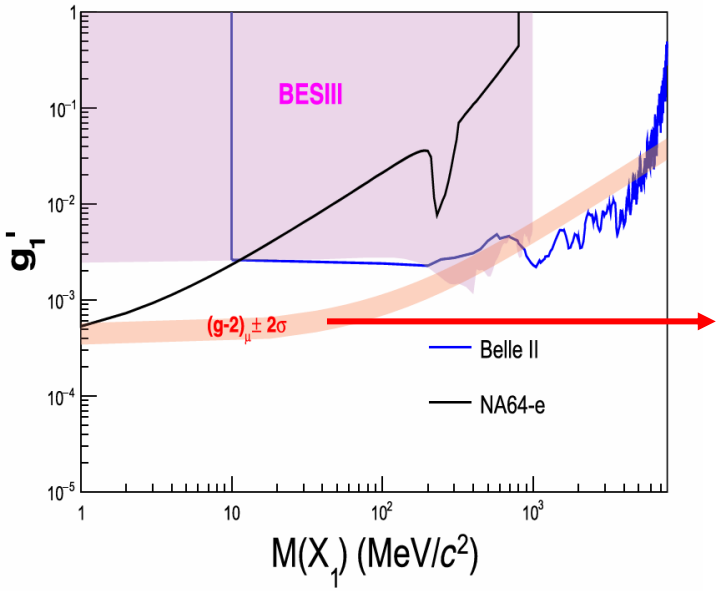
New Lattice value
arXiv: 2505.21476

Before 2025.5:

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (\mathbf{249 \pm 48}) \times 10^{-11}$$

After 2025.5:

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (\mathbf{38.5 \pm 64}) \times 10^{-11}$$

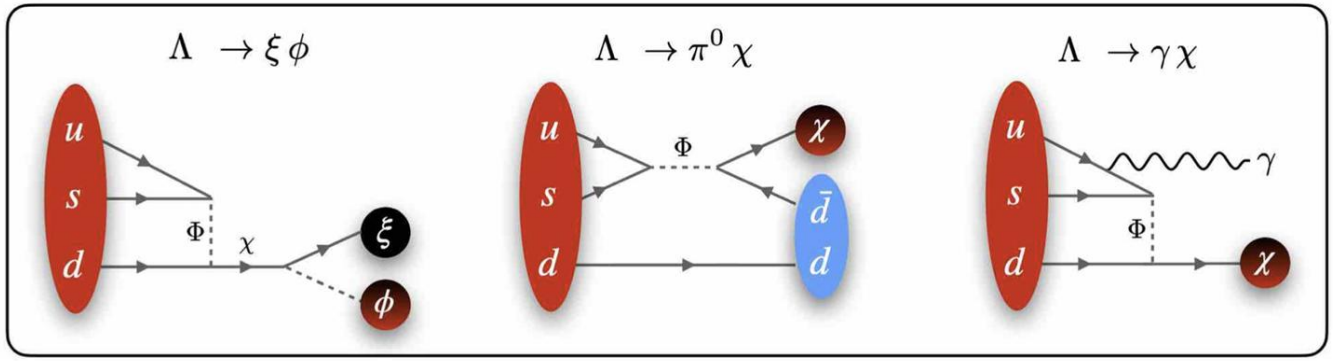


Before 2025.5:
Allowed region

After 2025.5:
Upper limit

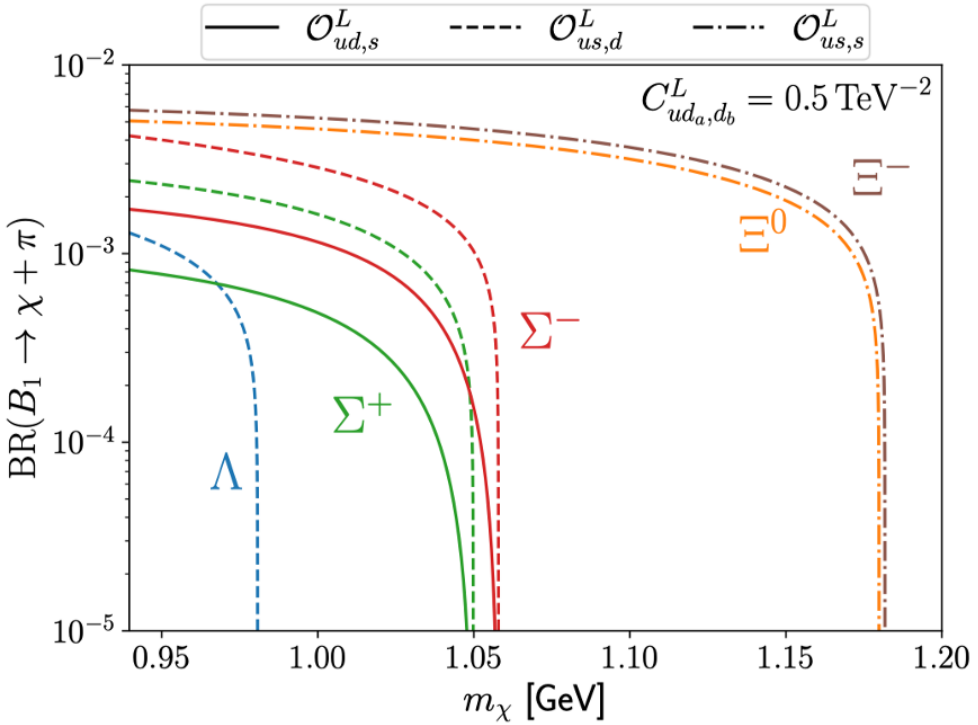
Not only muon-philic, others like dark photon, dark higg, axion… are also changed to an UL

Dark baryon in Hyperon decays



- Missing energy + pion: $B_1 \to \chi + \pi$, for $m_\chi < m_{B_1} - m_\pi$
- Missing energy + photon: $B_1 \to \chi + \gamma$, for $m_\chi < m_{B_1}$
- Missing energy only: $B_1 \to \xi + \phi$, for $m_\xi + m_\phi < m_{B_1}$

BESIII previous search: $\mathcal{B}(\Lambda \to \text{invisible}) < 7.4 \times 10^{-5}$
Phys.Rev.D 105 (2022) 7, L071101



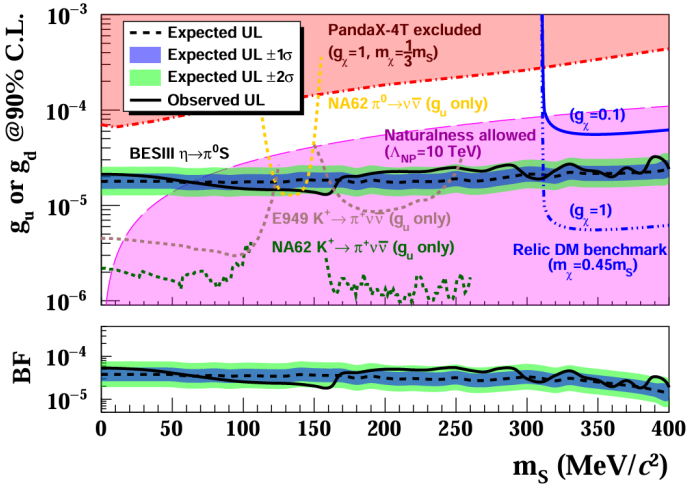
Phys.Rev.D 105 (2022) 11, 115005

$\Xi^- \to \pi^- \chi$: better sensitivity in theory

arXiv: 2601.10597

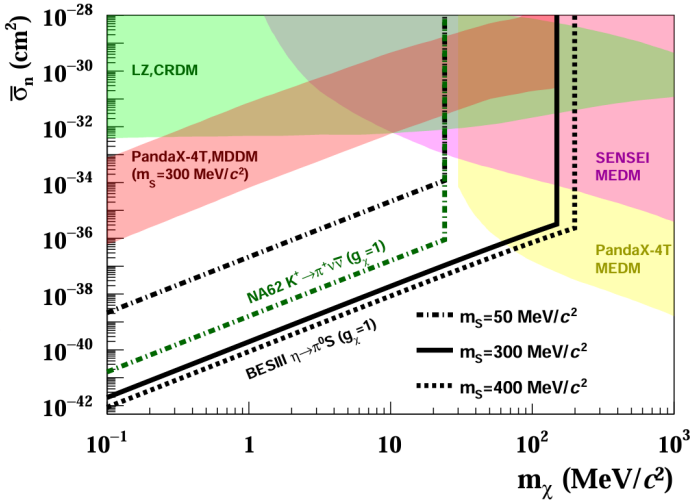
Discussion within the specific model

- $\mathcal{L} \supset -g_\chi S \bar{\chi}_L \chi_R - g_u S \bar{u}_L u_R + h.c., \quad g_u \equiv \frac{c_S v}{\sqrt{2}\Lambda_{NP}}$
  - The coupling strength g_u not necessarily proportional to the Higgs Yukawa couplings



$$\mathcal{B} \propto g_u^2 \lambda^{\frac{1}{2}} (1, \frac{m_S^2}{m_\eta^2}, \frac{m_{\pi^0}^2}{m_\eta^2})$$

- **Relic DM** benchmark
  - Freeze-out by $\chi\bar{\chi} \to \pi\pi$
  - **Excluded when $g_\chi = 0.1$**



$$\bar{\sigma}_n \propto \frac{g_u^2 g_\chi^2}{m_S^4} (\frac{m_\chi m_N}{m_\chi + m_N})^2$$

- **model-dependent**
  - Scattering mediated by on-shell S

- **UL on g_u @90% C.L.: $(1.3 \sim 3.2) \times 10^{-5}$**
  - Better than the result of atmospheric-boosted DM from PandaX-4T

- Constraint on DM-nucleon cross section ($\bar{\sigma}_n$)
  - **Improved by approximately 5 orders** of magnitude over previous DM-nucleon scattering experiments

- **Ongoing and Future**
  - Larger S mass in $\eta' \to \pi^0 \chi\bar{\chi}$
  - Off-shell S case in $\eta \to \pi^0 \chi\bar{\chi}$
  - Pseudo-scalar case in $\eta \to \pi^+\pi^- \chi\bar{\chi}$
  - Vector case in $\pi^0/\eta \to \gamma\chi\bar{\chi}$
  - ……