

BESIII



Search for dark sector at BESIII

Zhi-Jun Li (李志军)

Sun Yat-sen University

On behalf of the BESIII Collaboration

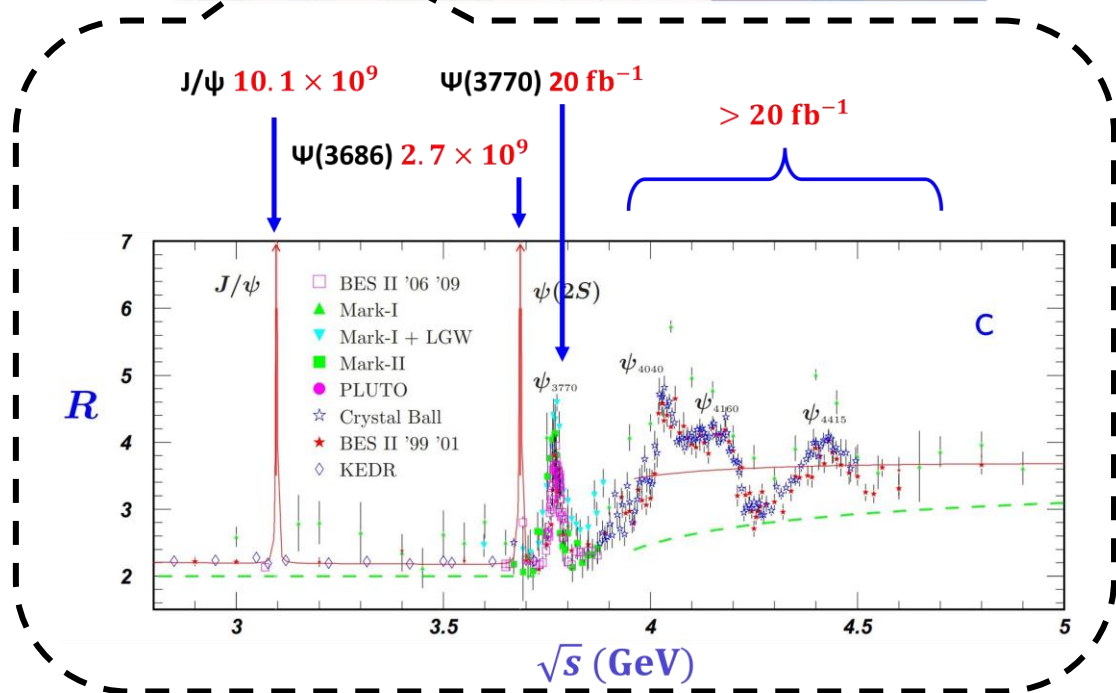
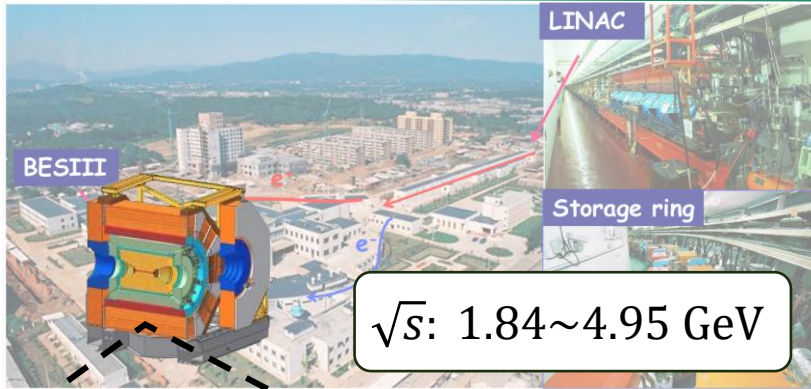
2026.4.12

第十八届粒子物理、核物理和宇宙学交叉学科前沿问题研讨会 广西·桂林



lizhj37@mail2.sysu.edu.cn

BESIII experiment



2026/4/10

■ $10.1 \times 10^9 J/\psi$ events

• Hyperon

• Light meson

Λ	$\bar{\Lambda}$	η	η'
$\Sigma^{0,+}$	$\bar{\Sigma}^{0,-}$	ϕ	ω
$\Xi^{0,-}$	$\bar{\Xi}^{0,+}$	K_S^0	

~ 10^7 ~ 10^7

■ $20 \text{ fb}^{-1} \psi(3770)$

D^0	\bar{D}^0	D^+	D^-
-------	-------------	-------	-------

~ 10^7

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

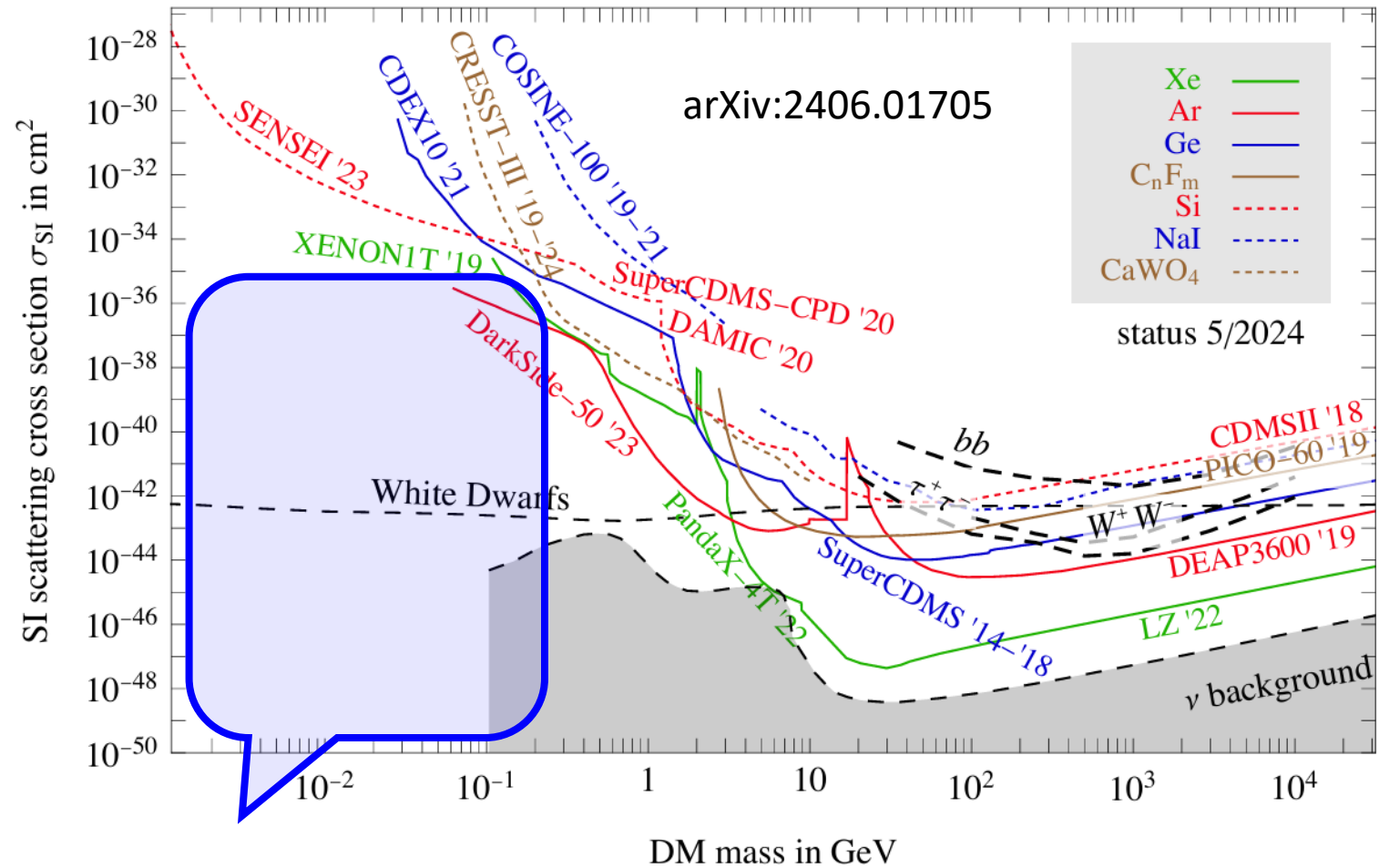
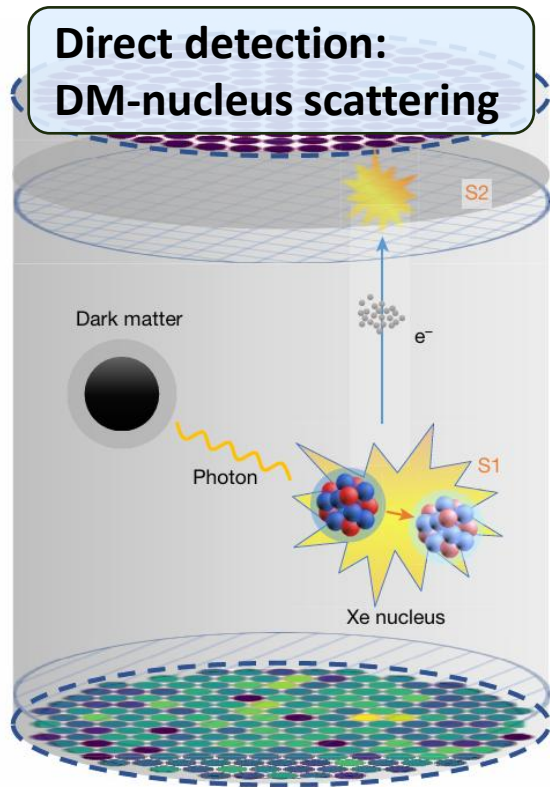


Dark sector search at BESIII (in recent years)

- Search for sub-GeV DM in $\eta \rightarrow \pi^0 + \text{invisible}$, [arXiv: 2601.10597](#) **Very recent results, This talk**
- Search for sub-GeV DM in $J/\psi \rightarrow \phi + \text{invisible}$, **Phys.Rev.Lett. 135, 151804 (2025)**
- Search for $K_S^0 \rightarrow \text{invisible}$, **JHEP 05 (2025) 092**
- Search for dark baryon in $\Xi^- \rightarrow \pi^- + \text{invisible}$, **Phys. Lett. B 872 (2026) 140099**
- Search for QCD axion in $\Sigma^+ \rightarrow p + \text{invisible}$, **Phys.Lett.B 852 (2024) 138614**
- Search for QCD axion in $\Xi^0 \rightarrow \Lambda + \text{invisible}$, **arXiv:2603.03199**
- Search for massless dark photon in $D^0 \rightarrow \omega/\gamma + \text{invisible}$, **Phys.Rev.D 111 (2025) 1, L011103**
- Search for massless dark photon in $\Lambda_c \rightarrow p + \text{invisible}$, **Phys.Rev.D 106 (2022) 7, 072008**
- Search for muon-philic particle in $J/\psi \rightarrow \mu^+\mu^- + \text{invisible}$, **Phys.Rev.D 109 (2024) 3, L031102**
- Search for dark photon in $e^+e^- \rightarrow \gamma + \text{invisible}$, **Phys.Lett.B 839 (2023) 137785**
- Search for axion-like particle in $J/\psi \rightarrow \gamma a, a \rightarrow \gamma\gamma$, **Phys.Lett.B 838 (2023) 13769**
- Search for axion-like particle in $J/\psi \rightarrow \gamma a, a \rightarrow \gamma\gamma$, **Phys.Rev.D 110 (2024) 3, L031101**
- Search for light vector boson in $\chi_{cJ} \rightarrow J/\psi V, V \rightarrow e^+e^-$, **Phys.Rev.D 113 (2026) 3, 032009**
-

Some in backup

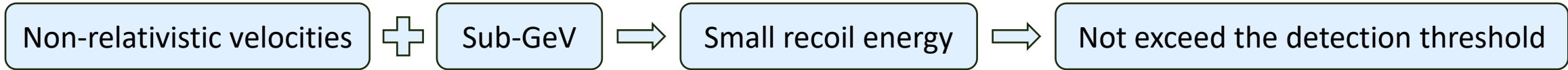
Dark matter (DM) search status



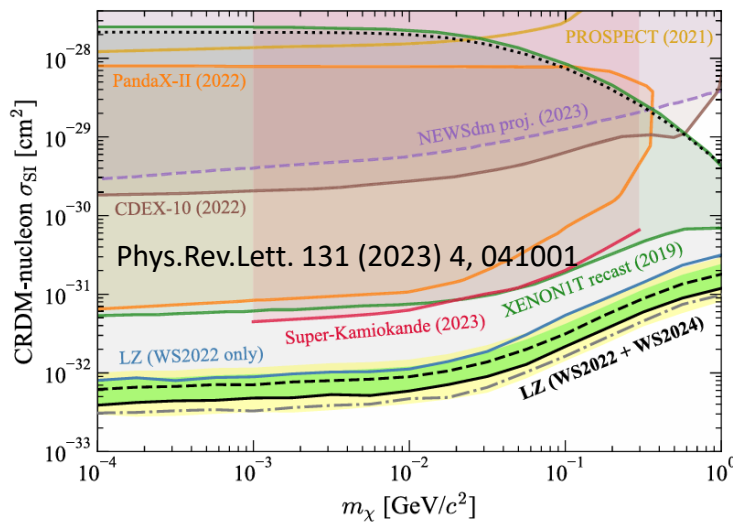
- GeV to TeV scale: strong constraint, not found any WIMP signal
- Sub-GeV: insufficient nuclear recoil energy to be detected, less exploration

Sub-GeV DM search status

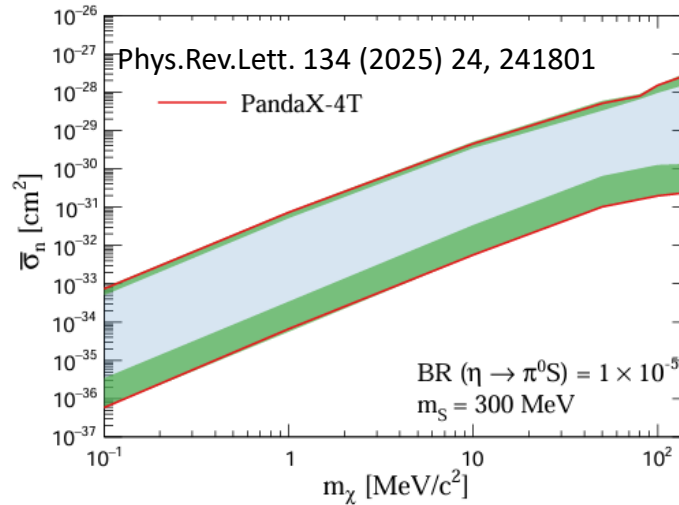
➤ The challenge of the sub-GeV DM detection



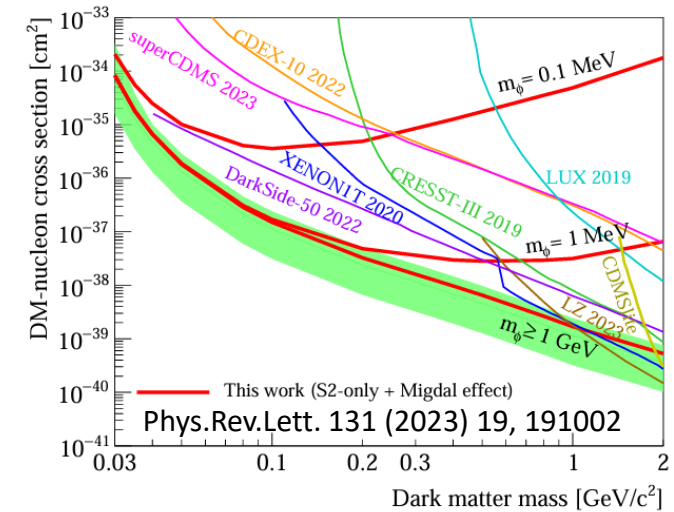
➤ Solutions of the sub-GeV DM detection: **1. boosted DM** **2. low threshold detection**



Cosmic-ray boosted DM



Atmospheric-meson-decay boosted DM

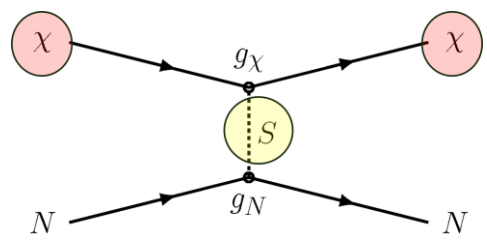


Migdal effect to lower the threshold

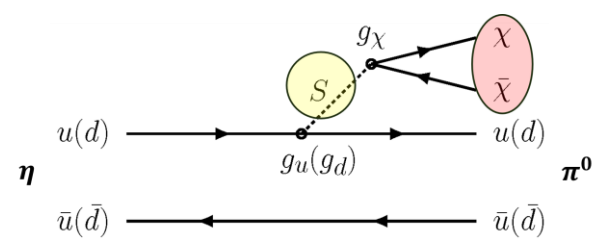
- Hard work but **sensitivity remains limited** due to the reduced DM Flux or reduced detection probability
- **BESIII operates in $\sim \text{GeV}$ region, can offer a unique opportunity to probe sub-GeV DM from the collider**



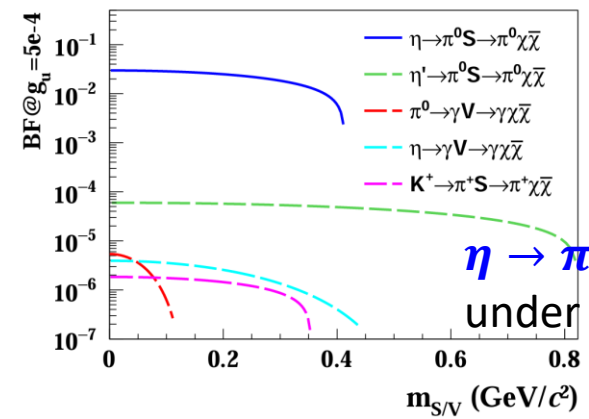
Search for $\eta \rightarrow \pi^0 + \text{invisible}$ at BESIII



DM-nucleon scattering



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



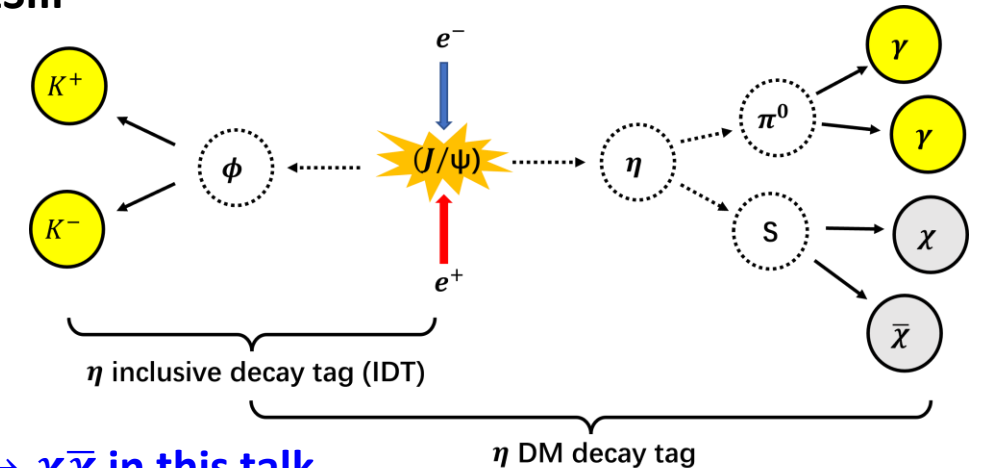
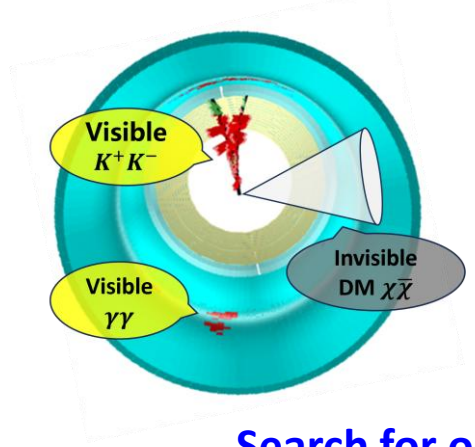
Flavor Conservation DM decays

$\eta \rightarrow \pi^0 S \rightarrow \pi^0 \chi \bar{\chi}$ 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 $\eta \rightarrow \pi^0 S \rightarrow \pi^0 \chi \bar{\chi}$ at BESIII

- Data set @ 3.097 GeV $(10087 \pm 44) \times 10^6 J/\psi$
- η source: $J/\psi \rightarrow K^+ K^- \eta$
- **Charged kaons help to tag η and DM**

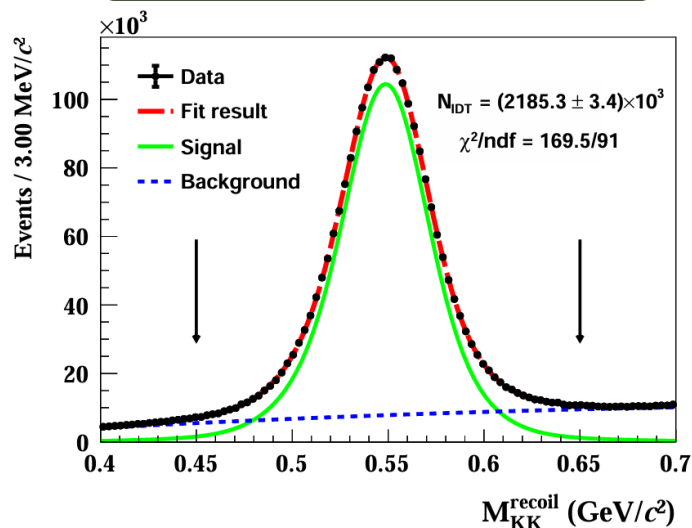


Search for on-shell $S \rightarrow \chi \bar{\chi}$ in this talk
The off-shell $S \rightarrow \chi \bar{\chi}$ search is ongoing



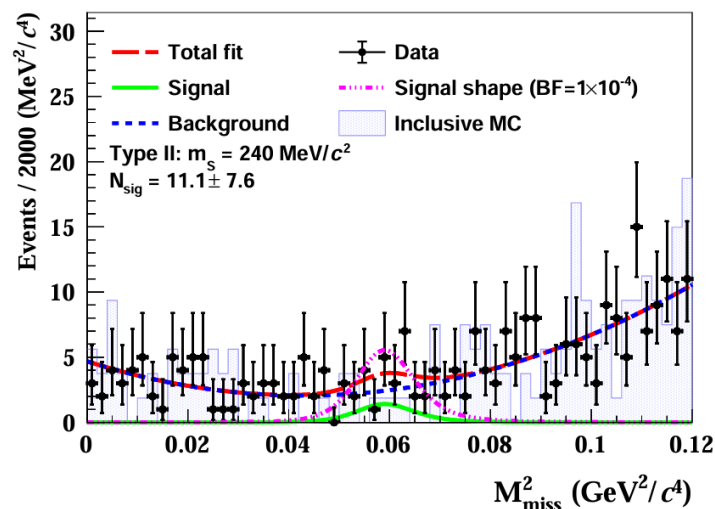
Search for $\eta \rightarrow \pi^0 + \text{invisible}$ at BESIII

Tag K^+K^- with $\eta \rightarrow \text{any}$



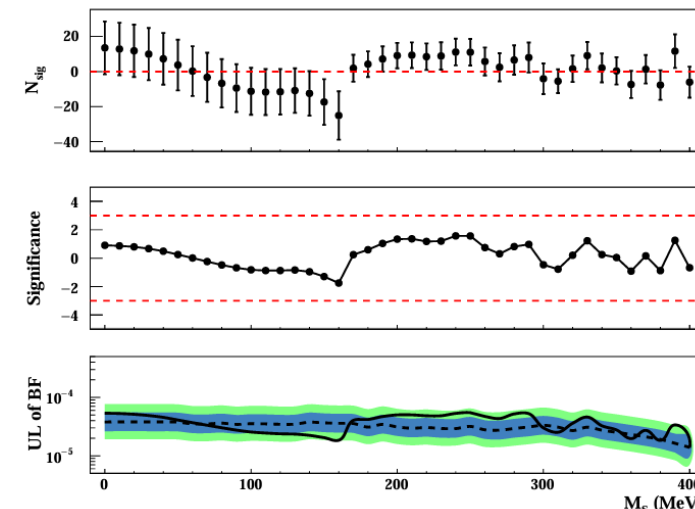
- The recoiling mass of K^+K^-
- $\sim 2 \times 10^6$ η events are tagged
- Not the world largest η data set, but may be the cleanest η data

Further tag $\eta \rightarrow \pi^0 + \text{inv}$



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

Scan signal with different m_S



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

▣ Advantages of **DM study at BESIII**

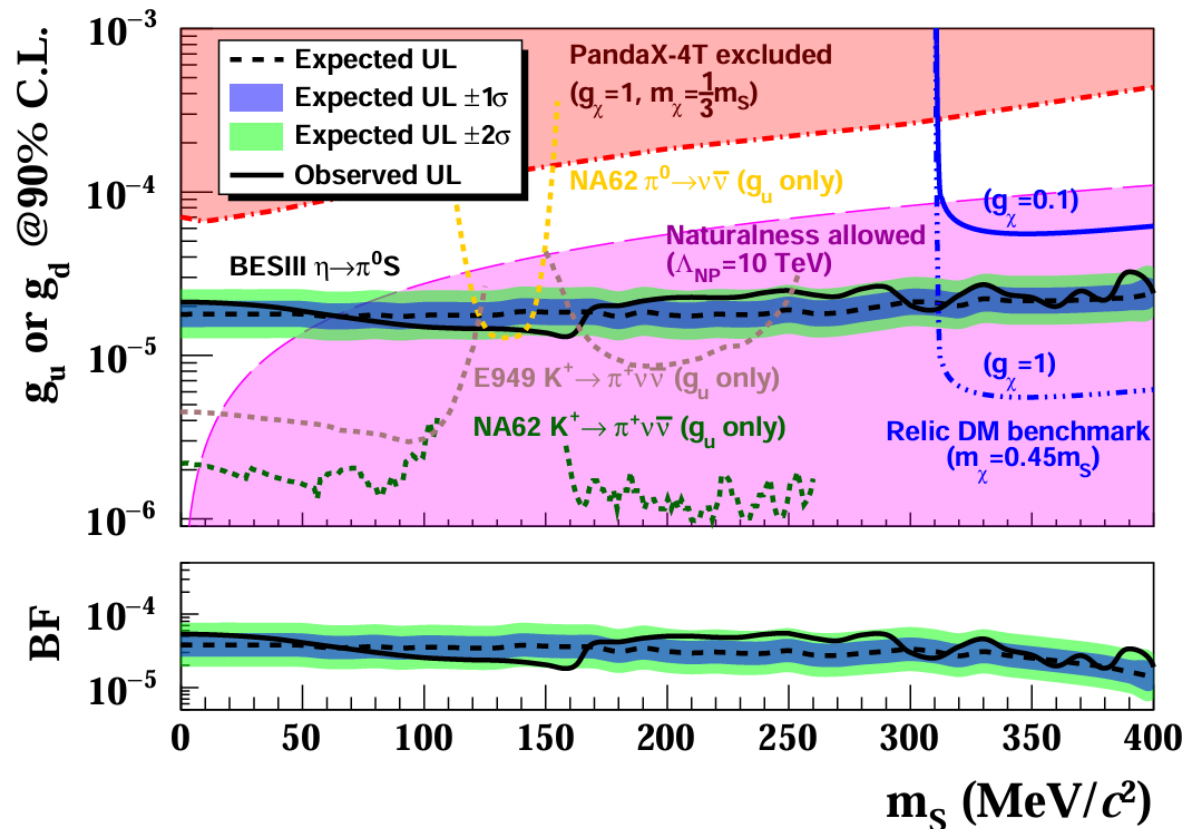
- **Clean background, full reconstruction, high efficiency, absolute BF measurement...**



Search for $\eta \rightarrow \pi^0 + \text{invisible}$ at BESIII

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

- The coupling strength g_u not necessarily proportional to the Higgs Yukawa couplings



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

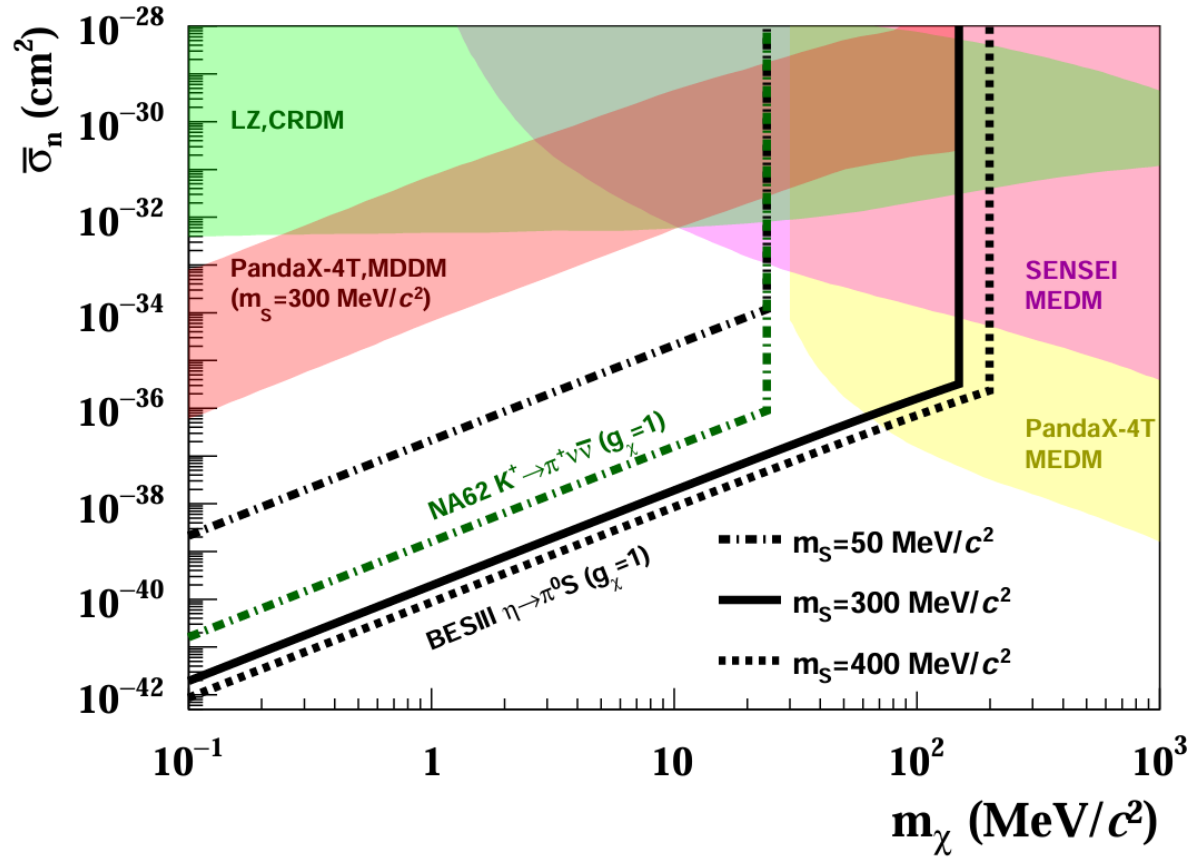
- **UL on g_u or g_d @90% C.L.:** $(1.3 \sim 3.2) \times 10^{-5}$
 - Better than the result of atmospheric-boosted DM from PandaX-4T
- Constraints from $K^+ \rightarrow \pi^+ + \text{invisible}$: only for g_u
- Naturalness bound in EFT, setting $\Lambda_{\text{NP}} = 10 \text{ TeV}$
 - $g_u \leq \frac{16\pi^2}{\sqrt{2}} \frac{m_S \nu}{\Lambda_{\text{NP}}^2}$
- **Thermal Relic DM** benchmark: Freeze-out by $\chi\bar{\chi} \rightarrow \pi\pi$
 - **Excluded when $g_\chi = 0.1$**



Search for $\eta \rightarrow \pi^0 + \text{invisible}$ at BESIII

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

- The coupling strength g_u not necessarily proportional to the Higgs Yukawa couplings

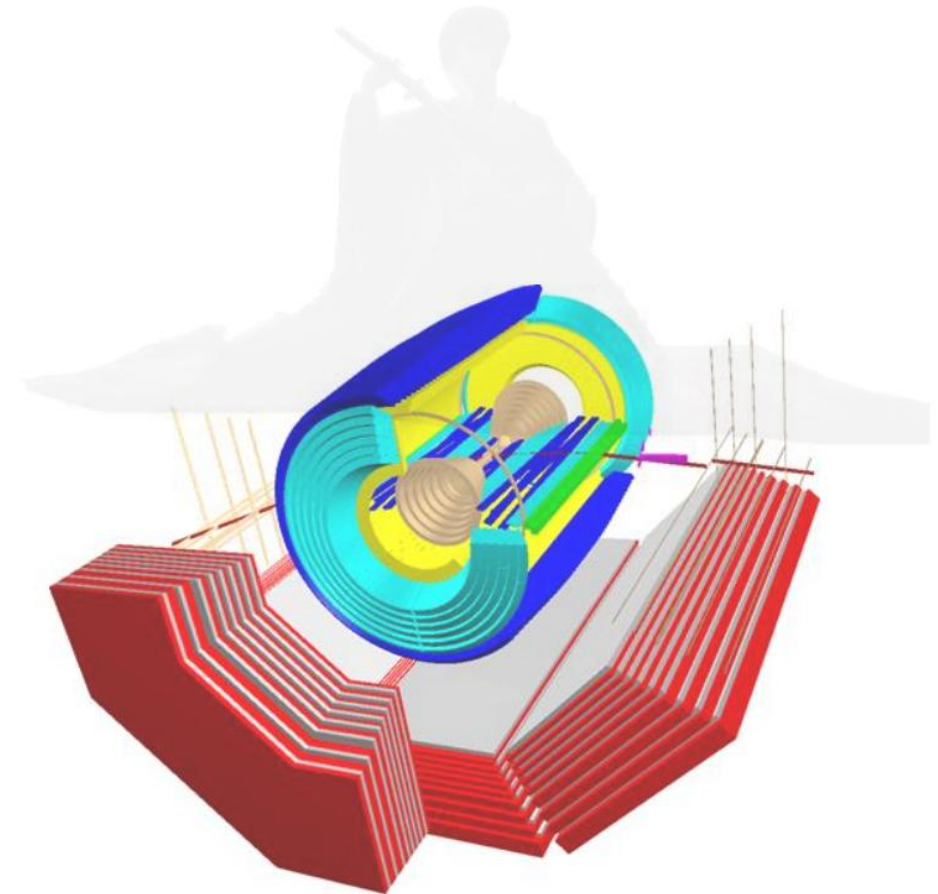


$$\bar{\sigma}_n \propto \frac{g_u^2 g_\chi^2}{m_S^4} \left(\frac{m_\chi m_N}{m_\chi + m_N} \right)^2$$

- 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 $\eta \rightarrow \pi^0 \chi \bar{\chi}$
 - Larger S mass in $\eta' \rightarrow \pi^0 \chi \bar{\chi}$
 - Pseudo-scalar case in $\eta \rightarrow \pi^+ \pi^- \chi \bar{\chi}$
 - Vector case in $\pi^0 / \eta \rightarrow \gamma \chi \bar{\chi}$
 -

Summary

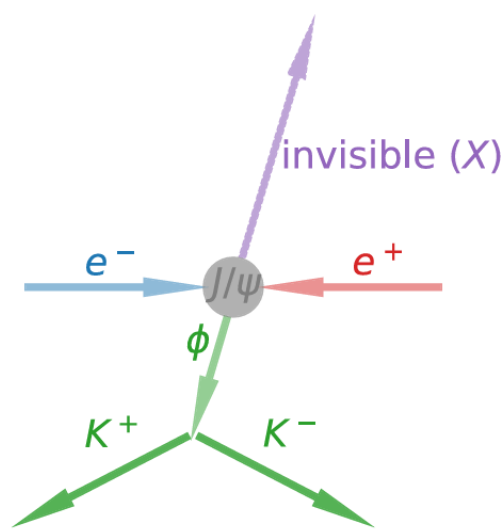
- **New result of sub-GeV dark sector at BESIII**
 - $\eta \rightarrow \pi^0 + \text{invisible}$
 - **Unique stringent constraints on the sub-GeV DM**
- **BESIII has collected $10^{10} J/\psi$, $2.7 \times 10^9 \psi'$, 20 fb^{-1} @ 3.77 GeV data ($D\bar{D}$) and more...**
- **More & better results are coming soon**



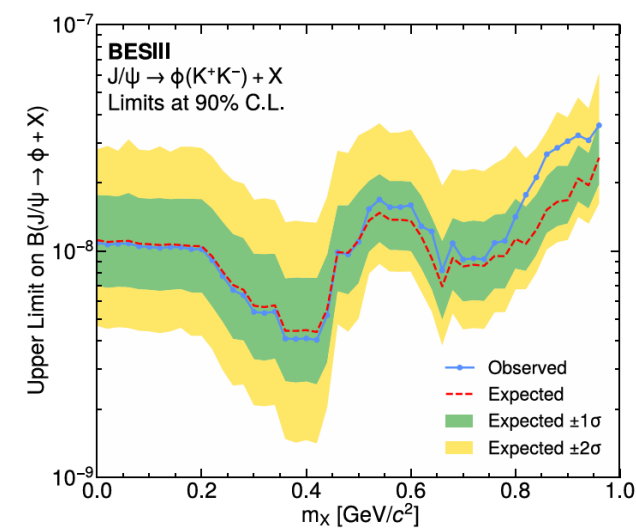
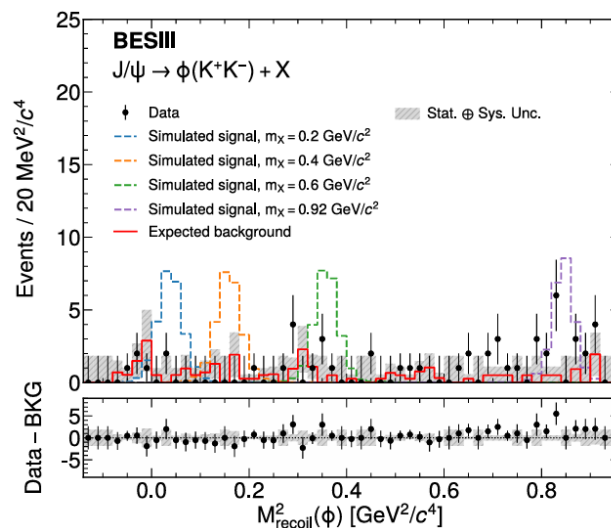


Search for $J/\psi \rightarrow \phi + \text{invisible}$ at BESIII

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



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

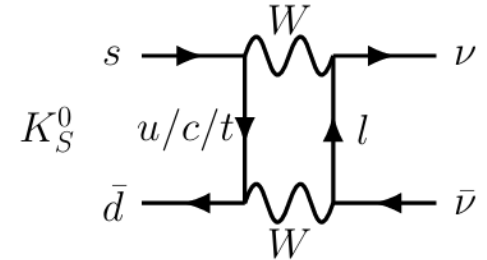
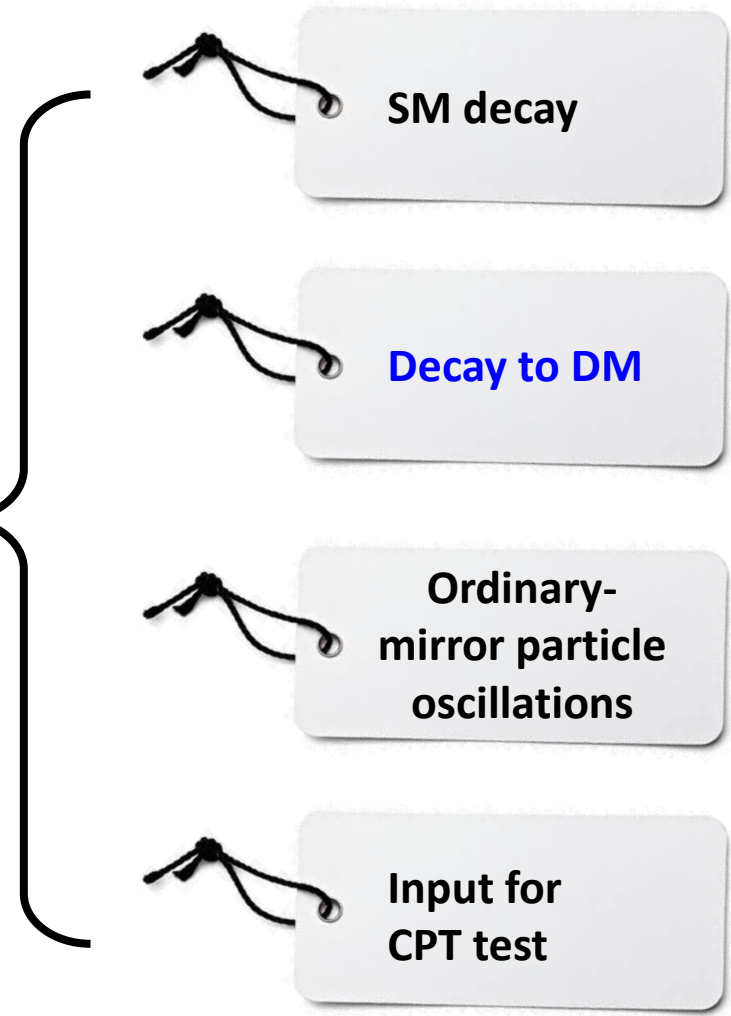


- **UL on $\mathcal{B}(J/\psi \rightarrow \phi X)$** with m_X ranging from 0 to 0.96 GeV @90% C.L.
 $4 \times 10^{-9} \sim 4 \times 10^{-8}$
- UL on the inclusive invisible BF of $J/\psi \rightarrow \phi X$: 7.0×10^{-8} @90% C.L.
- Taking $X = \eta$, **UL on $\mathcal{B}(\eta \rightarrow \text{invisible})$: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

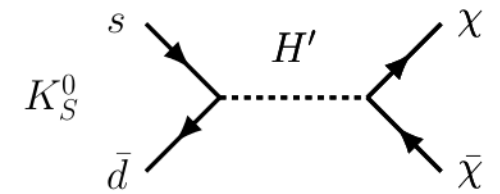
Lacking the theoretical connection to the physical coupling (and DM XS)
More theoretically complex in charm decay, still wait for a calculation...

K_S invisible decay

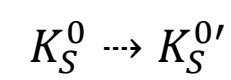
Invisible decay of K_S^0



BF 10^{-16}
FCNC && Helicity suppression
 Phys.Rev.D 91 (2015) 1, 015004



2HDM model
BF ~ $\mathcal{O}(10^{-6})$
 Natural Sci.Rev. 1 (2024) 5



Mirror matter model
BF ~ $\mathcal{O}(10^{-6})$ arXiv: 2006.10746

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

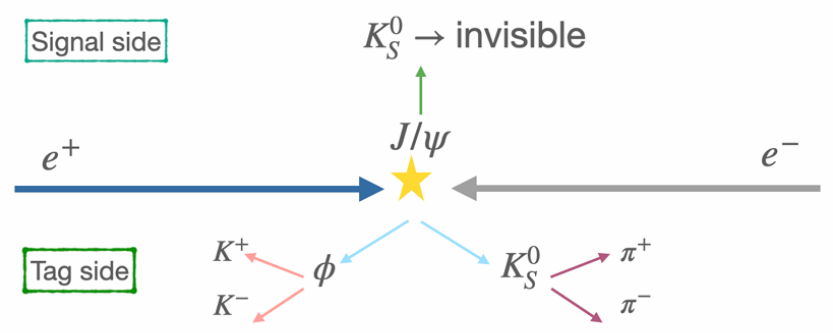
Phys.Rev.D 91 (2015) 1, 015004



Search for K_S^0 invisible decay at BESIII

K_S^0 source

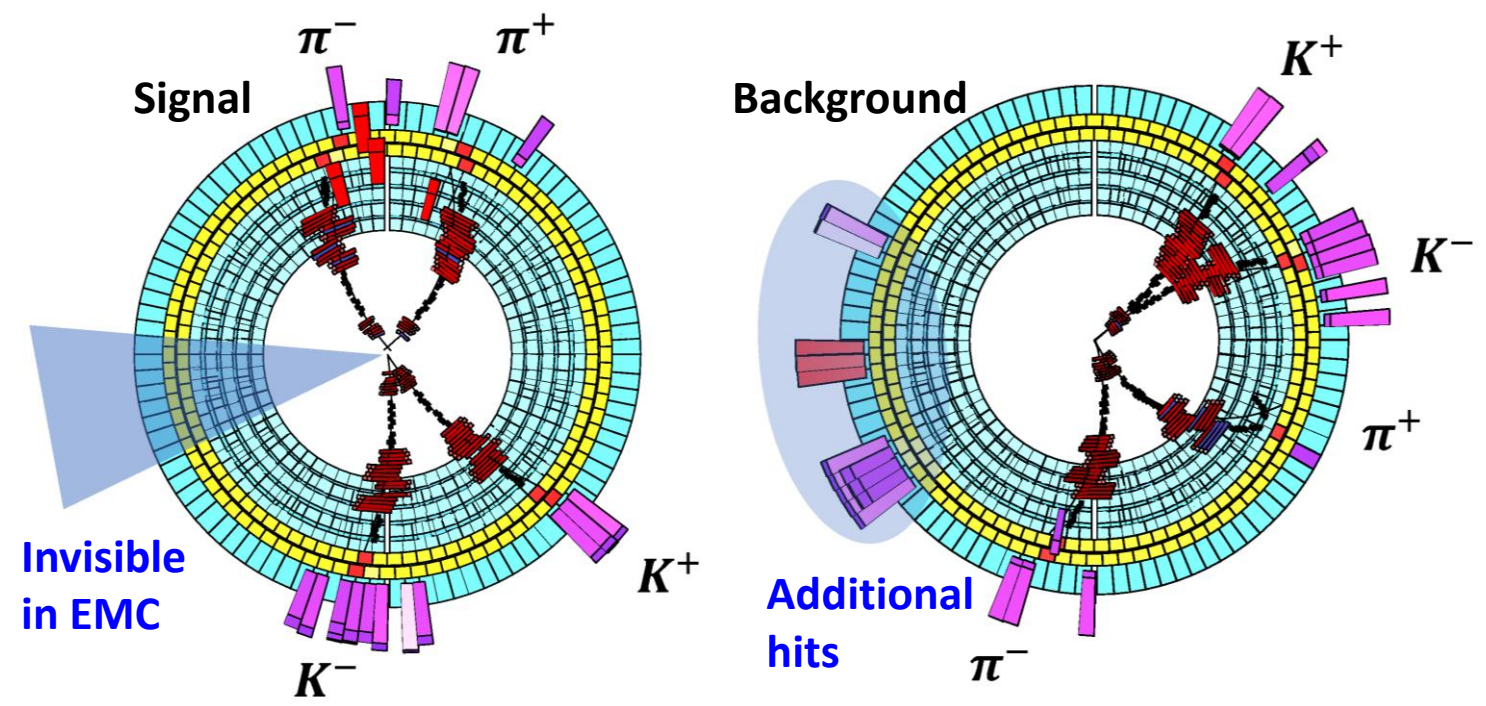
$J/\psi \rightarrow \phi K_S^0 K_S^0$ from $(10087 \pm 44) \times 10^6 J/\psi$



Why this channel?

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

Signal feature



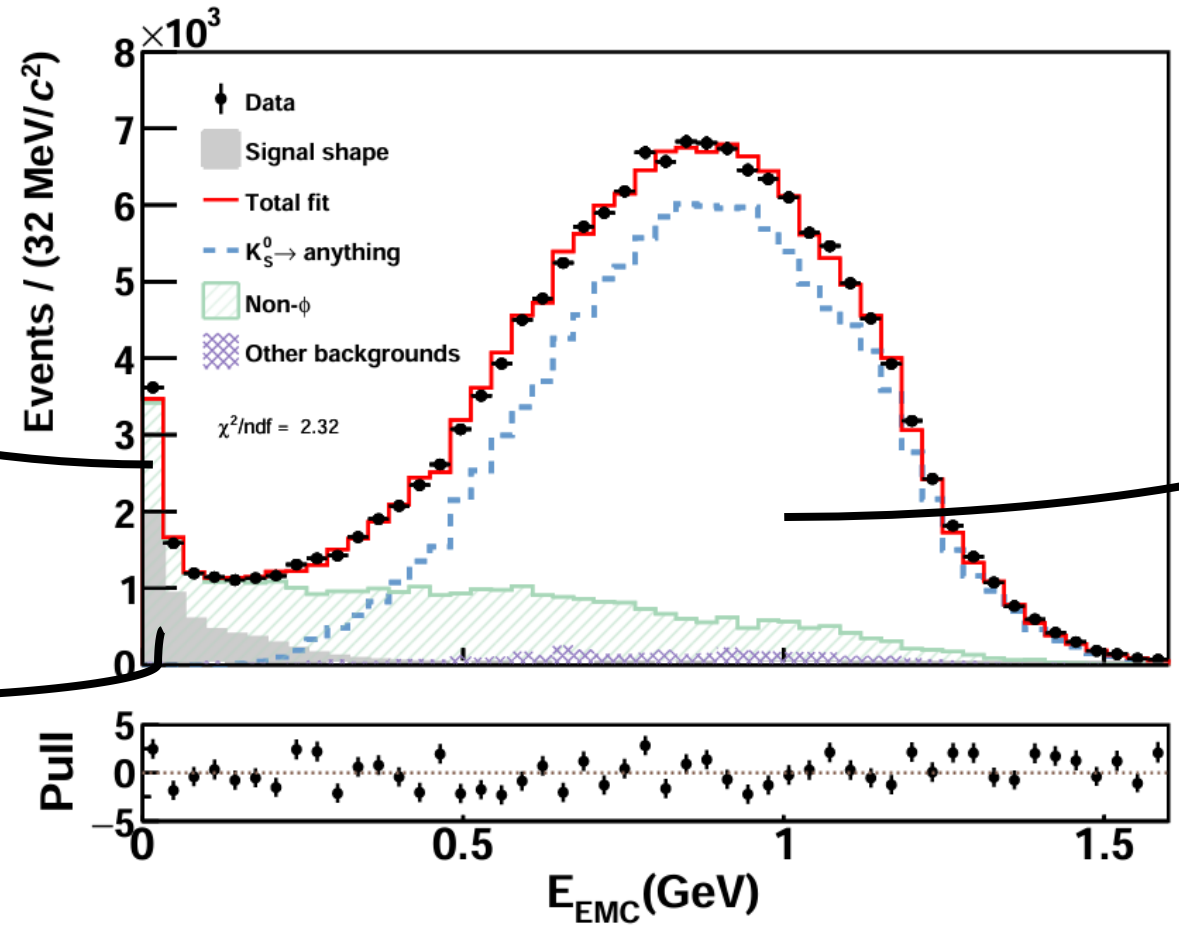
- Using the deposited energy in EMC to identify the invisible signal
- **An alternative method for invisible signal search at BESIII**



Search for K_S^0 invisible decay at BESIII

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

Invisible Signal
peaks around zero



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

$N_{sig} = 56 \pm 201$
 $\mathcal{B}(K_S^0 \rightarrow \text{invisible}) < 8.4 \times 10^{-4}$
(90% C.L.)

arXiv: 2501.06426

First direct measurement of $K_S^0 \rightarrow \text{invisible}$; the UL still lies above the NP prediction

Dark baryon

Coincidence problem

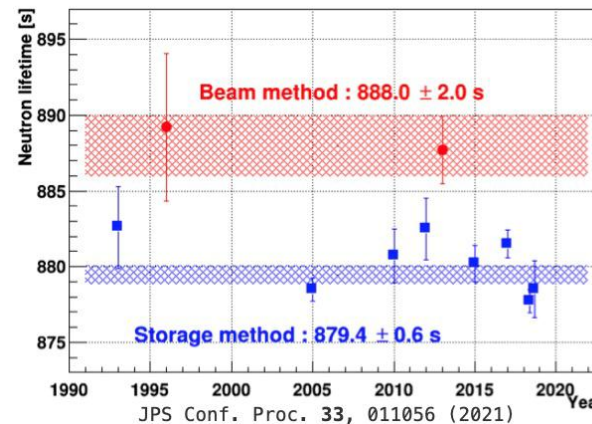


The baryon and dark matter energy densities are fairly similar
 $\Omega_{DM}/\Omega_b \cong 5.36 \pm 0.06$

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



Neutron lifetime puzzle



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

- **Motivates the existence of dark baryon**

B-Mesogenesis mechanism



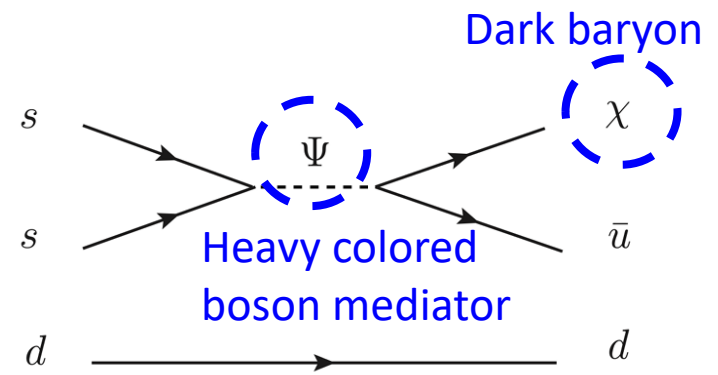
CP asymmetry in $B \rightarrow \text{baryon} + \text{dark baryon}$

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

Naturally, dark baryon interacts with all SM quark flavor
 \Rightarrow **Search for dark baryon in hyperon decay at BESIII**

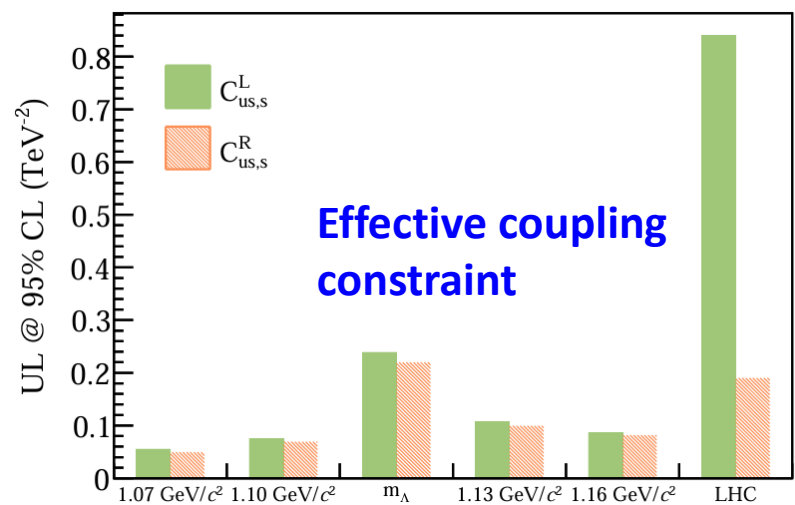
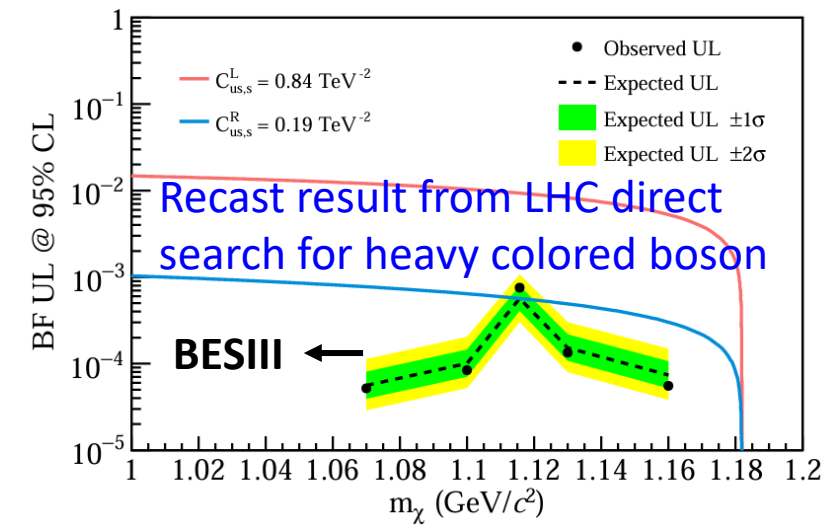
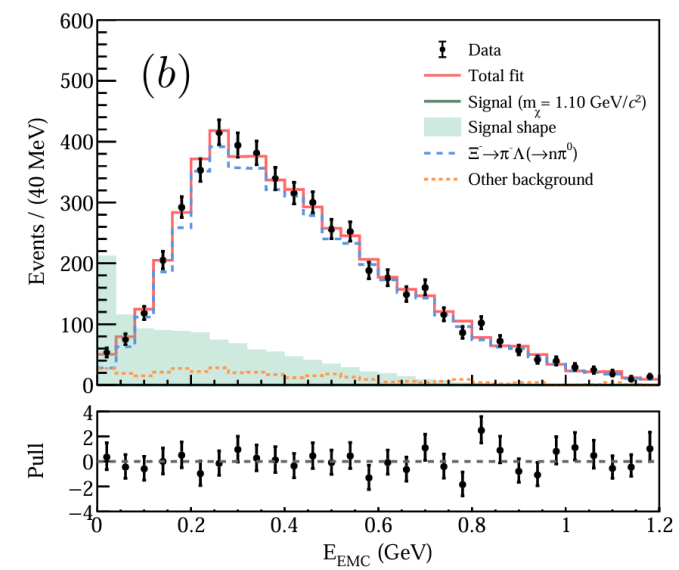


Search for $\bar{E}^- \rightarrow \pi^- + \text{invisible}$ at BESIII



➤ $J/\psi \rightarrow \bar{E}^+ E^-$ from $10^{10} J/\psi$

- $\bar{E}^+ \rightarrow \text{SM}, E^- \rightarrow \pi^- \chi$
- 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

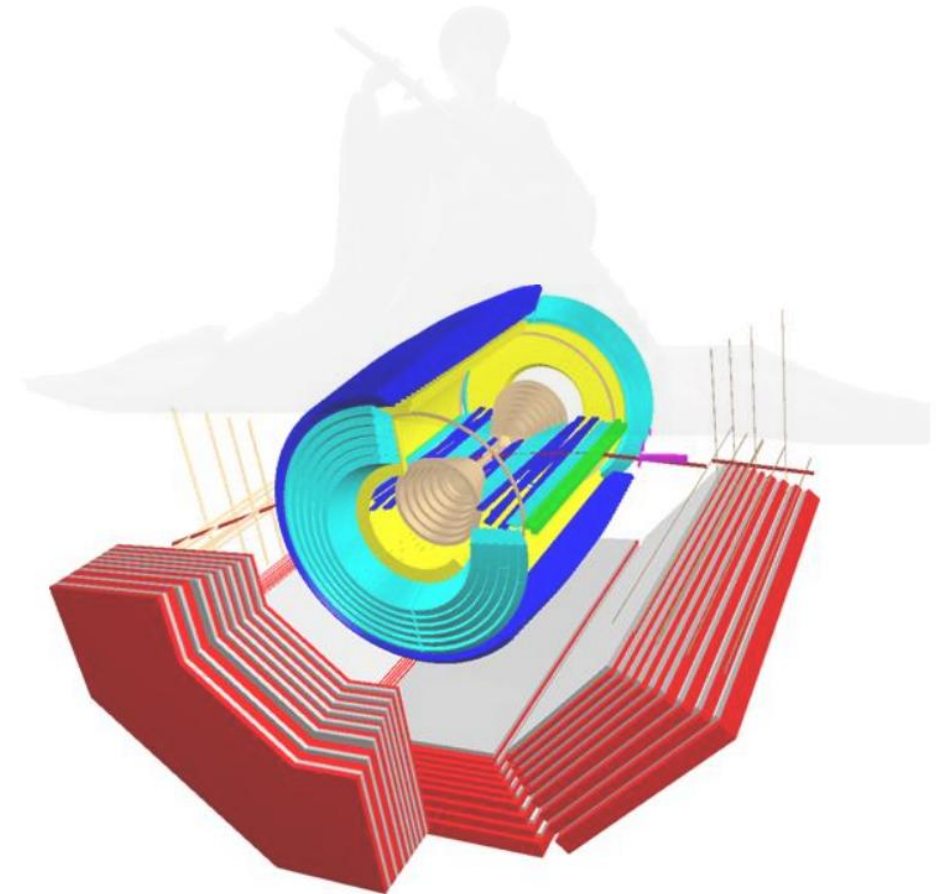


Better effective coupling constraints



Summary

- **New results of sub-GeV dark sector at BESIII**
 - $\eta \rightarrow \pi^0 + \text{invisible}, J/\psi \rightarrow \phi + \text{invisible}$
 - $K_S^0 \rightarrow \text{invisible}, \eta \rightarrow \text{invisible}$
 - $E^- \rightarrow \pi^- + \text{invisible}$
 - **Unique stringent constraints on the sub-GeV DM**
- **BESIII has collected $10^{10} J/\psi, 2.7 \times 10^9 \psi'$,
 20 fb^{-1} @ 3.77 GeV data ($D\bar{D}$) and more...**
- **More & better** results are coming soon



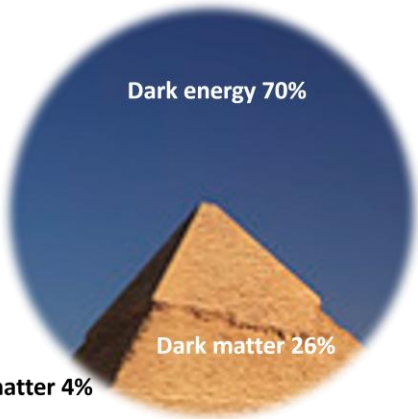


Appendix

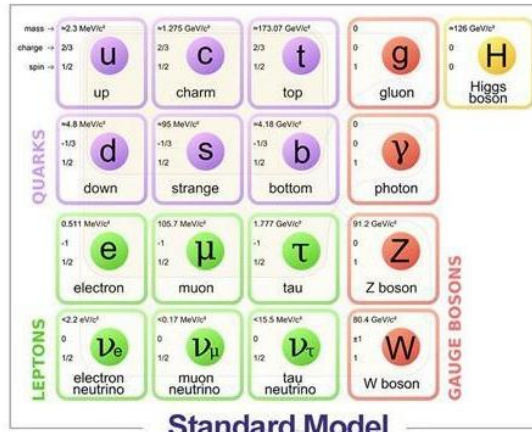
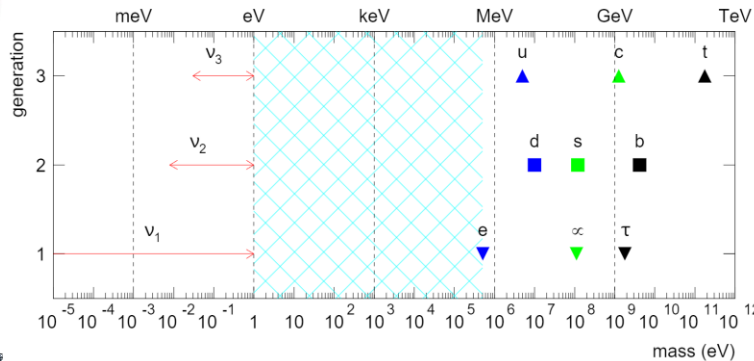
Standard model and Puzzles

Dark Matter
Dark Energy

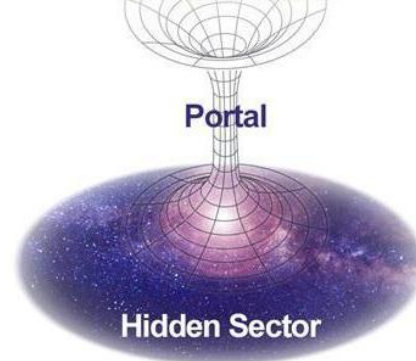
- SM explains most facts but not all
- More than two dark clouds



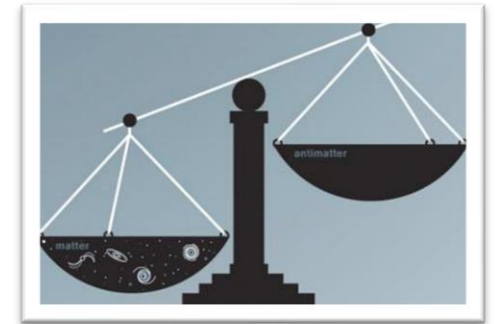
Fermion Mass Hierarchy



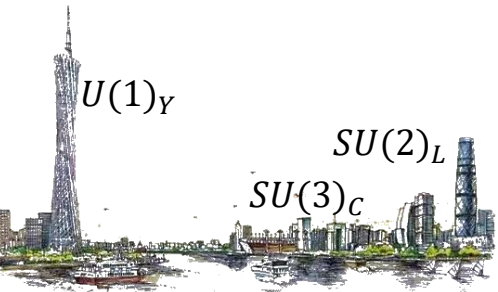
Standard Model



Matter Anti-matter Asymmetry



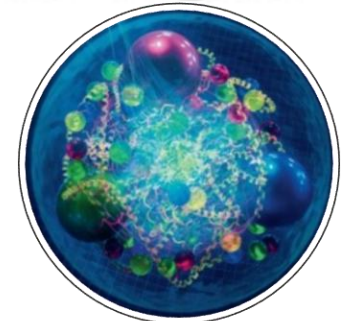
Strong CP Problem



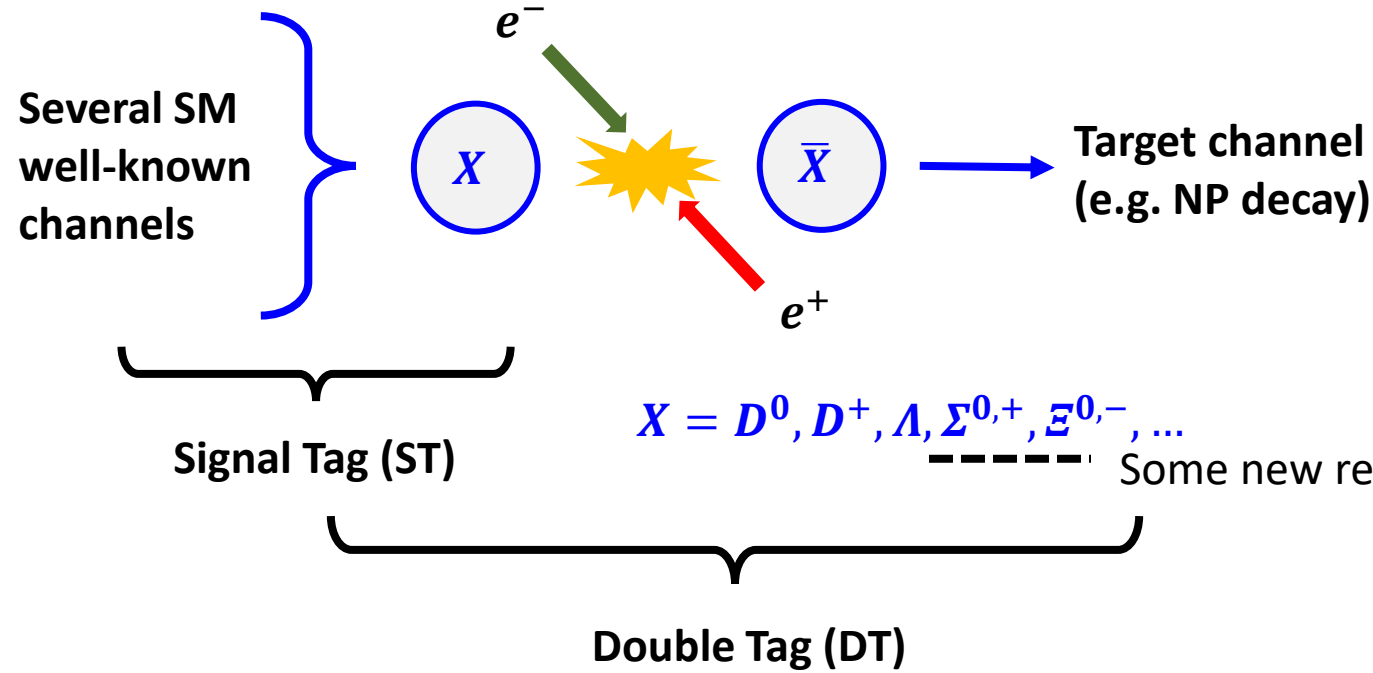
More ...

Potentials to find new physics

This talk: New dark sector result at BESIII

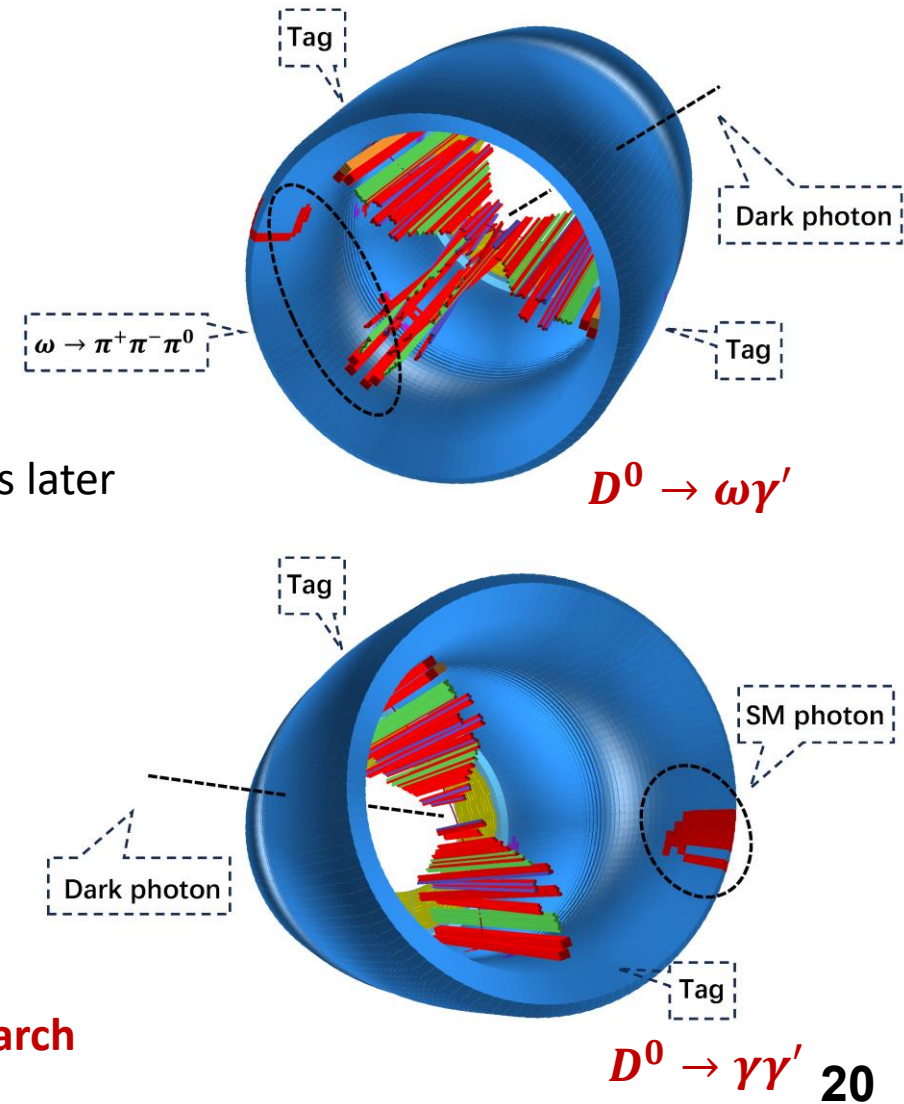


Double tag analysis at BESIII



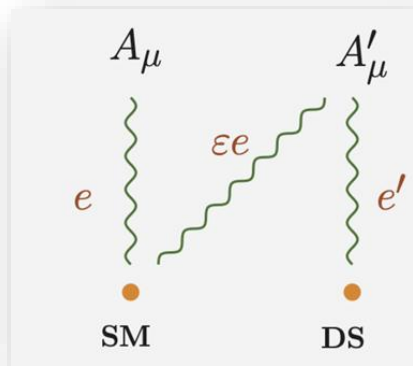
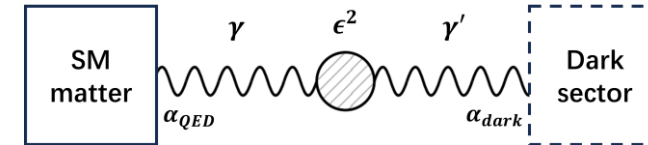
- Measure absolute branching fraction, $\mathcal{B} = \frac{N_{DT}/\epsilon_{DT}}{N_{ST}/\epsilon_{ST}}$
- **Clean background**
- **Recoil** missing particle, such as **invisible particle**
- Cancel systematic uncertainty

Active in dark sector search

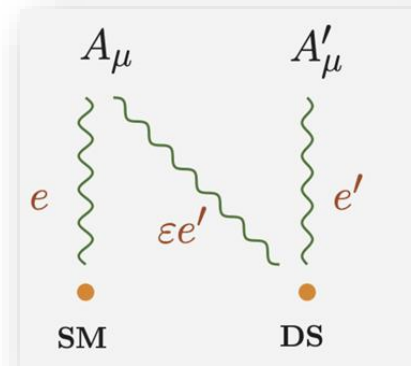


Massless dark photon

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



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



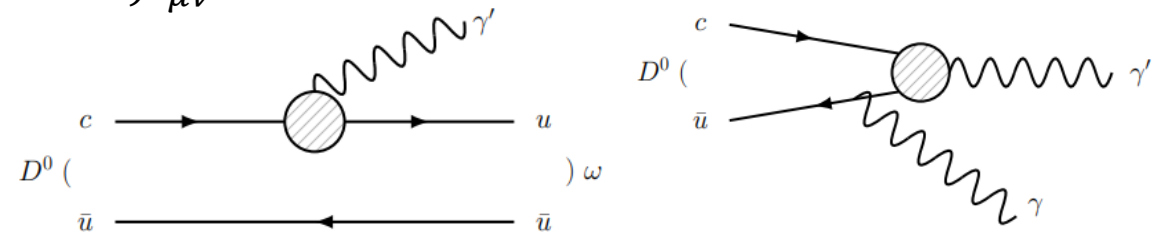
- **Massless** dark photon
- No direct coupling with SM fermion
- Less constraint
- Also important role in dark sector

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

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

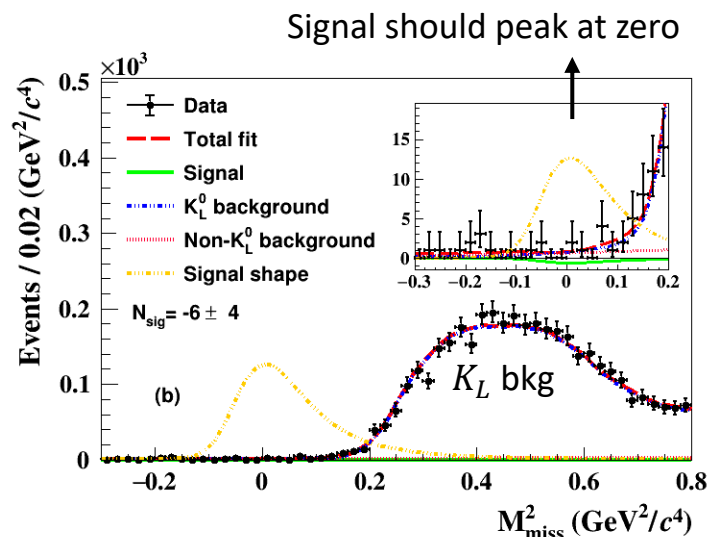
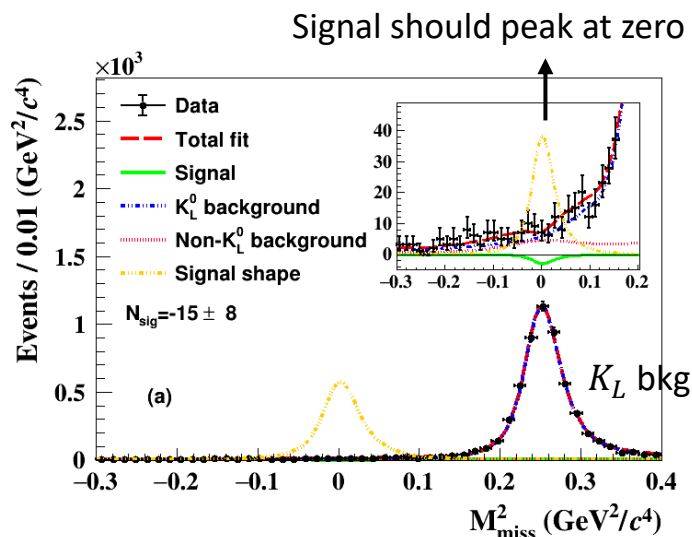
PRL 94, 151802 (2005)

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





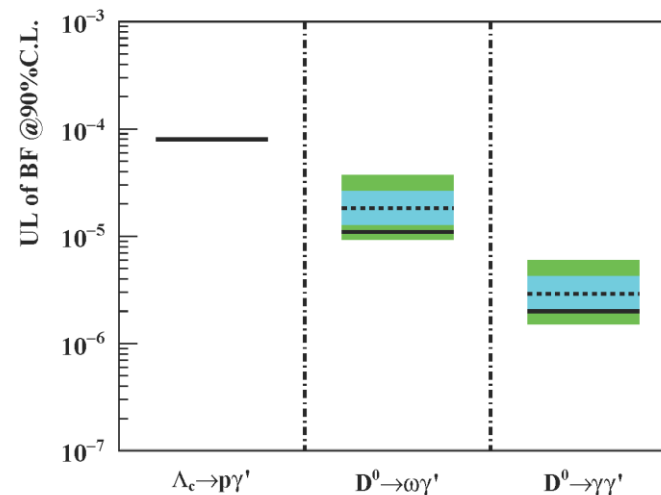
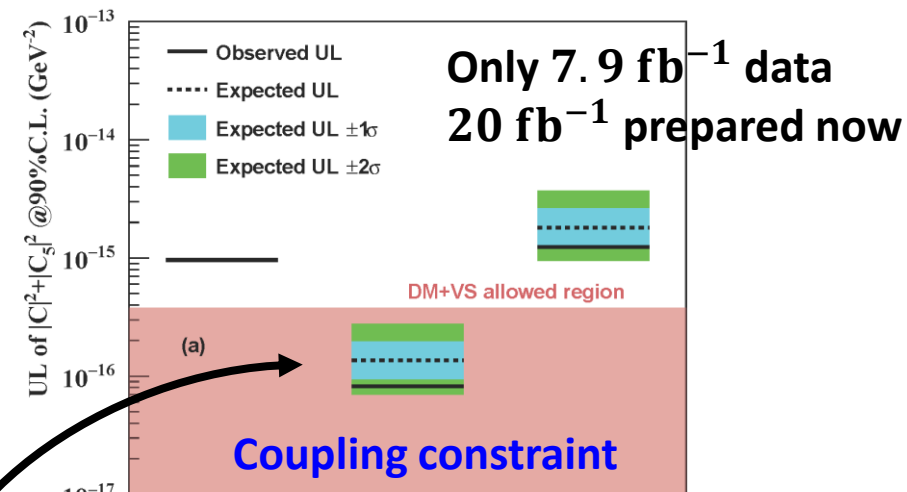
Search for $D^0 \rightarrow \omega\gamma'$ and $D^0 \rightarrow \gamma\gamma'$ at BESIII



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

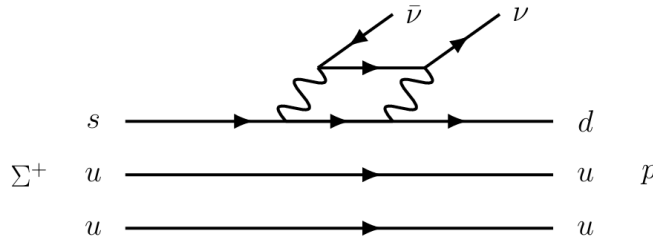
Signal extraction of $D^0 \rightarrow \gamma\gamma'$

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



$\Sigma^+ \rightarrow p + \text{invisible and QCD axion}$

SM decay



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

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

Decay to BSM particles

- **Solution to strong CP problem**

➤ Naturally allow the FCNC coupling

- An excellent **dark matter**

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

Vector coupling

Axial coupling

sensitive

$K^+ \rightarrow \pi^+ a$

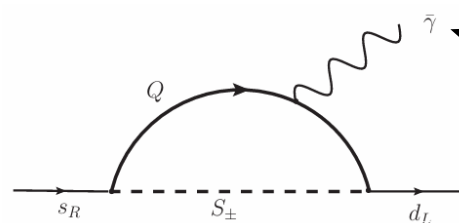
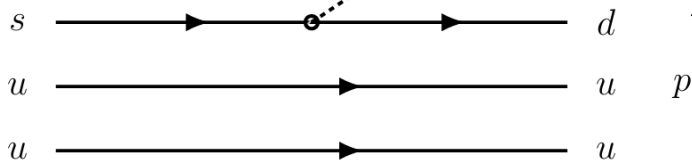
Both sensitive

Hyperon decay

Decay to QCD axion



- $m_a \sim g \sim \frac{1}{F_a} \Rightarrow m_a \ll 1 \text{ eV};$
 g : coupling strength;
 F_a : decay constant

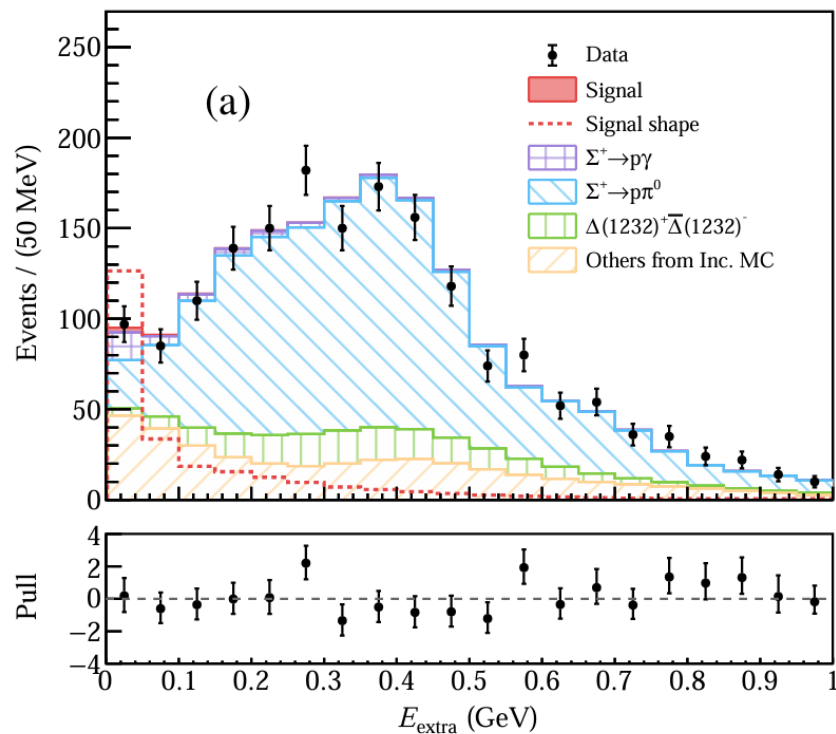


- Can also **Decay to massless dark photon**
- Maximum allowed BF $\sim 3.8 \times 10^{-5}$

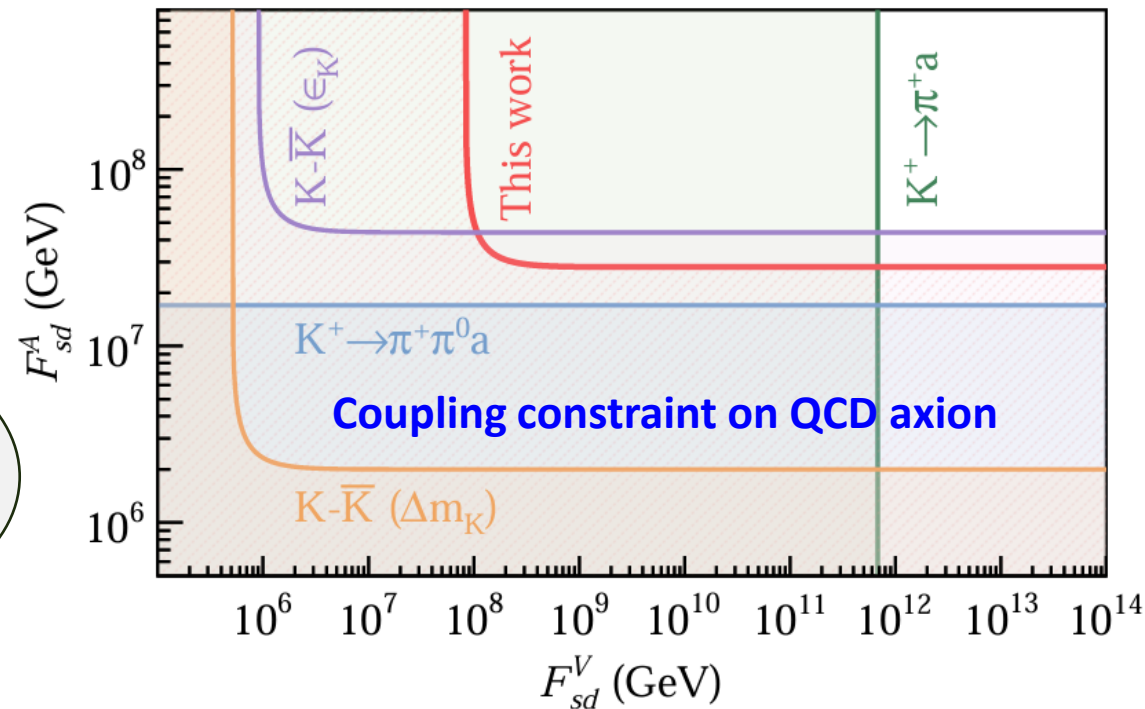


Search for $\Sigma^+ \rightarrow p + \text{invisible}$ at BESIII

- $J/\psi \rightarrow \Sigma^+ \bar{\Sigma}^-$ from $10^{10} J/\psi$
- Double tag method
- Invisible particle with mass hypothesis of zero
- Deposited energy in EMC used to extract the signal



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

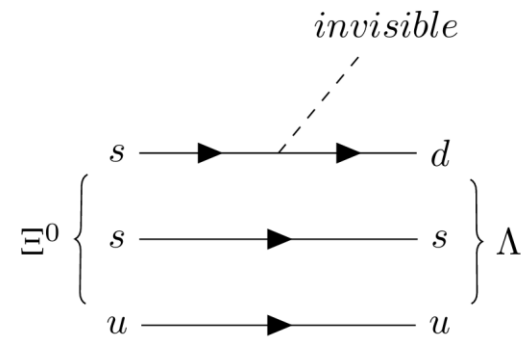


- Competitive constraint on the axial coupling temp F_{sd}^A of QCD axion
- The BF UL lies below the maximum allowed BF of massless dark photon decay (3.8×10^{-5})



Search for $\Xi^0 \rightarrow \Lambda + \text{invisible}$ at BESIII

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



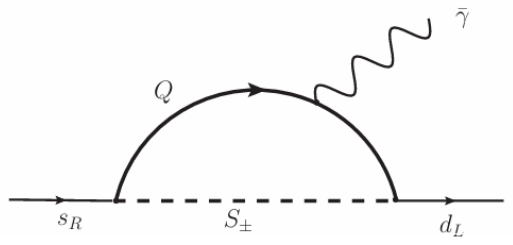
QCD axion a

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

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



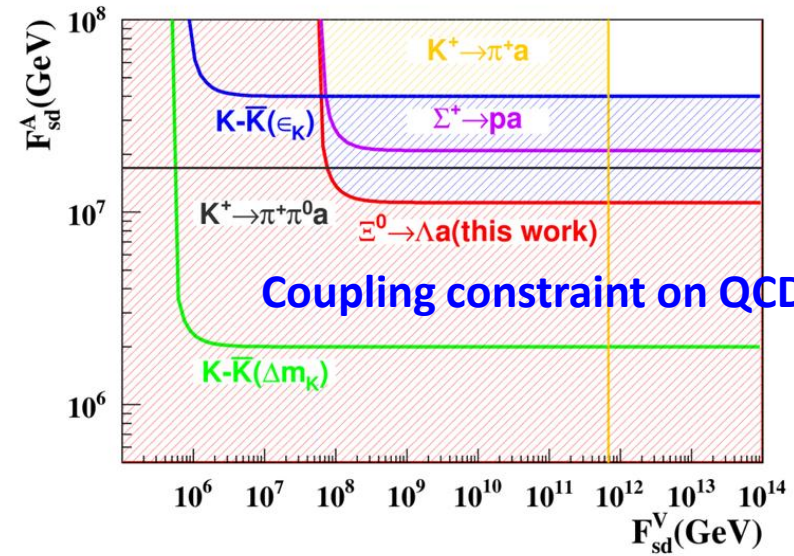
Massless dark photon γ'

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

Allowed BF: 1.2×10^{-4}

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

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



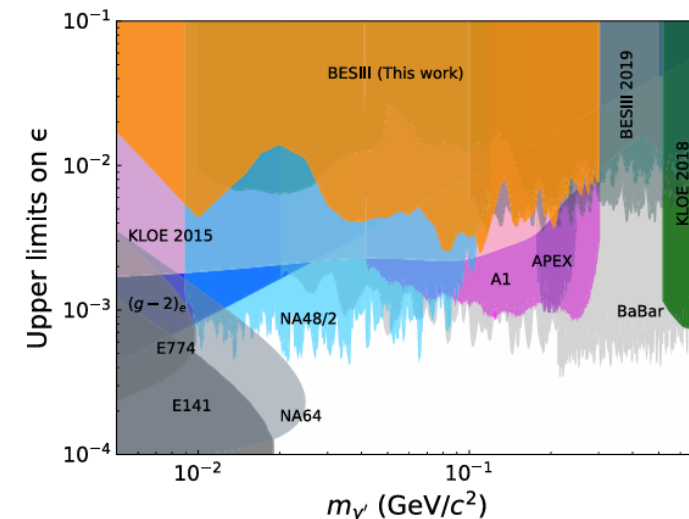
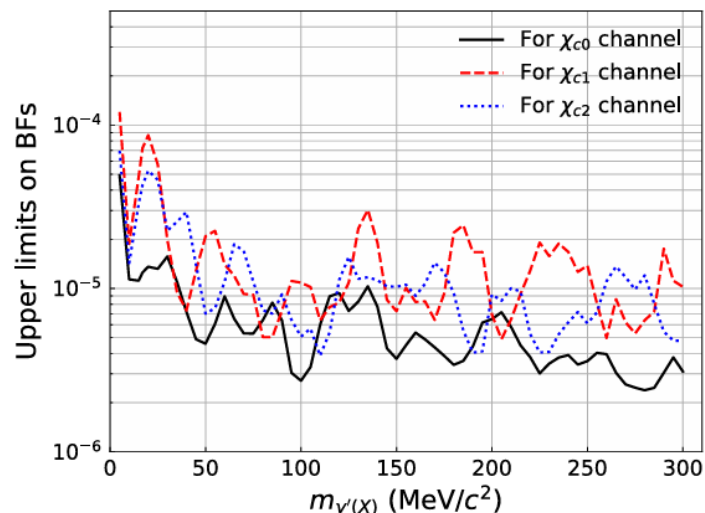
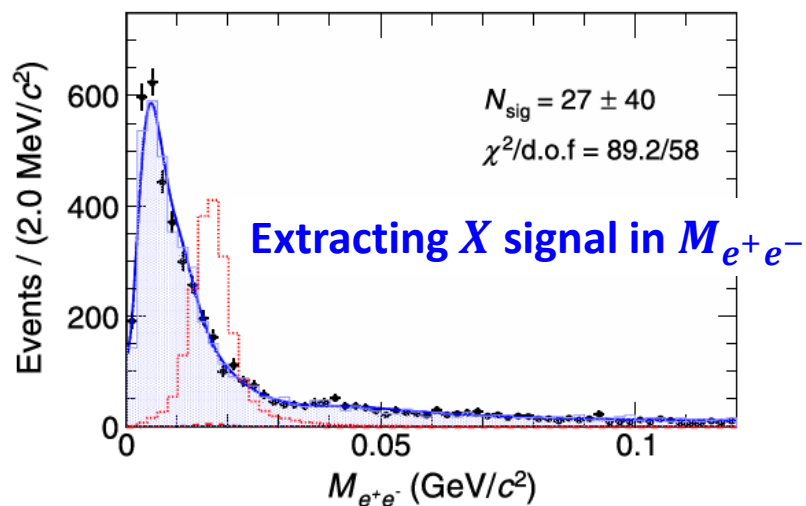
Coupling constraint on QCD axion

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



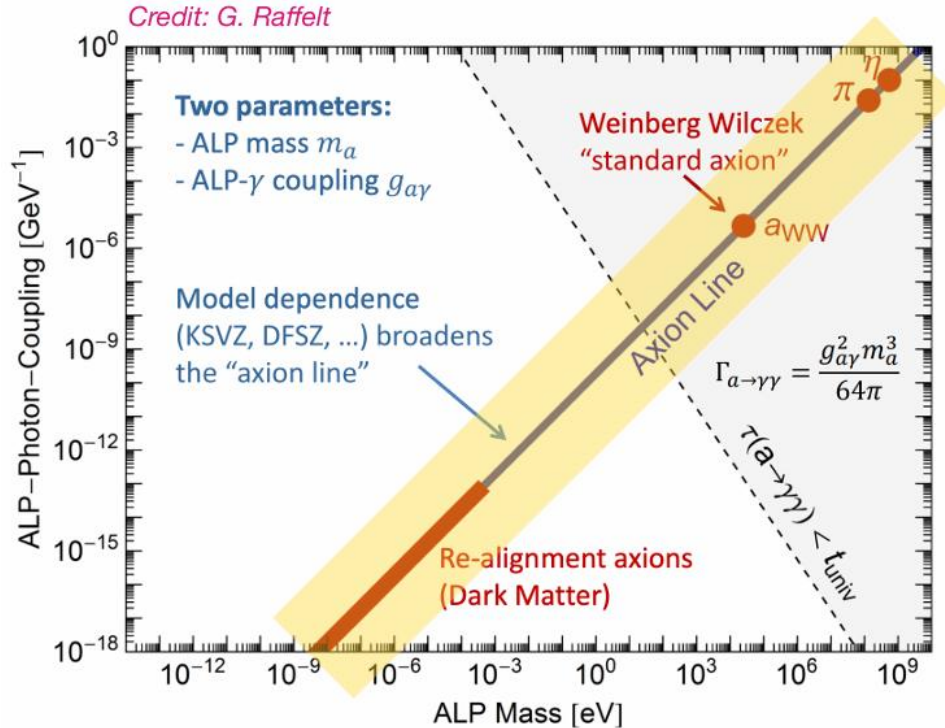
Search for $\chi_{cJ} \rightarrow J/\psi X, X \rightarrow e^+ e^-$ at BESIII

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



- UL on $\mathcal{B}(\chi_{cJ} \rightarrow J/\psi X) \times \mathcal{B}(X \rightarrow e^+ e^-)$ @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

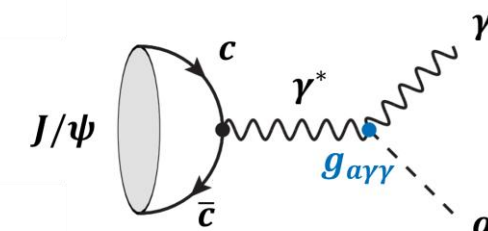
Axion-like particle



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

➤ **Considering the ALP-photon interaction**

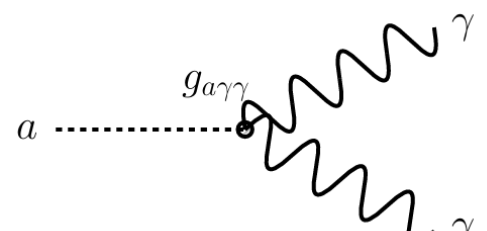
- $\mathcal{L} \supset -\frac{1}{4} g_{a\gamma\gamma} a F^{\mu\nu} \tilde{F}_{\mu\nu}$ JHEP 06 (2019) 091



- **Produced from heavy photon**

$$\frac{\mathcal{B}(J/\psi \rightarrow \gamma a)}{\mathcal{B}(J/\psi \rightarrow e^+ e^-)}$$

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

$$\Rightarrow \mathbf{BF} \sim g_{a\gamma\gamma}^2$$


- **Decay to di-photons**

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

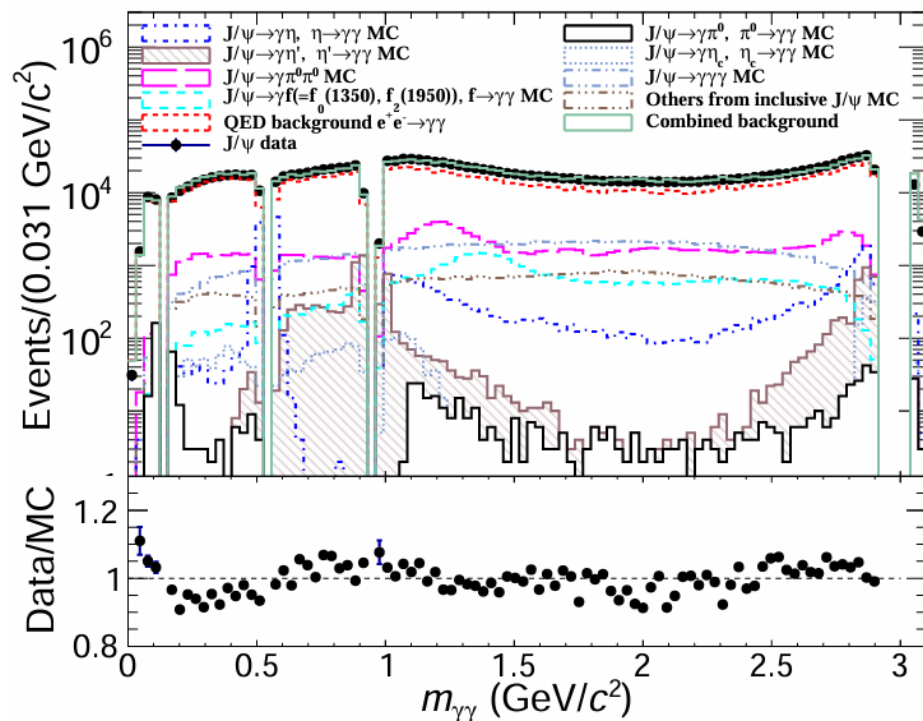
$$g_{a\gamma\gamma} \sim 10^{-4} \text{ GeV}^{-1}, m_a \sim \text{GeV}$$

$$\Rightarrow \mathbf{short-lived}$$

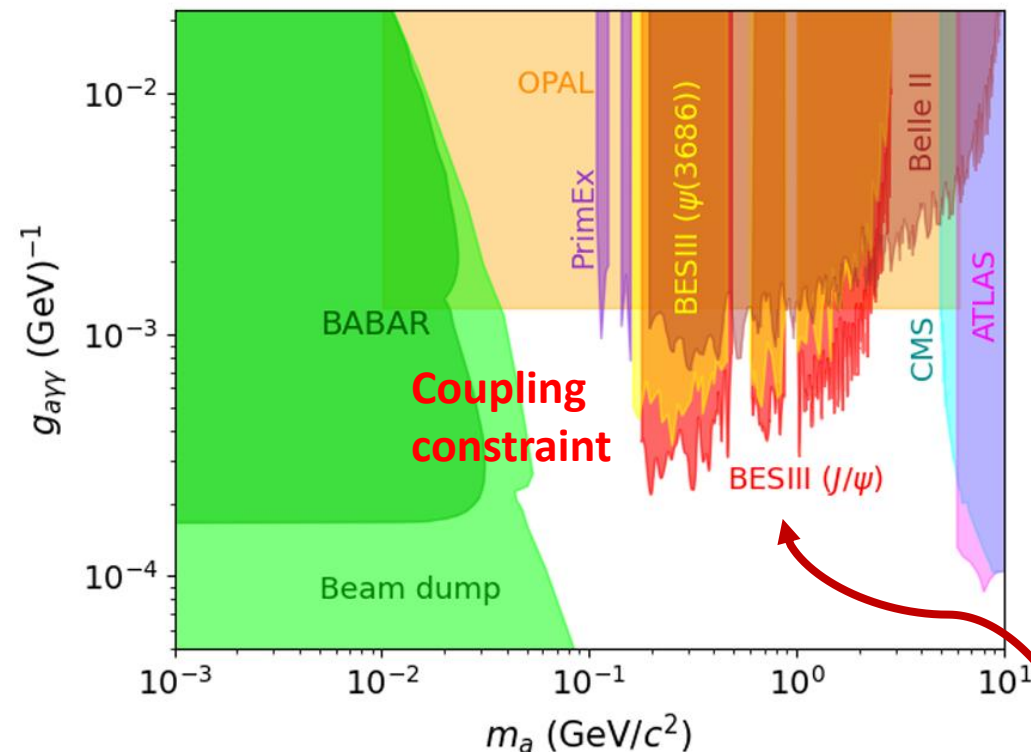
New searches for ALP at BESIII: $J/\psi \rightarrow \gamma a, a \rightarrow \gamma\gamma$



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



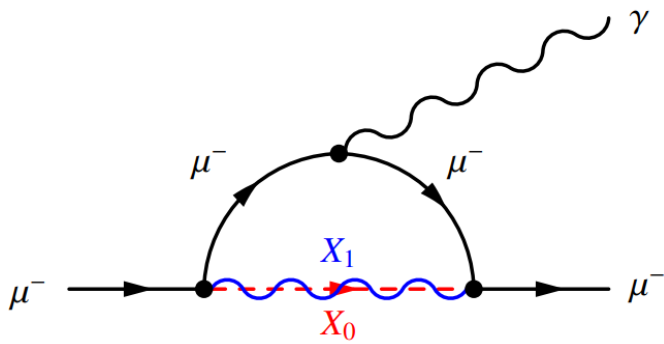
- 10^{10} J/ψ events
- Extract signal from $M_{\gamma\gamma}$ distribution
- Maximum signal significance: $< 3\sigma$



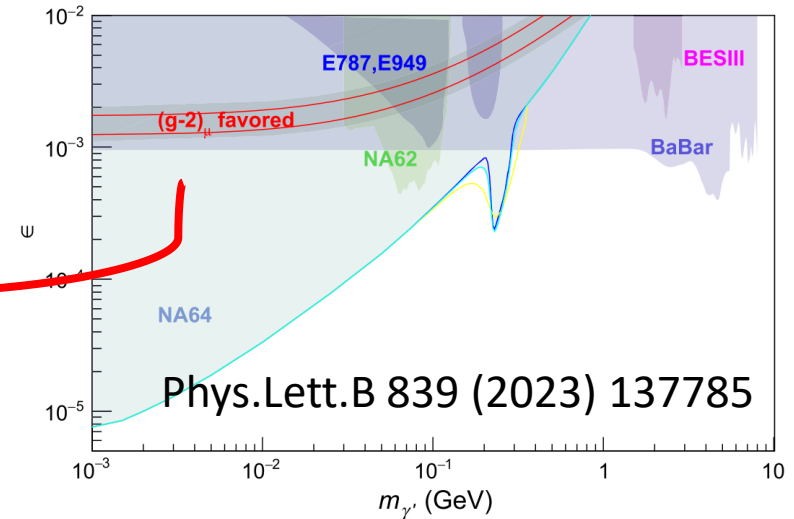
- UL on the BF of $\mathcal{B}(J/\psi \rightarrow \gamma a) \times \mathcal{B}(a \rightarrow \gamma\gamma)$
 $(3.6 \sim 53.1) \times 10^{-8}$ @ 90% C.L.
- New stringent constraints on ALP-photon coupling for $0.18 \leq m_a \leq 2.85$ GeV

Why we need the muon-philic particle

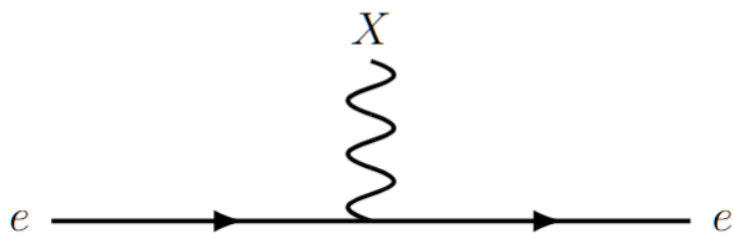
To explain $g_\mu - 2$ anomaly:
Add a new particle X, like dark photon



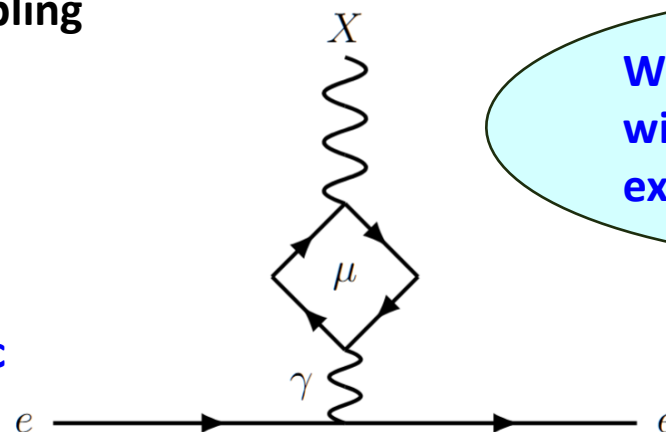
Has been Excluded



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



Search for $J/\psi \rightarrow \mu^+ \mu^- + \text{invisible}$ 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 $g'_{0,1}$

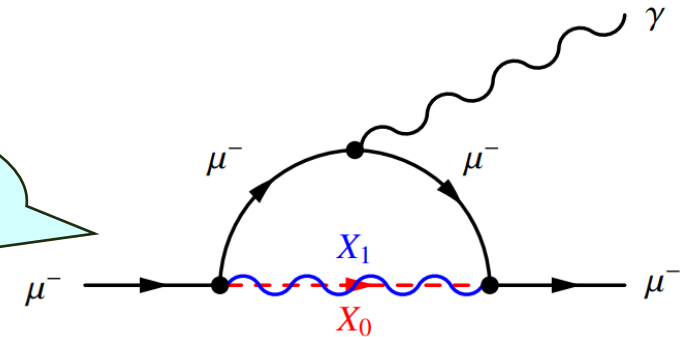
$$\mathcal{L}_\mu^{\text{scalar}} = -g_0 X_0 \bar{\mu} \mu,$$

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

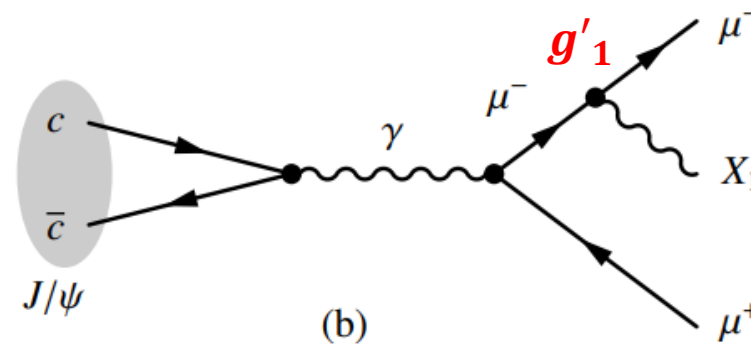
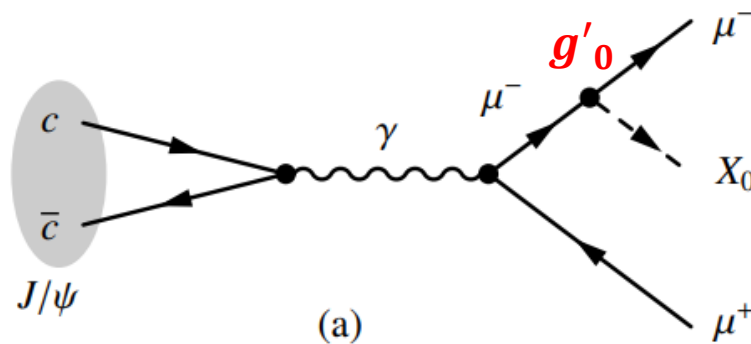
- The main muon source at BESIII:**
 $J/\psi \rightarrow \mu^+ \mu^-$
- Search for $J/\psi \rightarrow \mu^+ \mu^- X_{0,1}$**

Invisible $X_{0,1}$ at this time

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



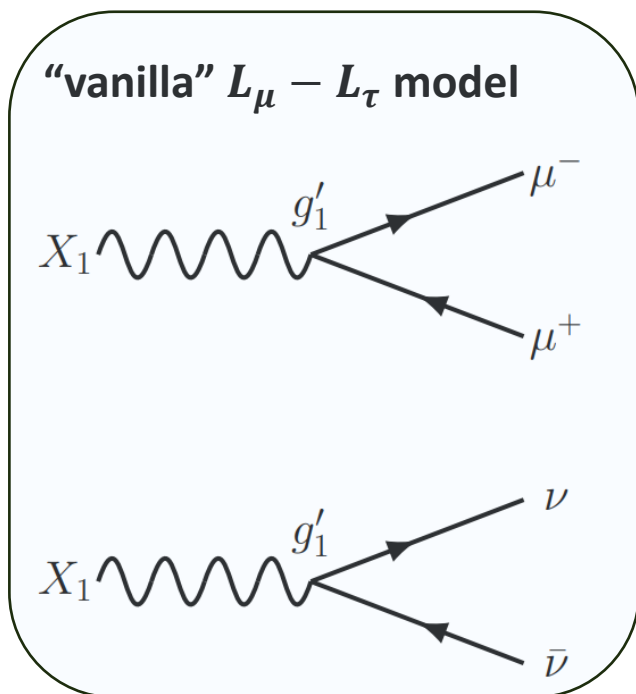
JHEP10(2020)207





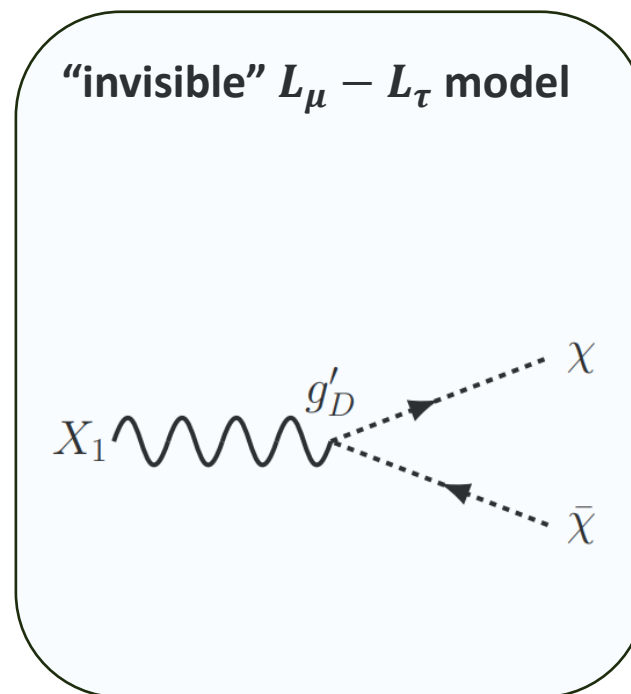
Search for $J/\psi \rightarrow \mu^+ \mu^- + \text{invisible}$ at BESIII

“vanilla” $L_\mu - L_\tau$ model



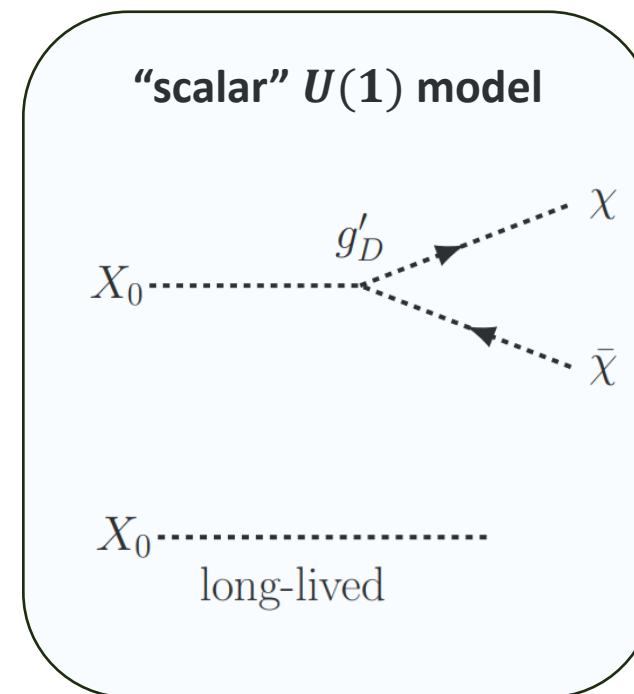
- Large mass of dark matter kind:
 $m_\chi > m_{X_1}/2$
- $\mathcal{B}(X_1 \rightarrow \nu\bar{\nu}) = 33\% - 100\%$
with different m_{X_1}

“invisible” $L_\mu - L_\tau$ model



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

“scalar” $U(1)$ model

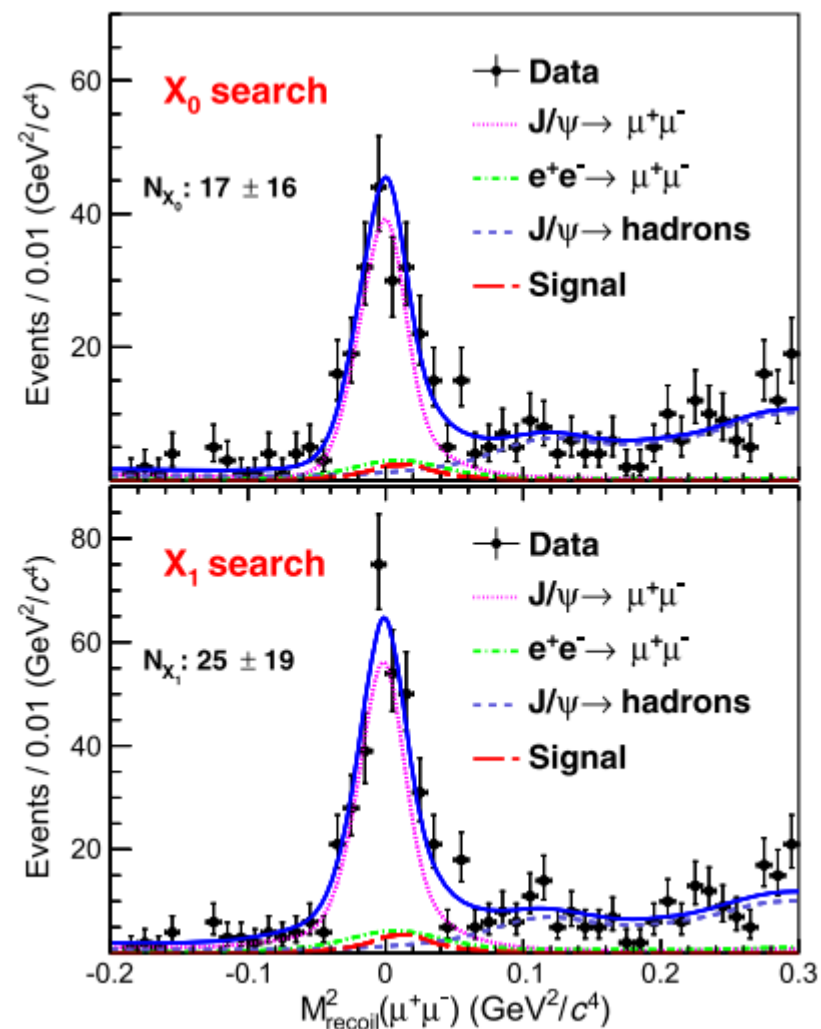


- Assuming the X_0 is long-lived or only decay to invisible final states

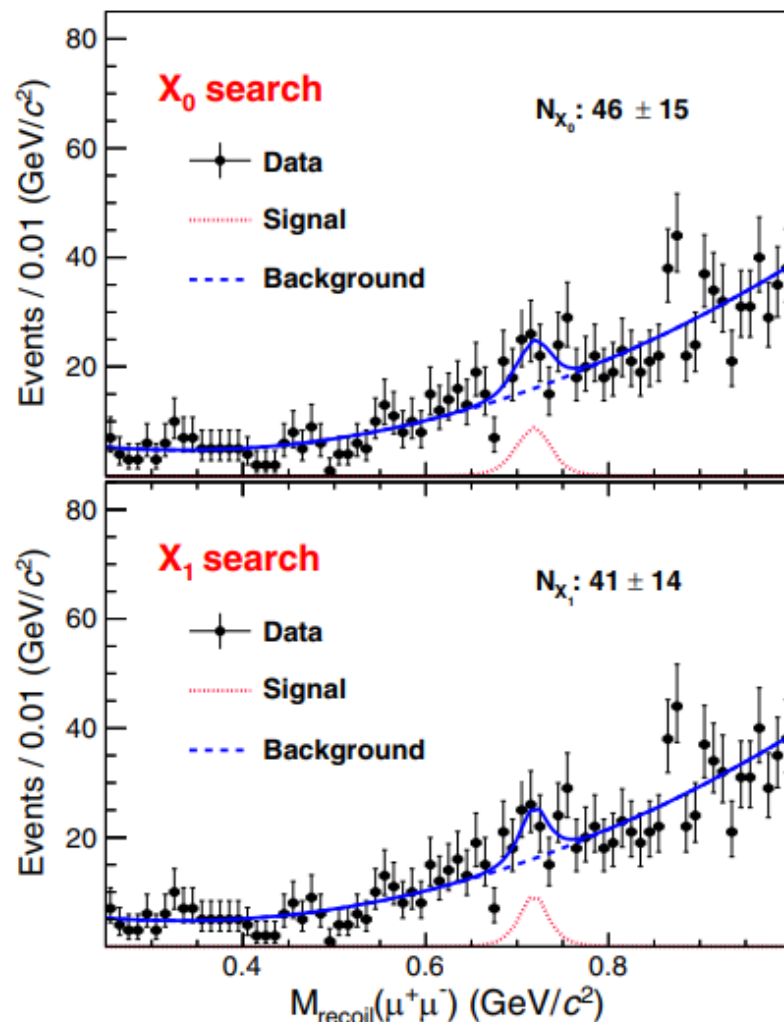


Search for $J/\psi \rightarrow \mu^+ \mu^- + \text{invisible}$ at BESIII

Low mass region



High mass region



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

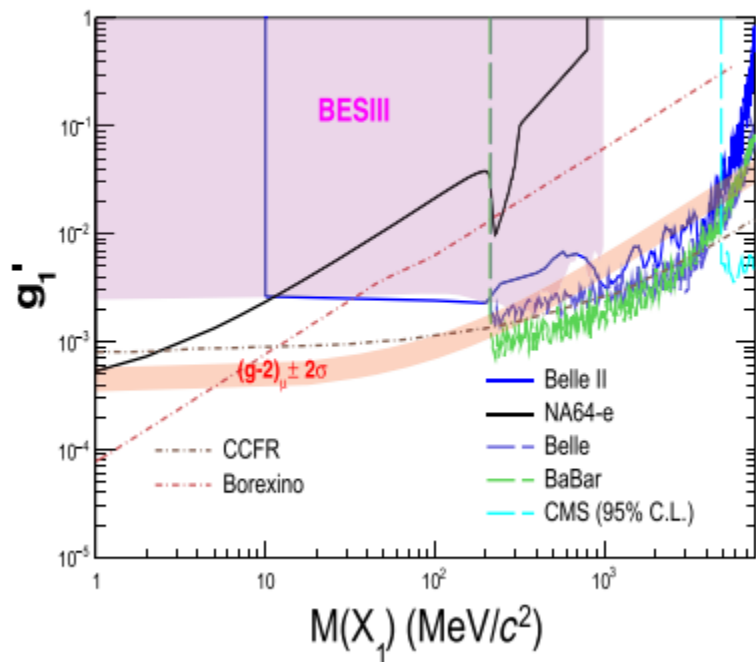
Maximum local signal significance:
 2.5σ at $M(X_{0,1}) = 720 \text{ MeV}/c^2$

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



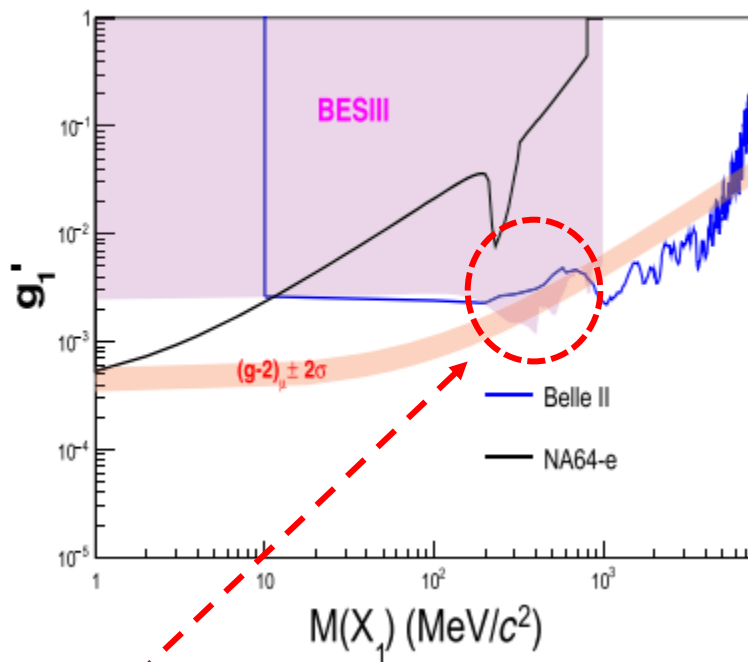
Search for $J/\psi \rightarrow \mu^+ \mu^- + \text{invisible}$ at BESIII

“vanilla” $L_\mu - L_\tau$ model



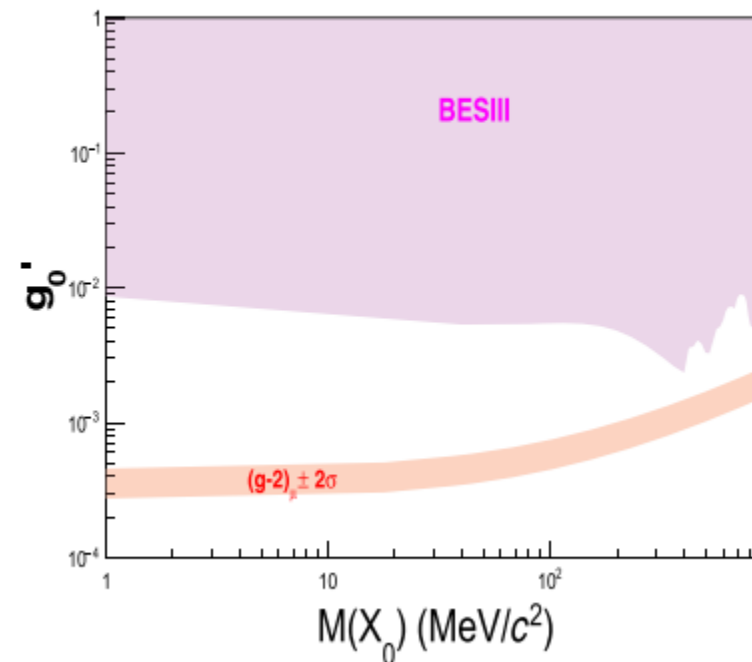
BarBar, CMS, Belle: $X_1 \rightarrow \mu^+ \mu^-$
 Belle II, BESIII: $X_1 \rightarrow \nu\bar{\nu}$
 (Taking $\mathcal{B}(X_1 \rightarrow \nu\bar{\nu})$ into account)

“invisible” $L_\mu - L_\tau$ model



**Better sensitivity in the range
 200-860 MeV/c²**

“scalar” $U(1)$ model



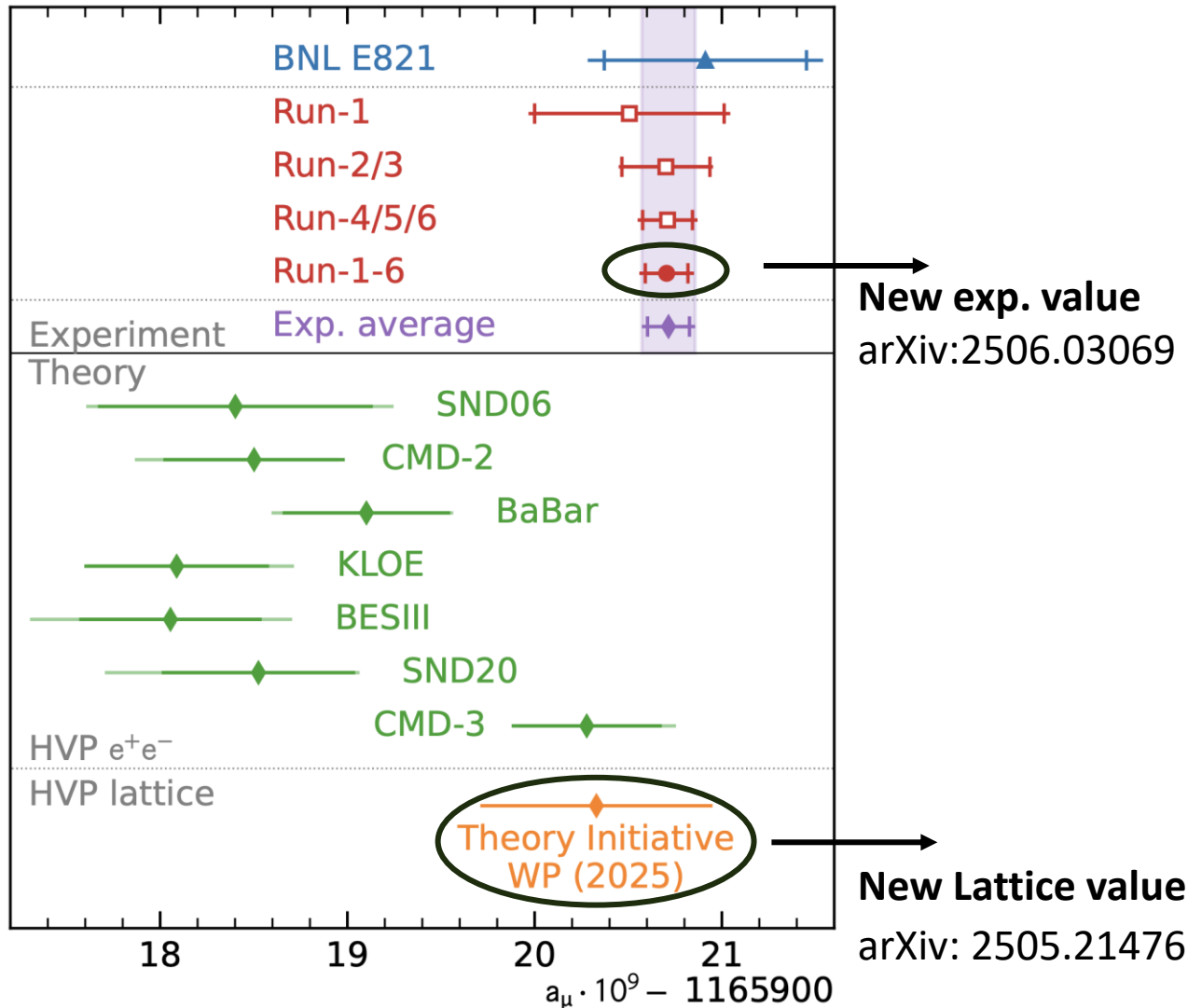
**First constraint for the “scalar”
 invisible X_0 case**

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 $(g - 2)_\mu$

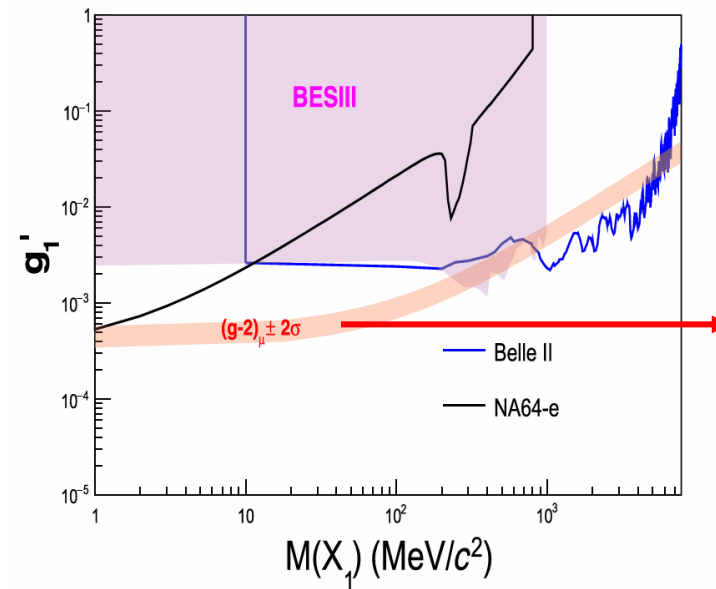


Before 2025.5:

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

After 2025.5:

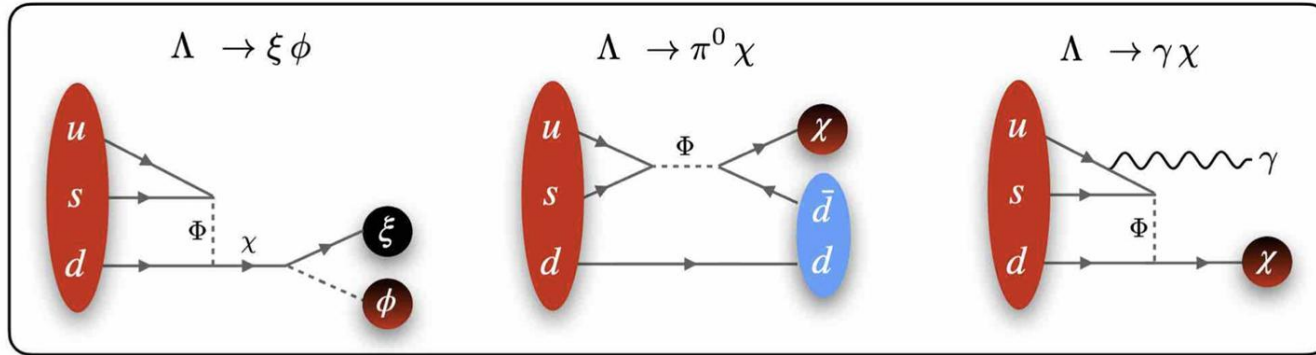
$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (38.5 \pm 64) \times 10^{-11}$$



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

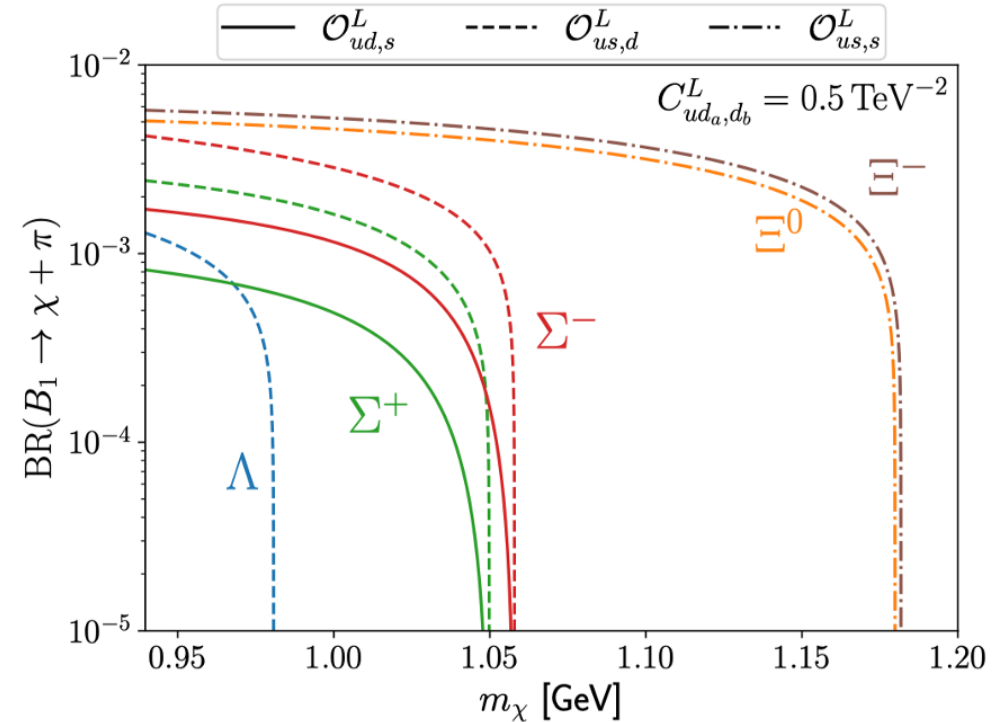


Dark baryon in Hyperon decays



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

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



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

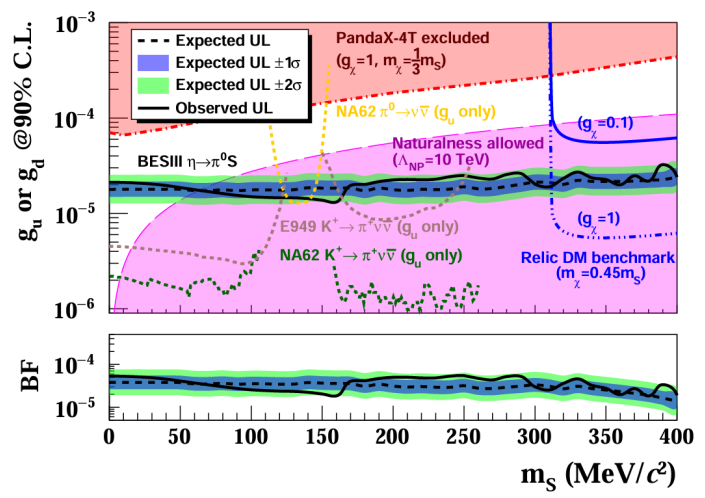
$\Xi^- \rightarrow \pi^- \chi$: better sensitivity in theory



Discussion within the specific model

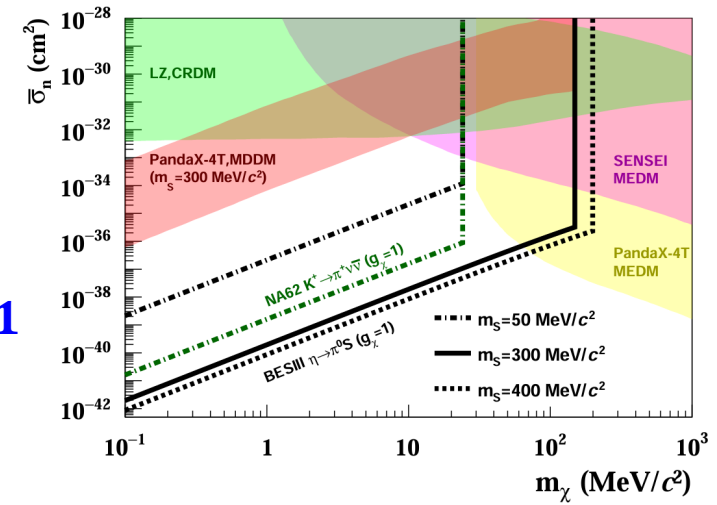
➤ $\mathcal{L} \supset -g_\chi S \bar{\chi}_L \chi_R - g_u S \bar{u}_L u_R + h.c., \quad g_u \equiv \frac{c_S v}{\sqrt{2} \Lambda_{NP}}$

- The coupling strength g_u not necessarily proportional to the Higgs Yukawa couplings



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

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



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

- **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 $\eta' \rightarrow \pi^0 \chi \bar{\chi}$
 - Off-shell S case in $\eta \rightarrow \pi^0 \chi \bar{\chi}$
 - Pseudo-scalar case in $\eta \rightarrow \pi^+ \pi^- \chi \bar{\chi}$
 - Vector case in $\pi^0 / \eta \rightarrow \gamma \chi \bar{\chi}$
 -