

Invisible decays at BESIII

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■ Introduction

■ BESIII experiment

■ Invisible decays at BESIII

- Search for invisible decays of a dark photon
- Search for a massless dark photon in $\Lambda_c^+ \rightarrow p\gamma'$ decay
- Search for invisible decays of the Λ baryon

PLB 839, 137785 (2023)

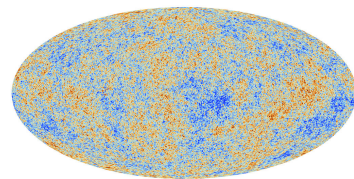
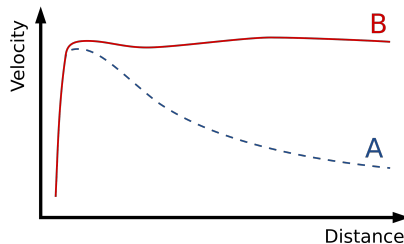
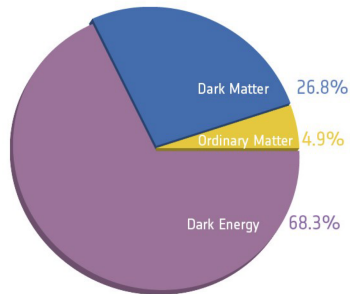
PRD 106, 072008 (2022)

PRD 105, L071101(2022)

■ Summary

Dark matter

- Existence of dark matter
 - Galaxy rotation curves
 - Gravitational lensing
 - Cosmic microwave background



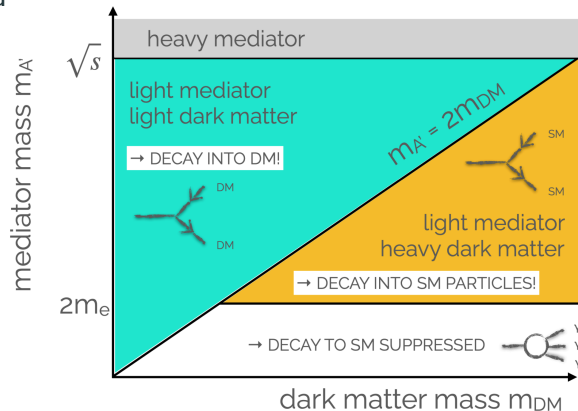
Invisible decays

- Dark matter may interact with Standard Model through “portal” interactions

- Vector portal (dark photon)
- Pseudo-scalar portal (axion-like particle)
- Scalar portal (dark Higgs)
- Neutrino portal (heavy neutrinos)

Standard Model \longleftrightarrow Mediator \longleftrightarrow Dark Sector

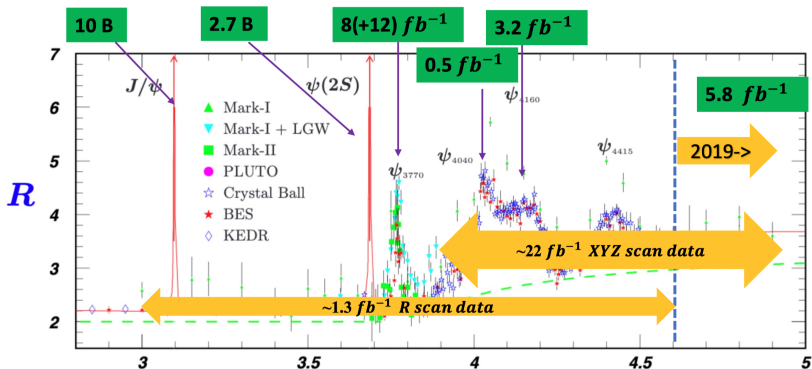
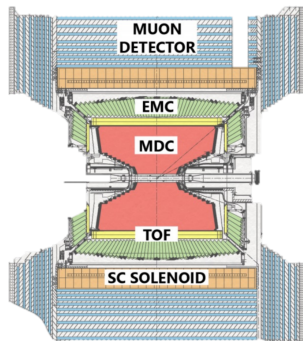
- Search for dark sector particles with invisible signatures



T. Ferber

BESIII experiment

- BESIII experiment is a symmetric electron positron collider running at tau-charm region
- BESIII has collected the largest data samples of 10 billion J/ψ , 2.7 billion $\psi(3686)$ on threshold in the world, and 20 fb^{-1} $\psi(3770)$ data samples are coming soon



Earlier invisible decay searches at BESIII

■ Invisible decays of η/η' mesons

- 225M J/ψ sample
- $\mathcal{B}(\eta \rightarrow \text{invisible}) < 1.01 \times 10^{-4}$ at 90% CL
- $\mathcal{B}(\eta' \rightarrow \text{invisible}) < 5.21 \times 10^{-4}$ at 90% CL

PRD 87, 012009 (2013)

■ Invisible decays of ω/ϕ mesons

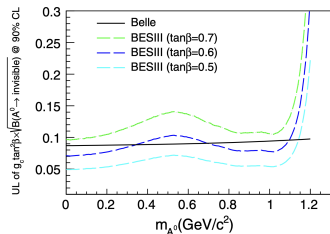
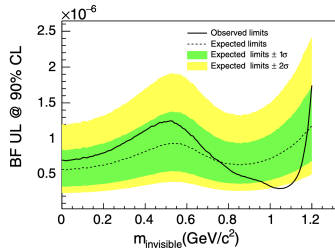
- 1.3B J/ψ sample
- $\mathcal{B}(\omega \rightarrow \text{invisible}) < 7.3 \times 10^{-5}$ at 90% CL
- $\mathcal{B}(\phi \rightarrow \text{invisible}) < 1.7 \times 10^{-4}$ at 90% CL

PRD 98, 032001 (2018)

■ Search for the decay $J/\psi \rightarrow \gamma + \text{invisible}$

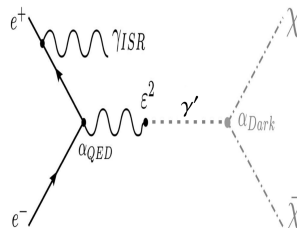
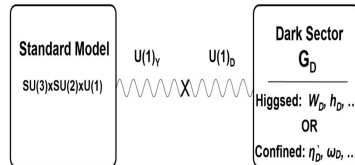
- 448M $\psi(3686)$ sample

PRD 101, 112005 (2020)

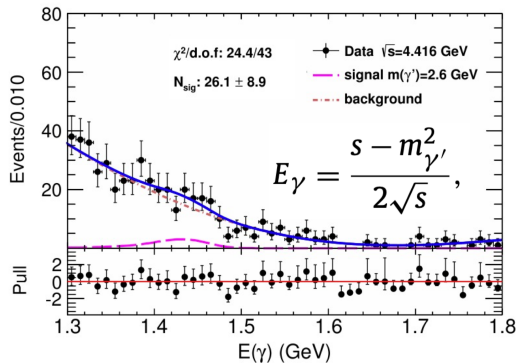


Massive dark photon

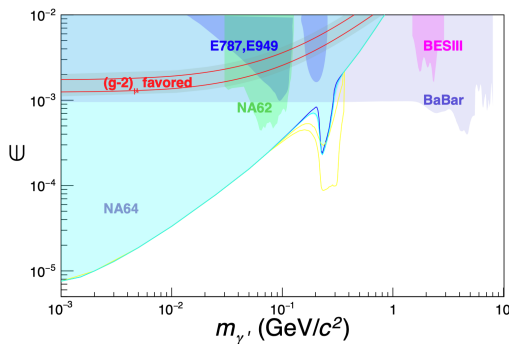
- A spin-one boson associated with a new Abelian gauge symmetry $U(1)_D$ **spontaneously broken, massive kind**
- Proposed as a force carrier connected to dark matter
- The dark photon couples weakly to a SM photon through kinetic mixing with a mixing parameter $\epsilon \sim 10^{-3}$
- The dark photon (γ') would predominately decay into a pair of DM particles $\gamma' \rightarrow \chi\bar{\chi}$ if $m_\chi < m_{\gamma'}/2$
- Search for the dark photon in the radiative annihilation process $e^+e^- \rightarrow \gamma\gamma'$, followed by an invisible decay of the γ'



- Data samples: $14.9 \text{ fb}^{-1} e^+e^-$ annihilation data at $\sqrt{s} = 4.13 \sim 4.60 \text{ GeV}$
- Search for single photon signals in $1.3 < E(\gamma) < 1.8 \text{ GeV}$ corresponding to $1.5 < m_{\gamma'} < 2.9 \text{ GeV}$
 - Low $E(\gamma)$ region \rightarrow low trigger efficiency & high background level
 - High $E(\gamma)$ region \rightarrow saturation of the EMC electronics
 - A simultaneous likelihood fit on the photon energy spectra is performed to all data sets
 - No obvious signal observed, the the maximum global significance, is determined to be 2.2σ

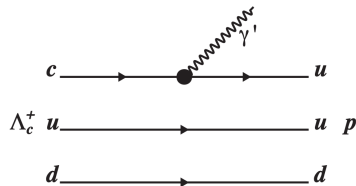


- $\sigma = \frac{2\pi\alpha^2}{E_{cm}^2} \epsilon^2 (1-x) \left[\left(1 + \frac{2x}{(1-x)^2}\right) \Theta - 2 \cos \theta_{cut} \right]$
- The 90% CL upper limits of coupling ϵ are $(1.6 - 5.7) \times 10^{-3}$
- The exclusion limits are consistent with what already excluded by BaBar PRL 119 (2017) 131804
- BESIII will produce more competitive results with 20 fb^{-1} data taken at 3.77 GeV in the future



Massless dark photon

- A spin-one boson associated with a new Abelian gauge symmetry $U(1)_D$ **unbroken, massless kind**
- FCNC process is highly suppressed by the GIM mechanism in the charm sector
less than 10^{-9} in SM, Phys. Rev. D 98, 030001 (2018)
- A massless dark photon could induce FCNC process through higher dimensional operators, allowing $\mathcal{B}(\Lambda_c^+ \rightarrow p\gamma')$ up to 1.6×10^{-5}
Phys. Rev. D 102, 115029 (2020)
- The missing energy due to the dark photon is the feature of the signal processes



■ Data samples: $4.5 \text{ fb}^{-1} e^+e^-$ annihilation data at $\sqrt{s} = 4.6 \sim 4.7 \text{ GeV}$

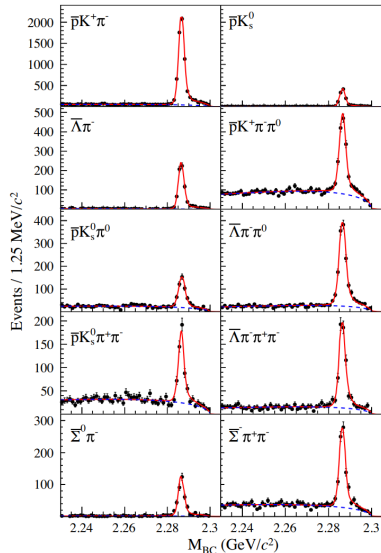
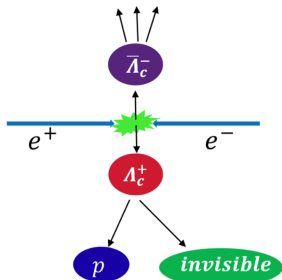
■ Double Tag Method

■ Tag side: reconstruct $\bar{\Lambda}_c^-$ with ten hadronic decay modes. Tag yields: 105244 ± 384

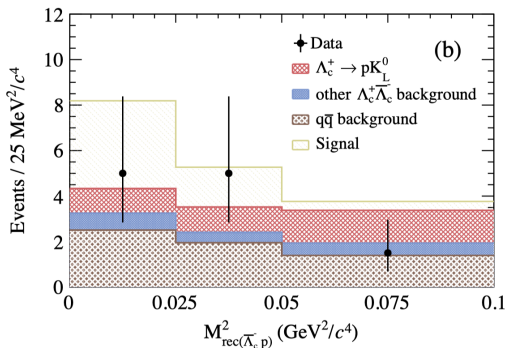
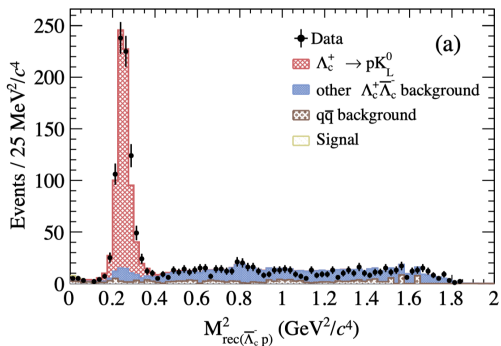
■ Signal side: $\Lambda_c^+ \rightarrow p\gamma'$

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\gamma') = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\sum_{ij} N_{ij}^{\text{ST}} \cdot (\epsilon_{ij}^{\text{DT}} / \epsilon_{ij}^{\text{ST}})}$$

10 hadronic decay modes

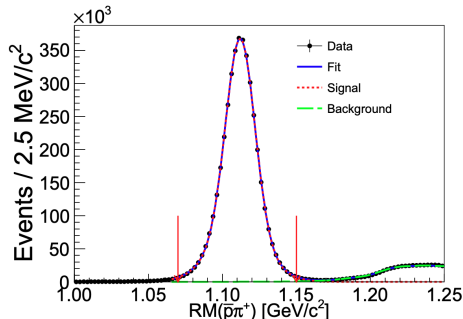
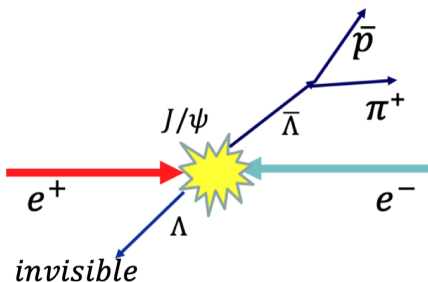


- Search for an invisible signature on the square of the recoil mass spectrum $M_{\text{rec}}^2(\bar{\Lambda}_c^- p)$
 - Signal region is defined as (0.0, 0.1) GeV^2/c^4 in the $M_{\text{rec}}^2(\bar{\Lambda}_c^- p)$
 - No significant signal observed, $\mathcal{B}(\Lambda_c^+ \rightarrow p\gamma') < 8.0 \times 10^{-5}$ at 90% CL
 - Currently consistent with the theoretical UL prediction: 1.6×10^{-5} PRD 102, 115029 (2020)
 - A more stringent constraint is expected with larger Λ_c^+ samples at BESIII

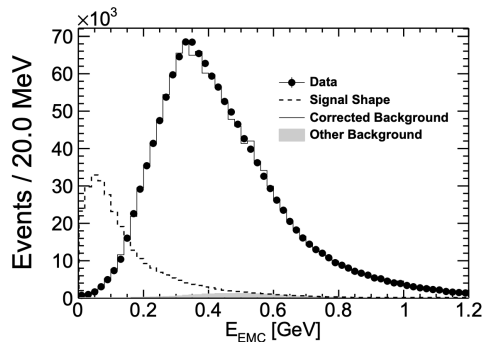
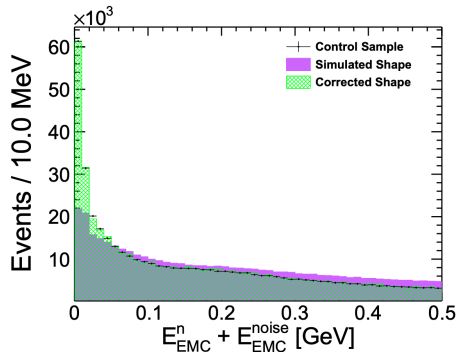


- Dark matter may be represented by baryon matter with invisibles, and many theories suggest a potential correlation between baryon symmetry and dark sector Phys. Rev. D 105, 115005 (2022)
 - B-Mesogenesis mechanism
- Discrepancy of neutron lifetime in beam method and the storage methods $\rightarrow \mathcal{B}(n \rightarrow p + X) \approx 99\%$ Phys. Rev. D 99, 035031 (2019)
- Data samples: 10B J/ψ events
- Double Tag Method: reconstruct $\bar{\Lambda}$ with $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ decay

$$\mathcal{B}(\Lambda \rightarrow \text{invisible}) = \frac{N_{\text{sig}}}{N_{\text{tag}} \cdot (\epsilon_{\text{sig}}/\epsilon_{\text{tag}})}$$



- Search for signal on total energy in EMC E_{EMC} (not charged tracks)
 - Dominating background: $\Lambda \rightarrow n\pi^0$, $E_{\text{EMC}} = E_{\text{EMC}}^{\pi^0} + E_{\text{EMC}}^n + E_{\text{EMC}}^{\text{noise}}$
 - $E_{\text{EMC}}^{\pi^0}$: based on the MC simulations
 - $E_{\text{EMC}}^n + E_{\text{EMC}}^{\text{noise}}$: based on control sample $J/\psi \rightarrow \Lambda(n\pi^0)\bar{\Lambda}(\bar{p}\pi^+)$
 - No obvious signal observed, $\mathcal{B}(\Lambda \rightarrow \text{invisible}) < 7.4 \times 10^{-5}$ at 90% CL
 - Consistent with the prediction of 4.4×10^{-7} from the mirror model [arXiv:2006.10746](#)



- Search for invisible decays has become an intriguing idea for understanding dark matter, and also for looking into new physics beyond SM
- BESIII plays an active role in invisible decay searches, with many first searches or best limits
 - Search for dark photon invisible decays (competitive results)
 - Search for a massless dark photon in Λ_c^+ decays (first FCNC search of charmed baryon)
 - Search for Λ invisible decays (first search for invisible baryon decays)
- With more data available, more exciting results are coming soon

STAY TUNED