南開大學
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BESIII新物理寻找的最新结果

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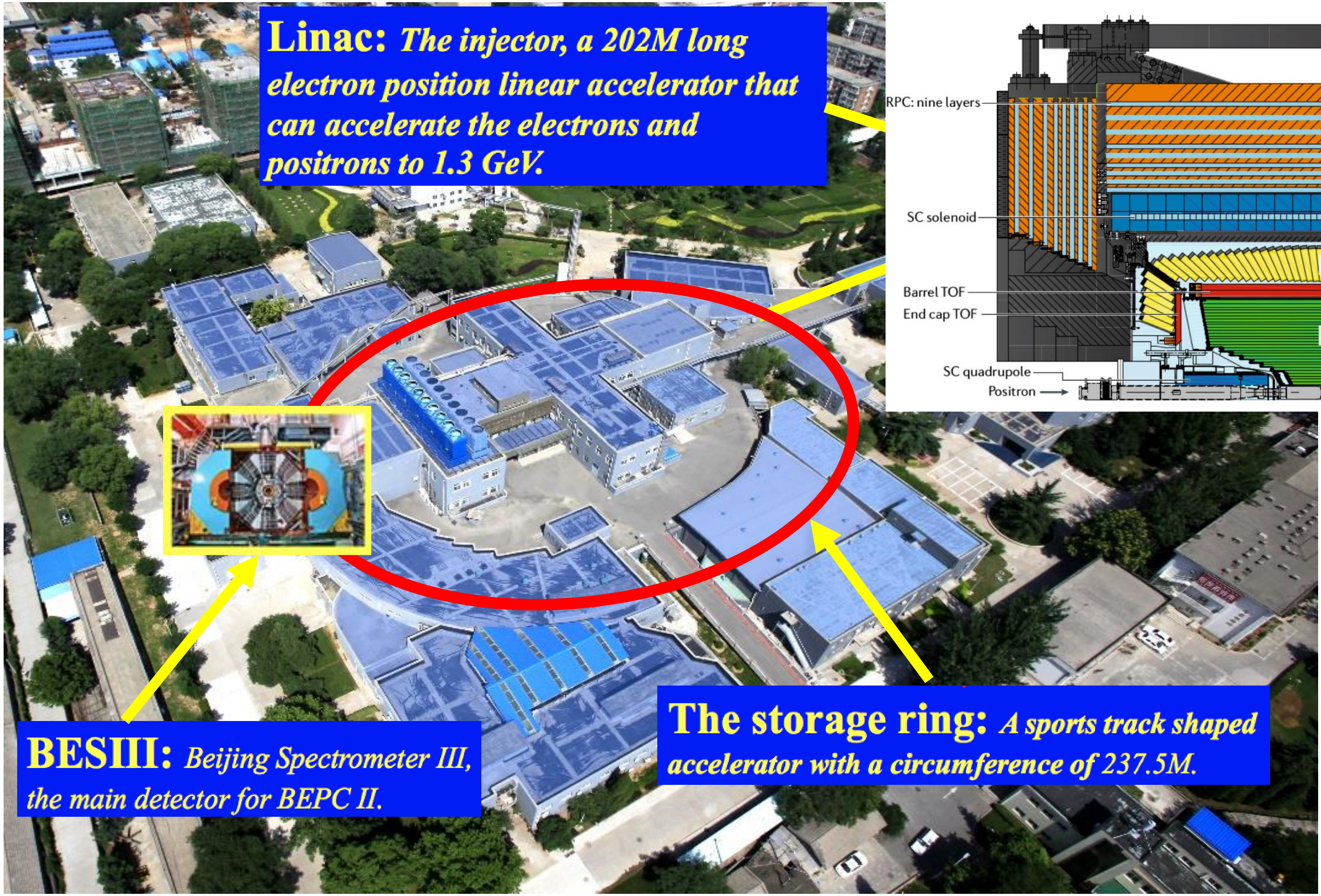
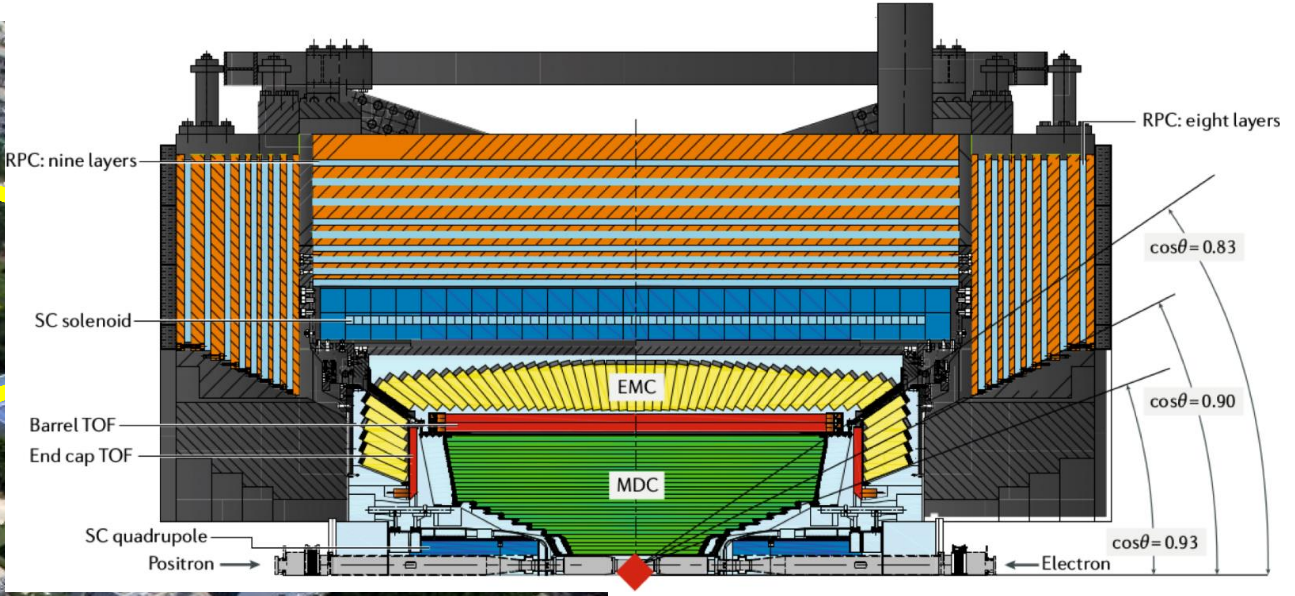
第五届强子与重味物理理论与实验联合研讨会

2026.03.27-31

Outline

01 Introduction





Electromagnetic Calorimeter

- CsI(Tl): $\frac{\sigma_E}{E} = 2.5\%(5\%)$ for barrel(endcap)

Time-of-Flight System

- $\sigma_T = 68(60)$ps for barrel(endcap)

Muon Chamber

Superconducting Solenoid ($1T$)

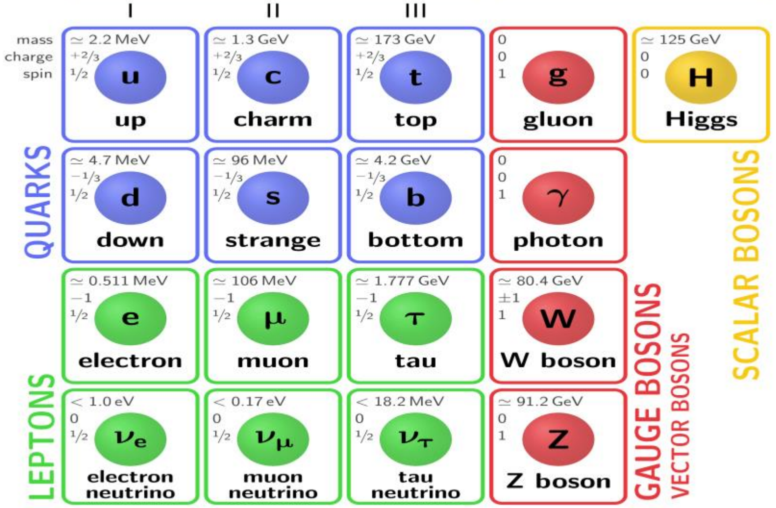
Main Drift Chamber

- $\frac{\sigma_p}{p} = 0.5\%$ @ $1\ \mathrm{GeV}/c$
- $\sigma_{dE/dx} = 6\%$

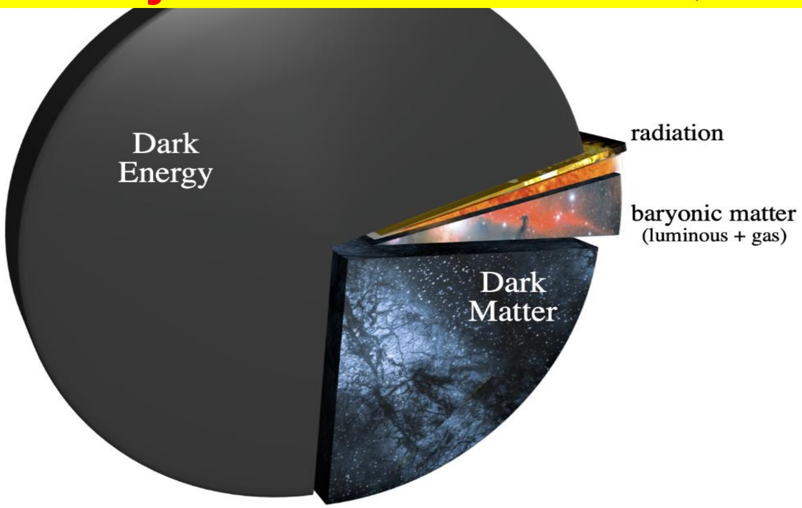
01 Introduction

- **The existence of new physics is inevitable**
  - ✓ Although SM is successful
  - ✓ Yet SM can't explain many experimental results
- **Why low energy region**
  - ✓ Non-Collider Exp.： many, no observation
  - ✓ High Energy Collider Exp.： many， no observation
  - ✓ Low Energy Collider Exp.： few， complementary
- **Our Advantages**
  - ✓ High lum, large data, good detector, clean environment
  - ✓ Complete kinematic constraint: MM^2, U_{miss}, M_{recoil} , M_{BC}, DT method
  - ✓ Richness of various control samples
  - ✓ Common usage of miscellaneous tools

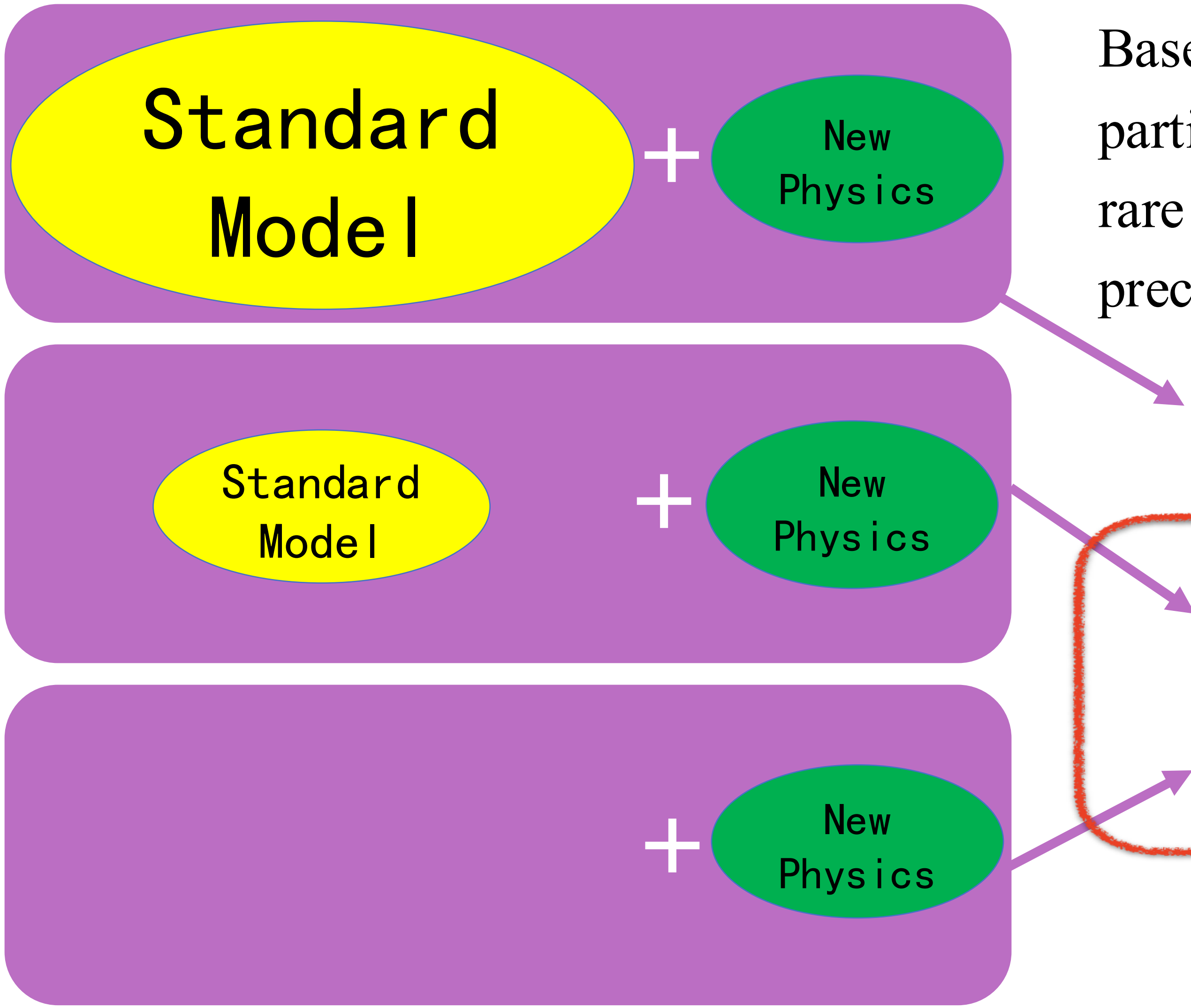
Seems already known a lot



Actually knows little(<5%)



01 Introduction



Based on vast data samples and the secondary particle samples $(\eta, \eta', \omega, \phi, K_S^0, \Lambda, \text{etc.})$ at BESIII, rare or forbidden processes are studied with high precision, thereby testing various BSM theories.

SM process: "dominant"

SM process: "highly suppressed"

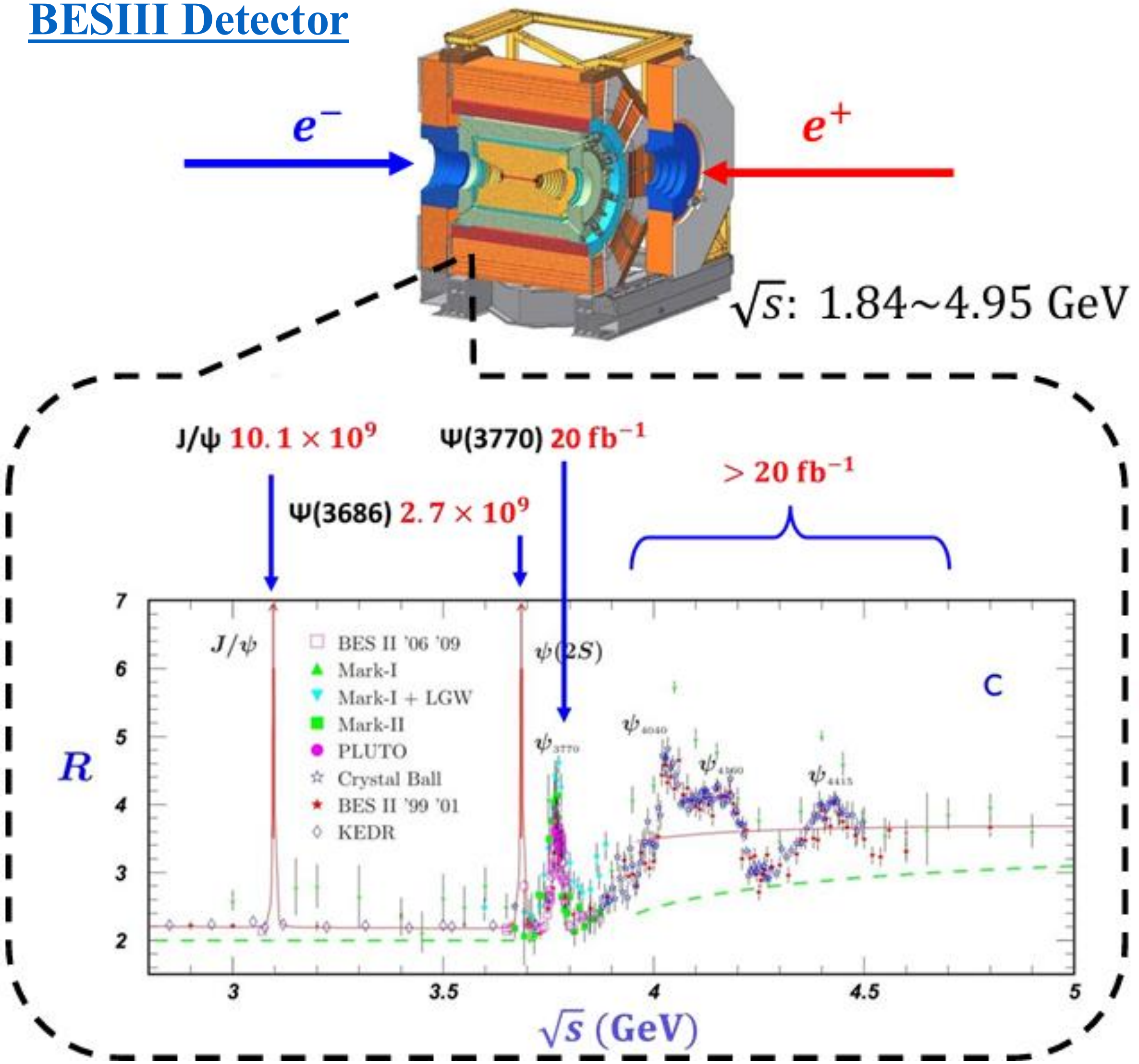
SM process: "forbidden"

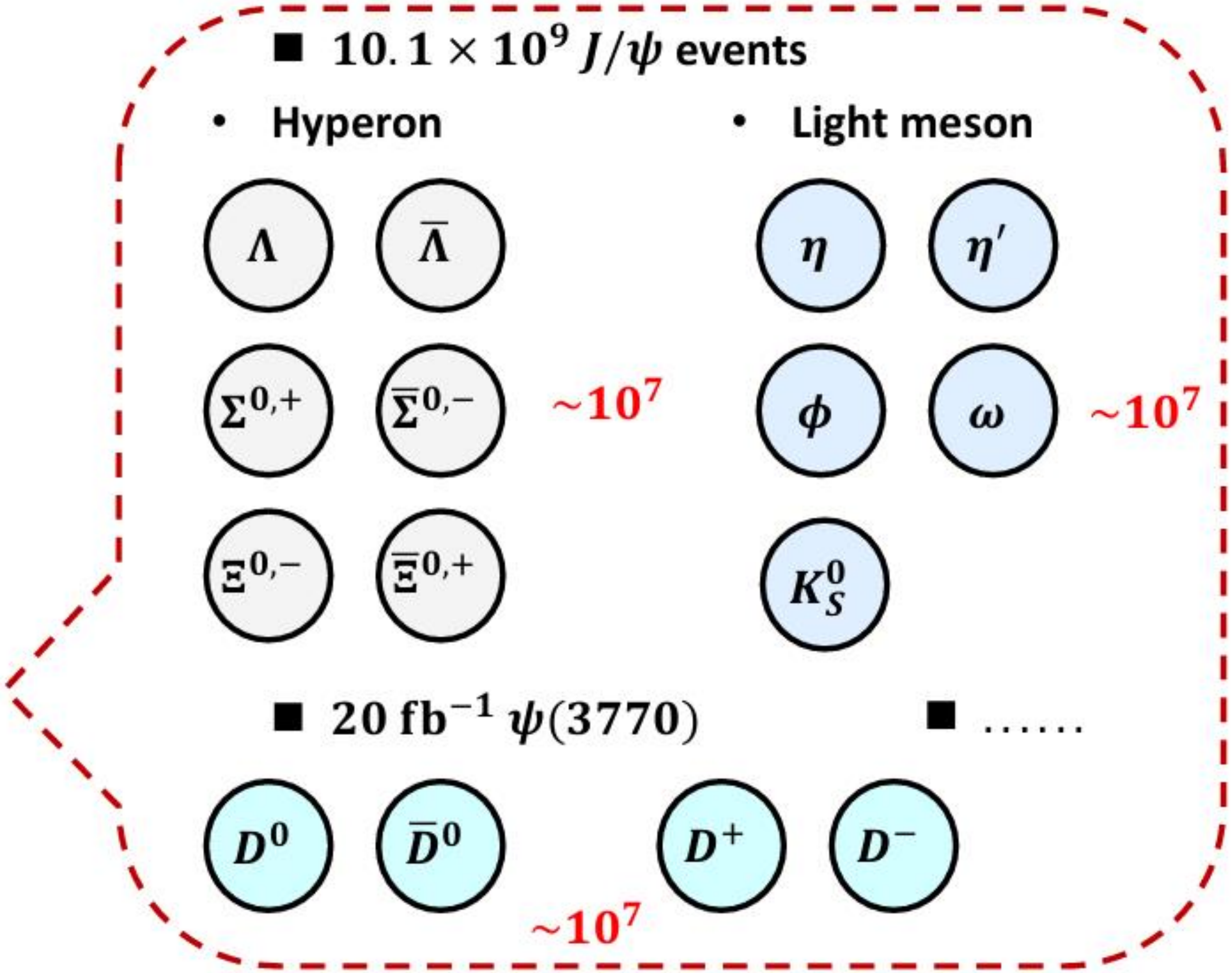
NP would be very small

$\Longrightarrow$ sensitive in rare/forbidden processes

01 Introduction

BESIII Detector





Rich Physics with clean environment

Chin. Phys. C **44**, 040001 (2020)

Outline

02 Searching for BSM particles

BSM particles Searching

Axion-like particle (ALP) via $J/\psi \to \gamma a$

a) With $\psi(2S)$ data
PLB **838**, 137698 (2023)

b) With J/ψ data
PRD **110,** L031101 (2024)

Light CP-odd Higgs boson via $J/\psi \to \gamma A^0$

- **Visible (di-muon) decay**
  PRD **105**, 012008 (2022)
  PRD **93**, 052005 (2016)
  PRD **85**, 092012 (2012)
- **invisible decay**
  PRD **101**, 112005 (2020)

Dark baryon

a) $\Xi^- \to \pi^- \chi$
PLB 872, 140099 (2026)

X17

a) $\chi_{cJ} \to e^+e^- J/\psi$
PRD Accepted (2026) (visible)

Dark photon

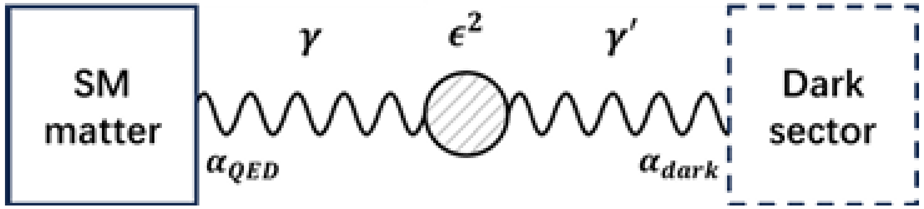
- **Massive**
  a) Via $J/\psi \to U\eta(')$
  PRD **99**, 012013 (2019)
  PRD **99**, 012006 (2019)
  PRD **102**, 052005 (2020)
  b) Via ISR process
  PLB **774**, 252 (2017) (visible)
  PLB **839**, 137785 (2023) (invisible)
- **Massless**
  a) $\Lambda_c^+ \to p\gamma'$
  PRD **106**, 072008 (2022)
  b) $D^0 \to \omega/\gamma\gamma'$
  PRD **111**, L011103 (2025)
  c) $\Sigma^+ \to p$ + invisible
  PLB **852**, 138614 (2024)

Fully invisible decays

- **Invisible decays of Λ baryon**
  PRD **105**, L071102 (2022)
- **Invisible decays of ω/ϕ mesons**
  PRD **98**, 032001 (2018)
- **Invisible decays of η/η' mesons**
  PRD **87**, 012009 (2013)
- **invisible muon philic scalar or vector meson**
  PRD **109**, L031102 (2024)
- **Invisible K_S^0 decays**
  JHEP **05**, 092 (2025)
- **$J/\psi \to \phi$ + invisible**
  PRL 135, 151804 (2025)

02 Searching for BSM particles: Dark Photon

- ✓ Dark matter has not seen yet in particle physics experiments.
- ✓ One of the simplest models is "DM hidden sector" that allows the coupling between DM and SM particles via the so called "portals"
- ✓ Can be accessible by high intensity e^+e^- collider experiments, such as BESIII experiment, if their masses are a few GeV
- ✓ Simplest extension of the SM $\Longrightarrow$ An extra Abelian gauge group, $\boldsymbol{U(1)_D} \Longrightarrow$ dark photon



Massive dark photon

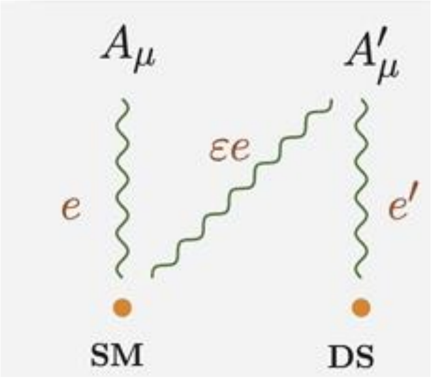
⇩

arises when the symmetry of the additional Abelian gauge group is spontaneously broken

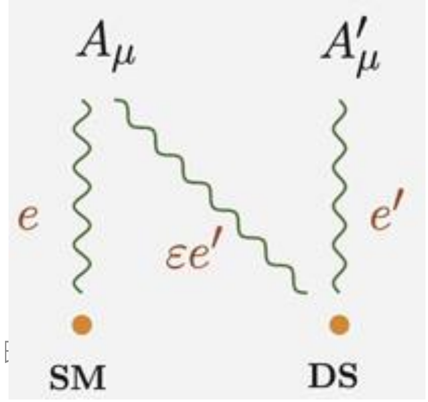
Massless dark photon

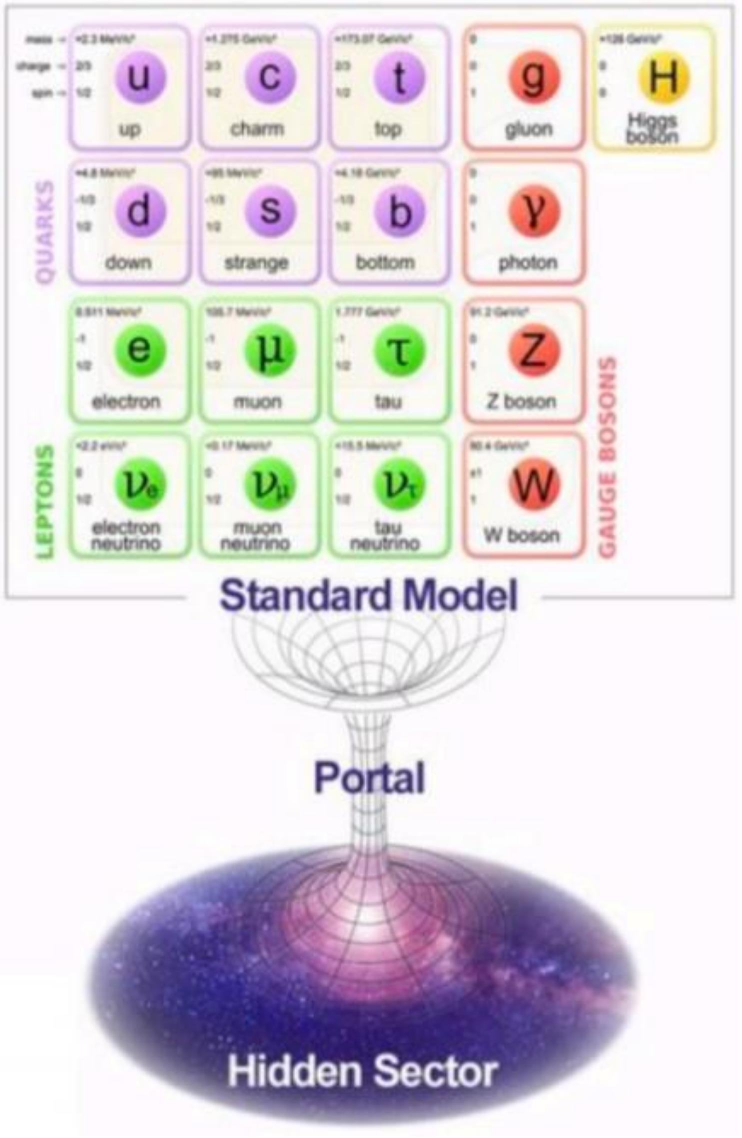
⇩

Symmetry remains unbroken



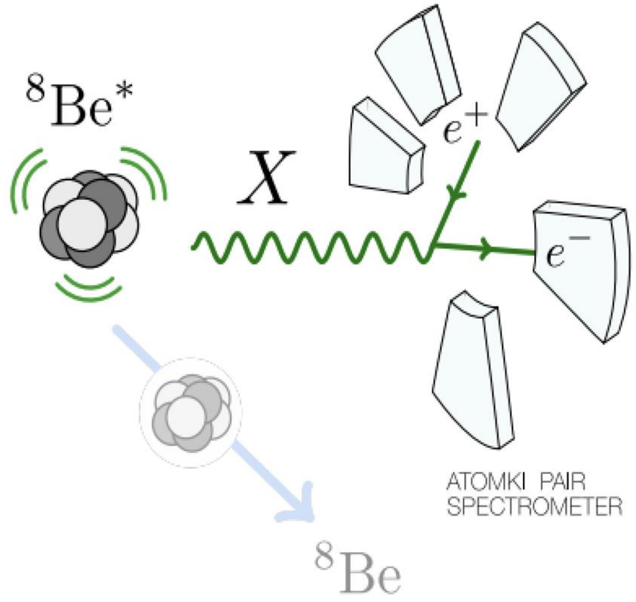
- Massive dark photon
  - ✓ Coupling with SM fermion
  - ✓ Strong constraint
- Massless dark photon
  - ✓ No direct coupling with SM fermion
  - ✓ Less constraint

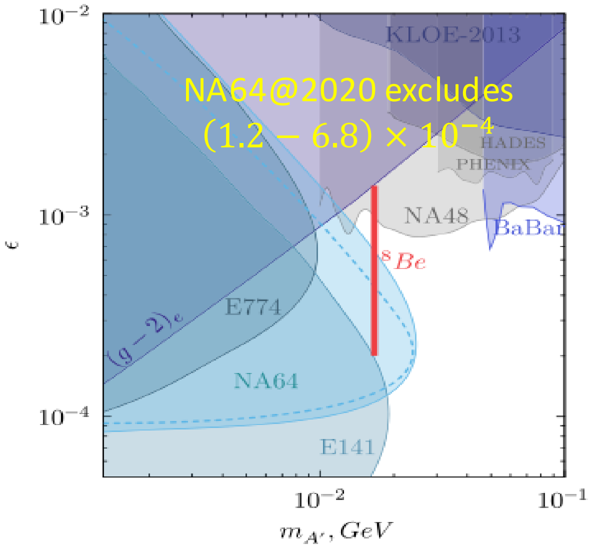


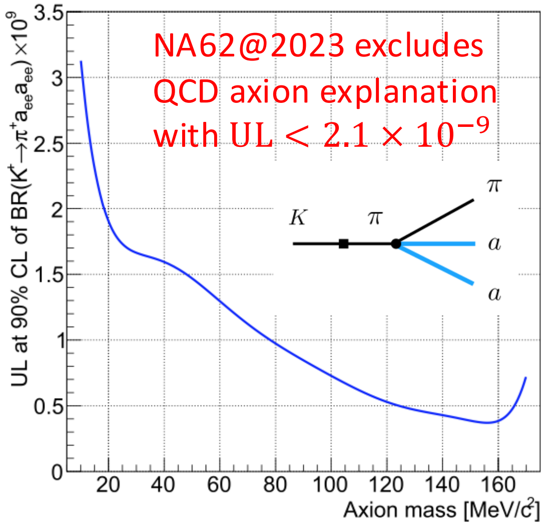


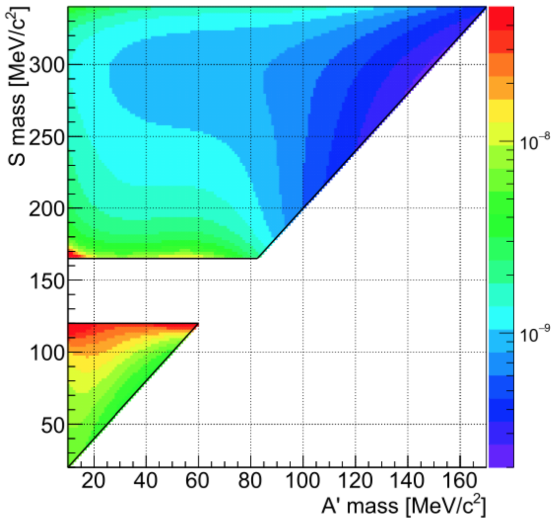
02 Searching for BSM particles: X17

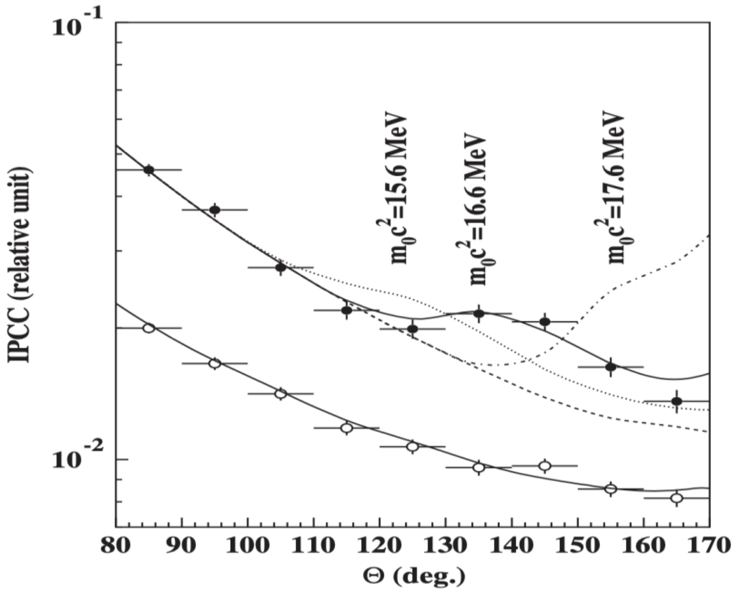
- The X17 anomaly was reported in the distribution of opening angles between e^+e^- pairs from the excited ^{8}Be, ^{7}Li, ^{4}He and ^{12}C nuclear transitions.
- Theories proposed the nature of X17 as axial vector boson, QCD axion, or protophobic vector gauge boson etc.
- In the protophobic vector gauge model, the X boson should have a nonuniversal coupling to quarks and a coupling strength with electrons in the range of $(0.2-1.4)\times10^{-3}$.
- Such a boson could also resolve the g-2 anomaly.











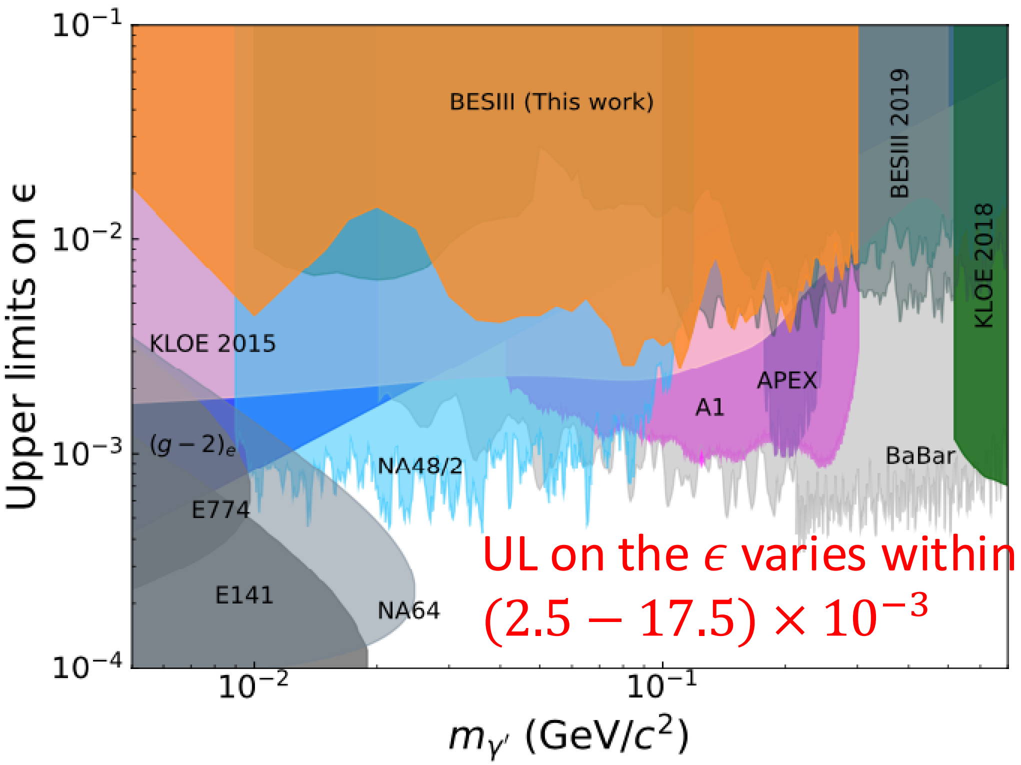
$$\mathcal{M}_{K_L\to\pi^0 aa}=\frac{\mathcal{M}_{K_L-\pi^0}}{m_{K_L}^2-m_{\pi^0}^2}\times\frac{m_a^2}{F_\pi^2}$$

arXiv: 2510.16531 (PRD accepted)

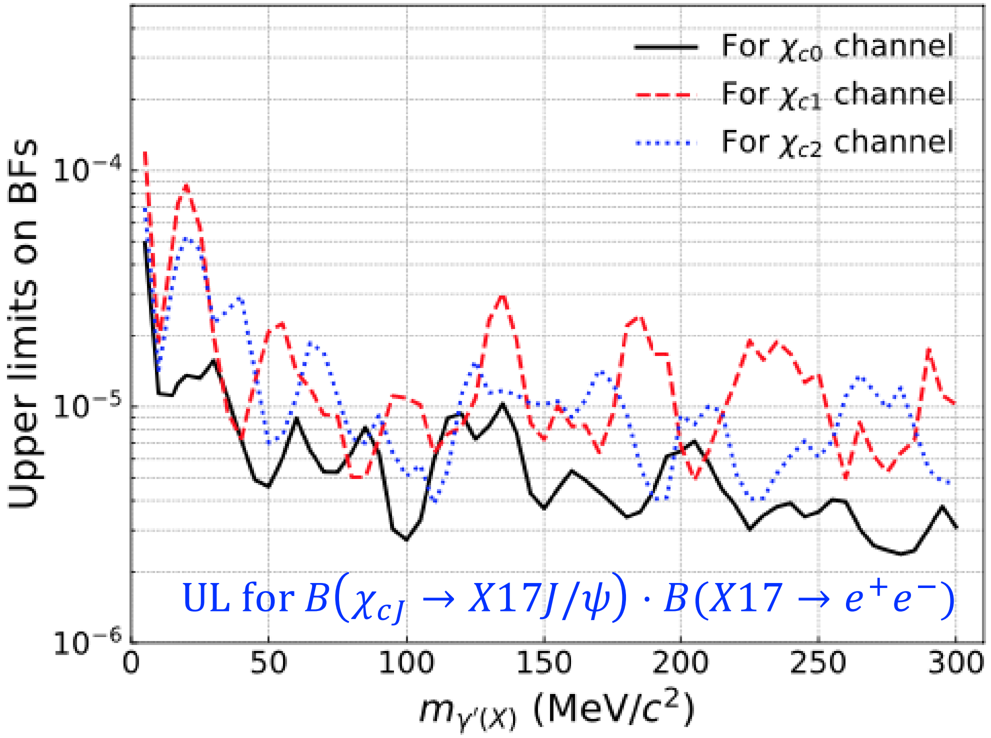
Analysis Strategy:

- ✓ Based on the $(2712.4 \pm 14.3) \times 10^6$ $\psi(3686)$ events.
- ✓ In the decay chain of $\psi(3686) \to \gamma\chi_{cJ} \to \gamma(X17J/\psi) \to \gamma(e^+e^-J/\psi)$, where $X17$ decays into e^+e^- and J/ψ is reconstructed with e^+e^- or $\mu^+\mu^-$.

$$\frac{\mathcal{B}(\chi_{cJ} \to \gamma' J/\psi)}{\mathcal{B}(\chi_{cJ} \to \gamma J/\psi)} = \epsilon^2 |F(q^2)|^2 \frac{\lambda^{3/2}(m_1^2, m_2^2, m_3^2)}{\lambda^{3/2}(m_1^2, m_2^2, 0)}$$

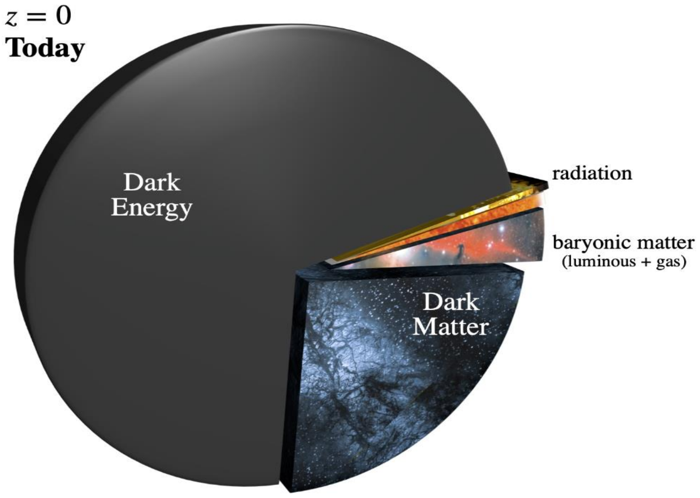


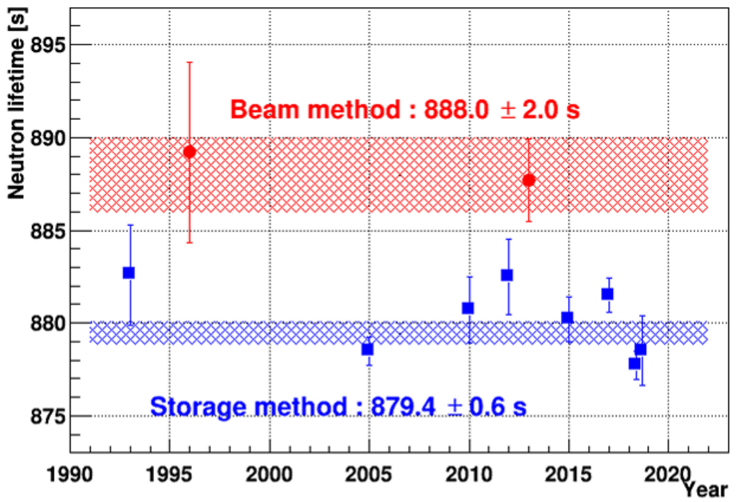
UL on the strength of the charm quark coupling at 17 MeV is determined to be $|\epsilon_c| < 1.2 \times 10^{-2}$, where $B(X17 \to e^+e^-) = 100\%$



02 Searching for BSM particles: Dark Baryon

- ✓ Coincidence issue [$\rho_{DM} \approx 5.4 \cdot \rho_{baryon}$]
- ✓ Neutron lifetime puzzle [B($n \to$ dark)~1%]
- ✓ B-Mesogenesis mechanism
- ✓ Hyperon dark decays

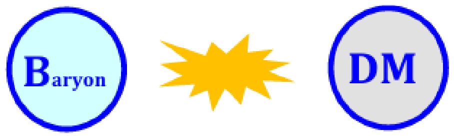




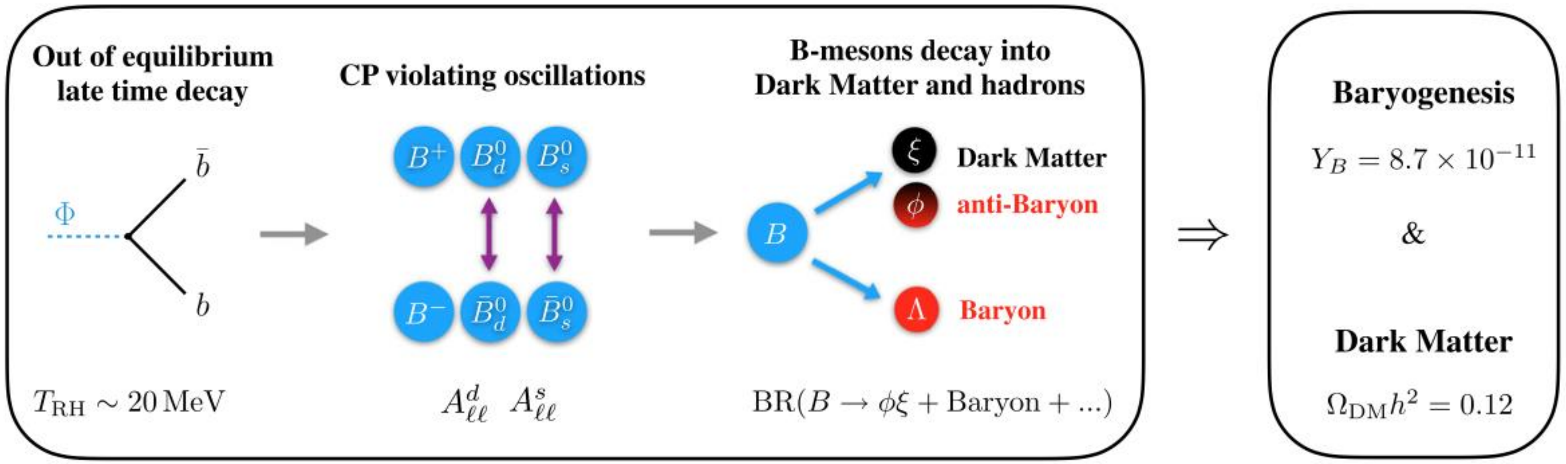
DM may have non-zero baryon number

Can explain the symmetry between visible mater and antimatter and origin of DM.

Benefits



- ✓ DM originates with SM
- ✓ Matter anti-matter asymmetry
- ✓ No BNV, proton would be stable

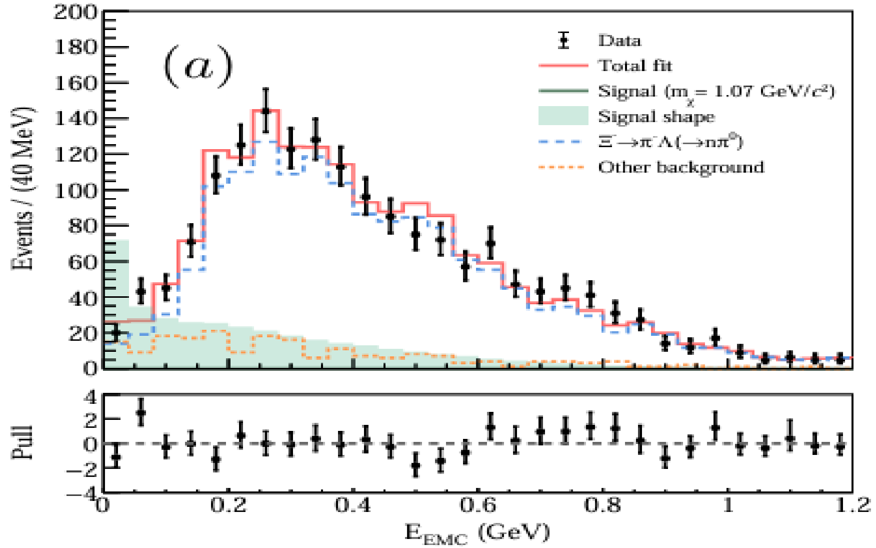


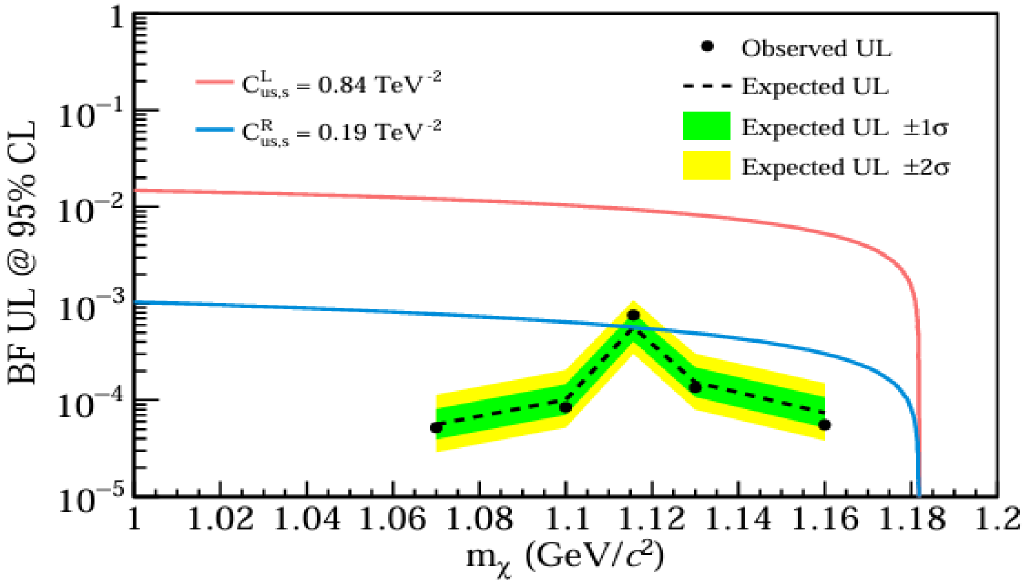
02 Searching for BSM particles: Dark Baryon

PLB 872, 140099 (2026)

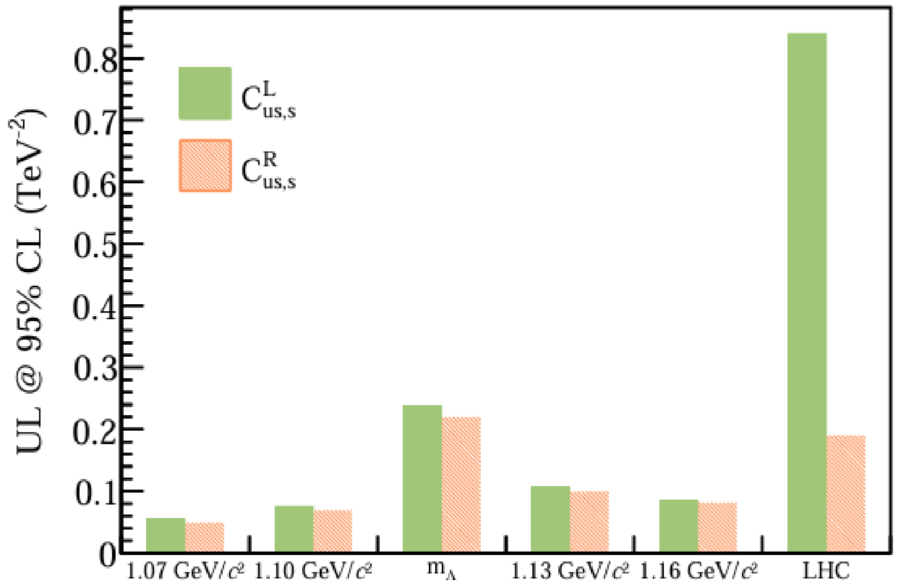
Analysis strategy

- ✓ $J/\psi \to \bar{\Xi}^+\Xi^-$ from 10 billion J/ψ events
- ✓ Double tag method: $\bar{\Xi}^+ \to \bar{\Lambda}\pi^+, \bar{\Lambda} \to \bar{p}\pi^+, \Xi^- \to \pi^- + \chi$
- ✓ χ is the dark baryon with an invisible signature with masses of 1.07, 1.10, m_Λ, 1.13, 1.13 GeV/c^2
- ✓ The invisible signal should have EMC energy deposit peaking at zero
- ✓ No evidence of significant signal events





Corresponding Wilson coefficients C^L_{uss} and C^R_{uss} are more stringent than the previous limits from the LHC searches for the colored mediators



UL on $B(\Xi^- \to \pi^- + \chi)$ varies from $(4.5 - 76) \times 10^{-5}$ (90% CL)

Outline

03 Investigation of rare decays

Investigation of Rare Decays

FCNC

Decay Mode	Publication
$D_S^+ \to \phi\pi^+, \phi \to e^+e^-$	PRL133, 121801 (2024)
$D_S^+ \to \phi\rho^+, \phi \to e^+e^-$	
$D_S^+ \to \pi^+\pi^0 e^+e^-$	
$D_S^+ \to K^+\pi^0 e^+e^-$	
$D_S^+ \to K_S^0\pi^+ e^+e^-$	
$D^0 \to \pi^0\nu\bar{\nu}$	PRD105, L071102 (2022)
$\psi(3686) \to \Lambda_c^+\bar{p}e^+e^-$	PRD97, 091102 (2018)
$D^+ \to \pi^+\pi^0 e^+e^-$	PRD97, 072015 (2018)
$D^+ \to K^+\pi^0 e^+e^-$	
$D^+ \to K_S^0\pi^+ e^+e^-$	
$D^+ \to K_S^0 K^+ e^+e^-$	
$D^0 \to \pi^+\pi^- e^+e^-$	
$D^0 \to K^+K^- e^+e^-$	
$D^0 \to K_S^0 e^+e^-$	
$D^0 \to \pi^0/\eta/\omega e^+e^-$	
$D^0 \to \gamma\gamma$	PRD91, 112015 (2015)

CWD

Decay Mode	Publication
$J/\psi \to \bar{D}^0\bar{K}^{*0}$	arXiv:2511.16083
$J/\psi \to D_s^- e^+\nu_e$	arXiv:2510.25100
$J/\psi \to D^0\mu^+\mu^-$	JHEP04, 61 (2025)
$J/\psi \to D_s^-\rho^+$	JHEP12, 77 (2025)
$J/\psi \to D_s^-\pi^+$	
$J/\psi \to D^-\mu^+\nu_\mu$	JHEP01, 126 (2024)
$J/\psi \to \gamma D^0$	PRD110, 112012 (2024)
$J/\psi \to D^0\pi^0, D^0\eta, D^0\rho^0$	PRD110, 032020 (2024)
$J/\psi \to D^-\pi^+, D^-\rho^+$	
$\psi(3686) \to \Lambda_c^+\bar{\Sigma}^-$	CPC47, 013002 (2023)
$J/\psi \to D^- e^+\nu_e$	JHEP06, 157 (2021)
$J/\psi \to D^0 e^+e^-$	PRD96, 111101 (2017)
$\psi(3686) \to D^0 e^+e^-$	
$J/\psi \to D_s^{*-} e^+\nu_e$	PRD90, 112014 (2014)
$J/\psi \to D_s^-\rho^+$	PRD89, 071101 (2014)
$J/\psi \to \bar{D}^0\bar{K}^{*0}$	

Others

a) $\Omega^- \to \Sigma^0\pi^-, nK^-$
JHEP05, 141 (2024)

b) $J/\psi \to l^+l^-l^+l^-$
PRD109, 052006 (2024)

c) $\Xi^0 \to \Sigma^- e^+\nu_e$
PRD107, 012002 (2023)

d) $\Xi^- \to \Xi^0 e^-\bar{\nu}_e$
PRD104, 072007 (2021)

e) $\psi' \to e^+e^-\eta_c$
PRD106, 112002 (2022)

f) $J/\psi \to e^+e^-\phi$
PRD99, 052010 (2019)

03 Investigation of rare decays: Charmonium Weak Decays

- Charmonium weak decays are **allowed in SM**, but highly suppressed to 10^{-10} by strong and EM decays.
- The inclusive J/ψ weak decay is predicted to be at the order of $\mathbf{10^{-8}}$ **or below in SM** [Z. Phys. C 62 271 (1994)].
- Some **new physics models** can enhance the BF of J/ψ weak decay to 10^{-5}.
- Searching for the J/ψ weak decays can provide an experimental test of the SM.
- Searching for NP: top-color model, the minimal supersymmetric, and the two-Higgs doublet model.

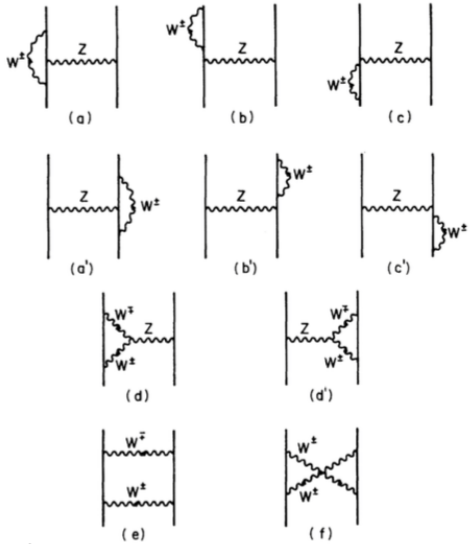
Top-color model

[Phys. Letter. B 16 (1982)]

- $0\nu\beta\beta$ decay Mediated by the photino λ_γ is negligible for reasonable photino masses
- Predict the existence of a light mass (~100 keV) scalar boson very weakly coupled to matter.

Minimal supersymmetric

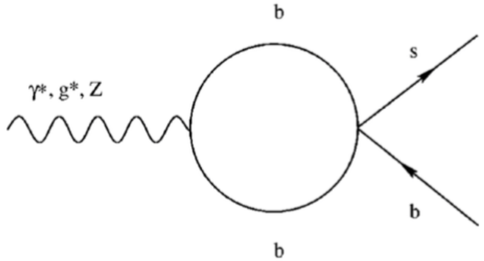
[PRD 15, 1958 (1977)]



Produce strangeness-nonconserving (charm-nonconserving) Fermi interactions of order αG_F

Two-Higgs doublet model

[PRD 60, 014011 (1999)]

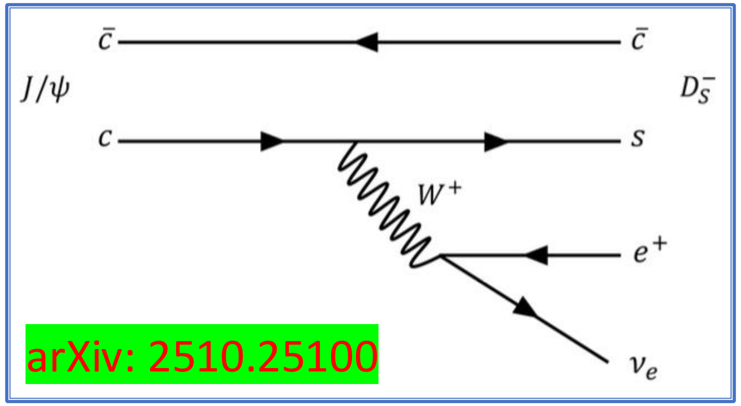


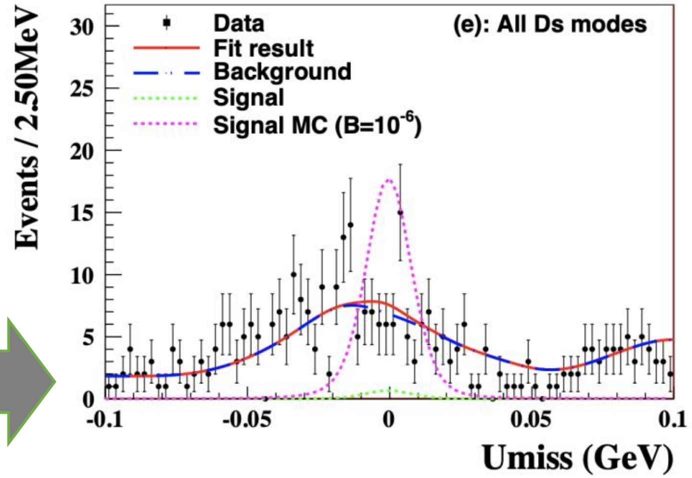
- Effective $\bar{s}b\gamma^*(g^*, Z)$ vertices generated by L_{new}
- L_{new}: Four-quark operators with two scalar currents:

03 Investigation of rare decays: Charmonium Weak Decays

arXiv: 2510.25100
arXiv: 2511.16083

- ✓ Based on the 10 billion J/ψ events taken at 3.097 GeV.
- ✓ Semi-leptonic decay $J/\psi \to D_s^- e^+ \nu_e$ for the first time, and improved constraint on $J/\psi \to \bar{D}^0 \bar{K}^{*0}$.

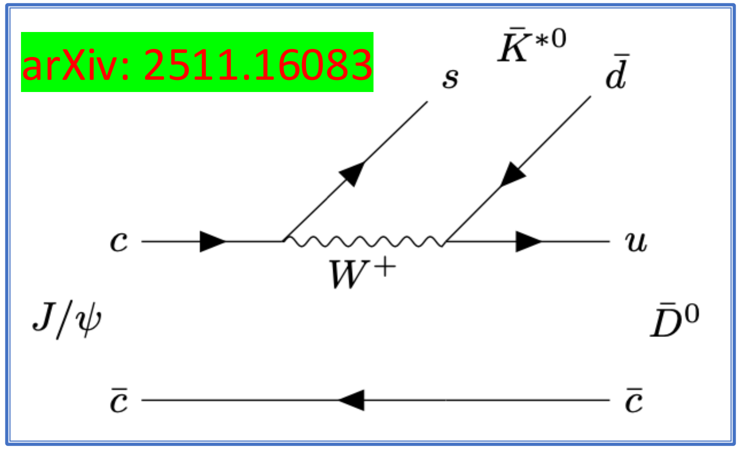


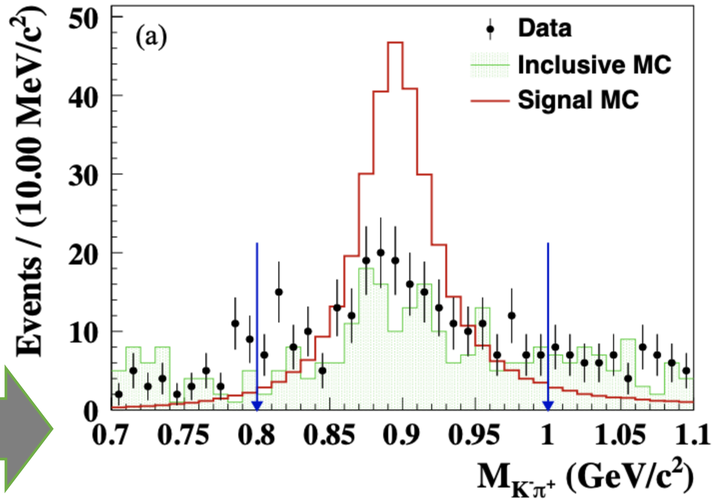


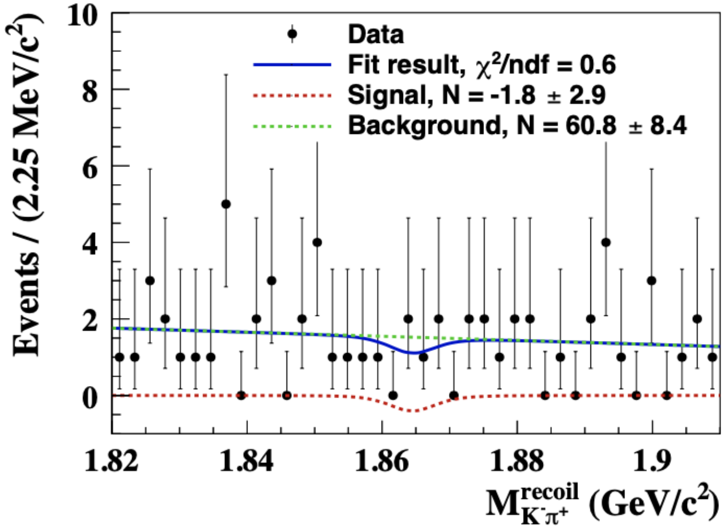
UL at 90% confidence level

$B(J/\psi \to \bar{D}^0 \bar{K}^{*0}) < 1.4 \times 10^{-7}$

$B(J/\psi \to D_s^- e^+ \nu_e) < 1.0 \times 10^{-7}$







Outline

04 Precision test of conservation laws

Test of Conservation Laws

cLFV

Decay Mode	Publication
$\psi(3686) \to e\mu$	SCPMA Accepted (2026)
$J/\psi \to e\mu$	SCPMA66, 221011 (2023)
	PRD87, 112007 (2013)
$J/\psi \to e\tau(\tau \to \pi\pi^0\nu_\tau)$	PRD103, 112007 (2021)

BNV

Decay Mode	Publication
$\Lambda - \bar{\Lambda}$ *osc in* $J/\psi \to \Lambda\bar{\Lambda}$	PRD111, 052014 (2025)
$\Lambda - \bar{\Lambda}$ *osc in* $J/\psi \to pK^-\bar{\Lambda}$	PRL131, 121801 (2023)
$J/\psi \to pe^- + c.c.$	PRD111, 112010 (2025)
$\Xi^0 \to K^+e^-$	PRD108, 012006 (2023)
$\Xi^0 \to K^-e^+$	
$D^+ \to \bar{n}e^+$ / $D^- \to ne^-$	PRD106, 112009 (2022)
$D^+ \to ne^+$ / $D^- \to \bar{n}e^-$	
$D^0 \to \bar{p}e^+$	PRD105, 032006 (2022)
$D^0 \to pe^-$	
$D^+ \to \Lambda e^+$	PRD101, 031102(R) (2020)
$D^+ \to \Sigma^0 e^+$	
$D^+ \to \bar{\Lambda}e^+$	
$D^+ \to \bar{\Sigma}^0 e^+$	
$J/\psi \to \Lambda_c^+ e^- + c.c.$	PRD99, 072006 (2019)

LNV

Decay Mode	Publication
$\Xi^- \to \Sigma^+ e^- e^-$	arXiv:2511.15394
$J/\psi \to K^+K^+e^-e^-$	CPC50, 013107 (2026)
$\eta \to \pi^+\pi^+e^-e^-$	PRD112, 112021 (2025)
$\omega \to \pi^+\pi^+e^-e^-$	CPC49, 103002 (2025)
$\phi \to \pi^+\pi^+e^-e^-$	CPC49, 043001 (2025)
$D_s^+ \to \phi\pi^-e^+e^+$	JHEP01, 109 (2025)
$D_s^+ \to \phi K^-e^+e^+$	
$D_s^+ \to K_S^0\pi^-e^+e^+$	
$D_s^+ \to K_S^0K^-e^+e^+$	
$D_s^+ \to \pi^0\pi^-e^+e^+$	
$D_s^+ \to \pi^0K^-e^+e^+$	
$\Sigma^- \to pe^-e^-$	PRD103, 052011 (2021)
$D^0 \to K^-\pi^-e^+e^+$	PRD99, 112002 (2019)
$D^+ \to K_S^0\pi^-e^+e^+$	
$D^+ \to K^-\pi^0e^+e^+$	

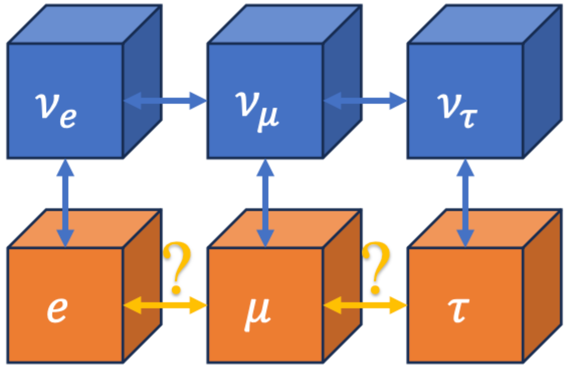
CV

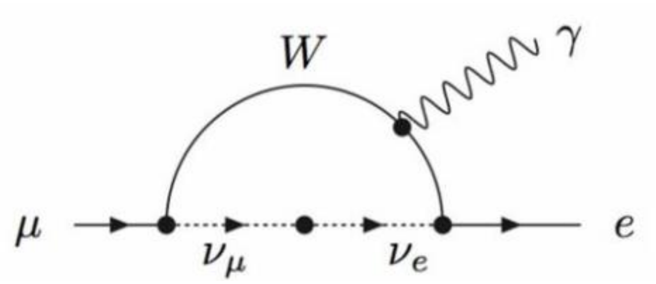
a) $J/\psi \to \gamma\gamma, \gamma\phi$

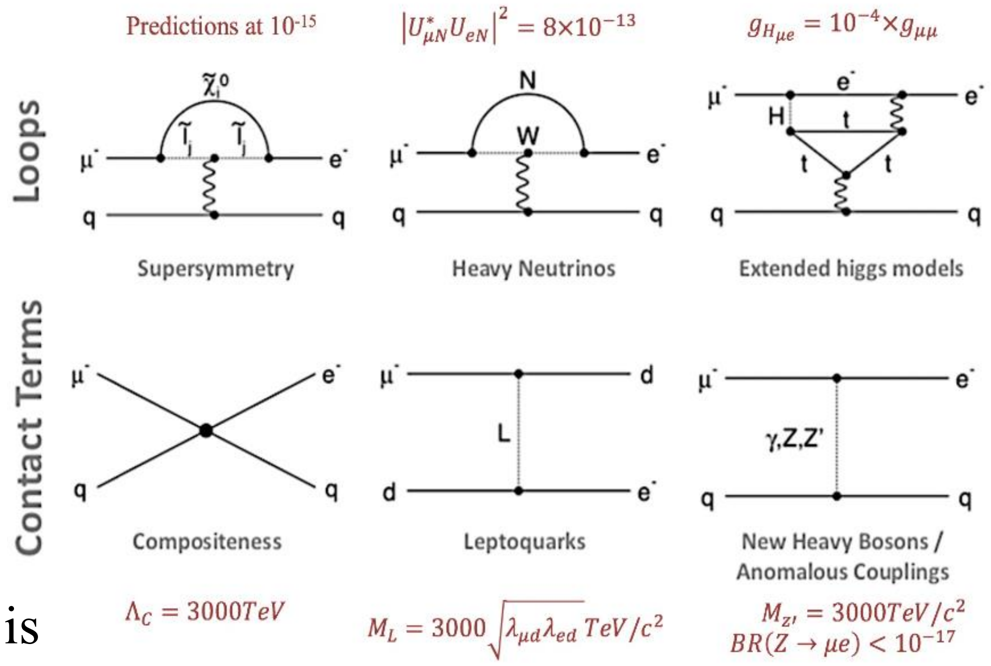
PRD90, 092002(2014)

04 Precision test of conservation laws： Changed Lepton Flavor Violation

✓ Neutrino flavor violation is observed







✓ In the Standard Model (SM) of particle physics, the LFV process is forbidden. However, flavor non-conserving mixing among generations has been observed in neutrino oscillations.

✓ The smallness of neutrino masses leads to a very large suppression of the predicted branching fractions. So, any significant sign of a CLFV signal could indicate physics beyond the SM.

$$BR(\mu\to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i}U_{ei}\frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

04 Precision test of conservation laws： Changed Lepton Flavor Violation

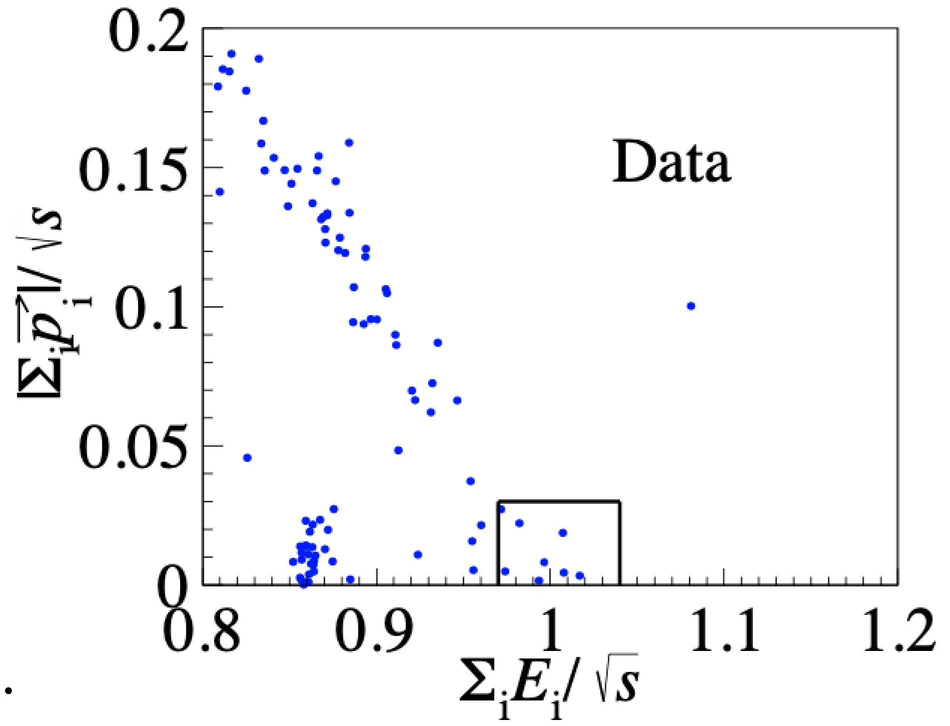
New Physics

- ✓ Many New Physics models enhance CLFV effects up to a detectable level
  - Series model based on SUSY
  - Two higgs doublet model with extra Yukawa couplings
  - Technicolor models with lepton flavor changing coupling vertices
- ✓ New Physics models predicts charmonium CLFV
  - SUSY-based GUTs
  - SUSY with various new bosons (scalars, vectors)
  - top-color assisted technicolor (TC2) model
  - MSSM with gauged baryon and lepton number

Analysis Strategy

- ✓ Based on $(2367.0 \pm 11.1) \times 10^6$ $\psi(3686)$ events.
- ✓ Search for $\psi(3686) \to e^{\pm}\mu^{\mp}$ for the first time.
- ✓ UL for $B(\psi(3686) \to e^{\pm}\mu^{\mp}) < 1.4 \times 10^{-8}$ at 90% CL.

arXiv: 2507.10331
(accepted by SCPMA)



04 Precision test of conservation laws： Lepton Number Violation

- ✓ Experimentally, neutrino oscillations strongly indicate neutrinos have mass
- ✓ Theoretically, "see-saw" mechanism can explain the neutrino mass
  - The small mass of the observed neutrino arises from heavy Majorana neutrino
  - Whether neutrino is Dirac or Majorana particle is an open question
- ✓ Majorana neutrino can be manifested through the LNV decays by $\Delta L = 2$
  - Most promising way: neutrinoless double beta ($0\nu\beta\beta$) decay

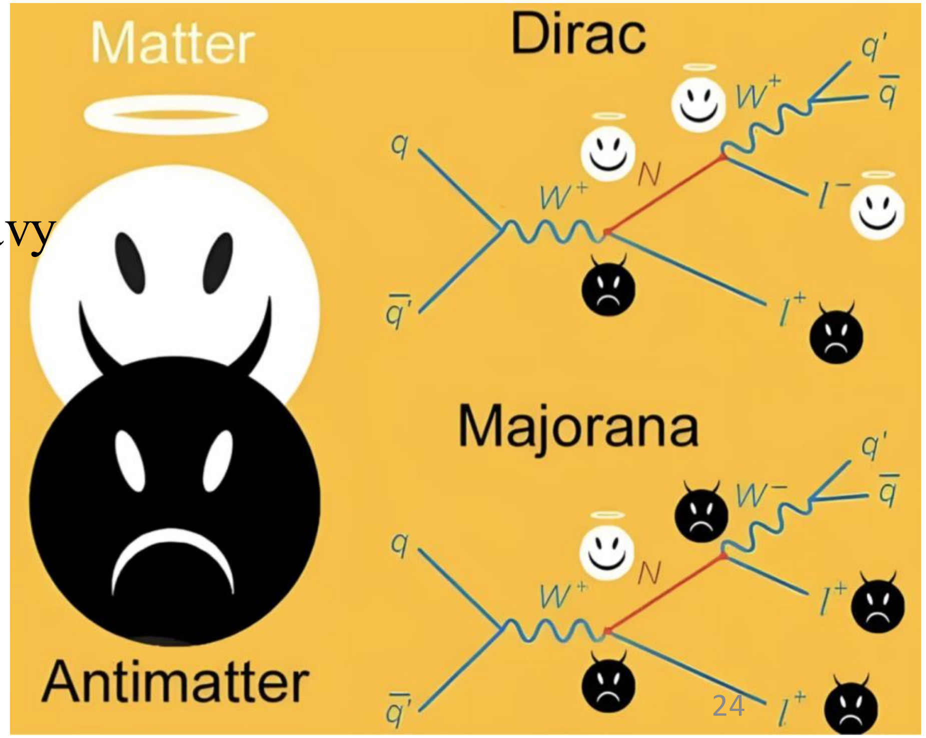
$$\mathcal{L} = -\frac{g}{\sqrt{2}} W_\mu^+ \sum_{l=e}^{\tau} V_{lN}^* \overline{N^c} \gamma^\mu P_L l + \text{h.c.}$$

CPC39,013101 (2015)

  - V_{lN}: Mixing matrix between the charged lepton l nuetrino ν_l and heavy Majorana neutrino

$$|V_{eN}|^2 < 3\times10^{-3},\ |V_{\mu N}|^2 < 3\times10^{-3},\ |V_{\tau N}|^2 < 6\times10^{-3}$$

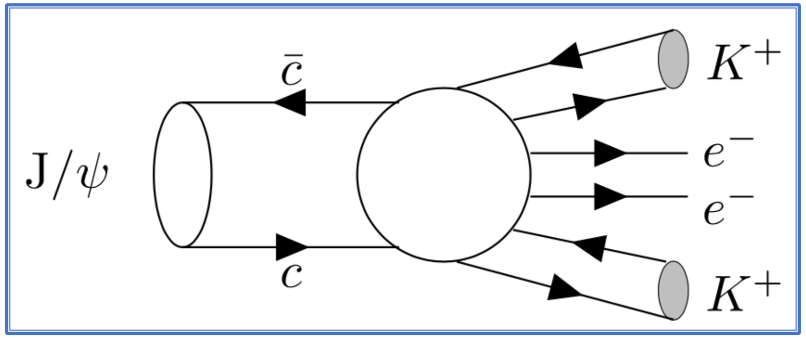
- ✓ Search for $\Delta L = 2$ process in hadron decays

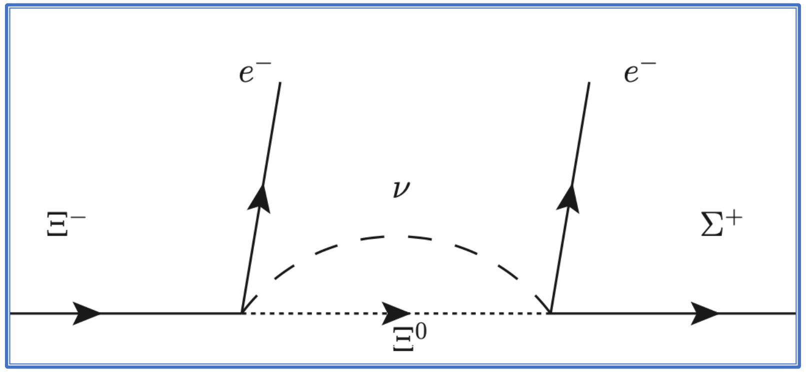


04 Precision test of conservation laws： Lepton Number Violation

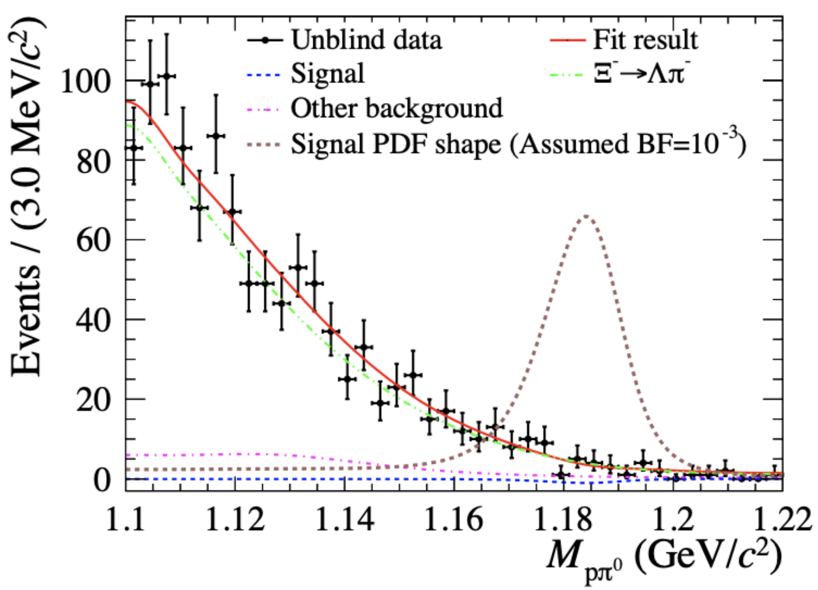
Analysis Stragety:

- ✓ Based on $(10087 \pm 44) \times 10^6\ J/\psi$ events taken at 3.097 GeV.
- ✓ LNV processes $J/\psi \to K^+K^+e^-e^-$ and $\Xi^- \to \Sigma^+e^-e^-$ are searched for the first time.
- ✓ Double Tag method is used in $\Xi^- \to \Sigma^+e^-e^-$ via $J/\psi \to \bar{\Xi}^+\Xi^-$.
- ✓ ULs of $B(J/\psi \to K^+K^+e^-e^-) < 2.1 \times 10^{-9}$ and $B(\Xi^- \to \Sigma^+e^-e^-) < 2.0 \times 10^{-5}$.

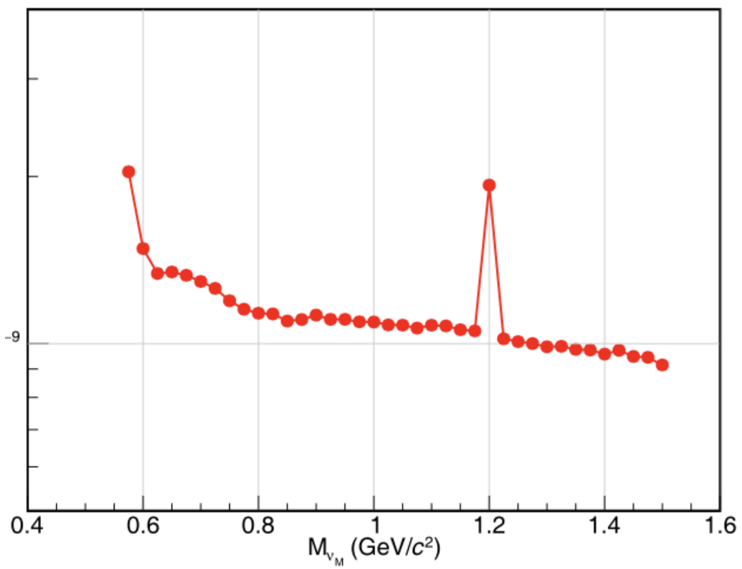




arXiv: 2511.15394



CPC50, 013107 (2026)



Outline

05 Summary

- Rare/forbidden decays provide a unique lab to look for NP.
- Rare charm/charmonium decays is a unique window on NP, which are complementary to those of strange and beauty hadrons.
- Present limits are still above SM predictions, no NP effects have been found yet.
- Better limits and new results are expected from BESIII, Belle II, LHCb, and Super Tau-Charm Factories.
- More constraints on dark sectors, conservation laws, rare decays, are ongoing.

BSM searches

谢谢！