BSM searches with Charmonium at BESIII

Zhengyun YOU

Sun Yat-sen University, China

(On behalf of the BESIII Collaboration)

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Outline

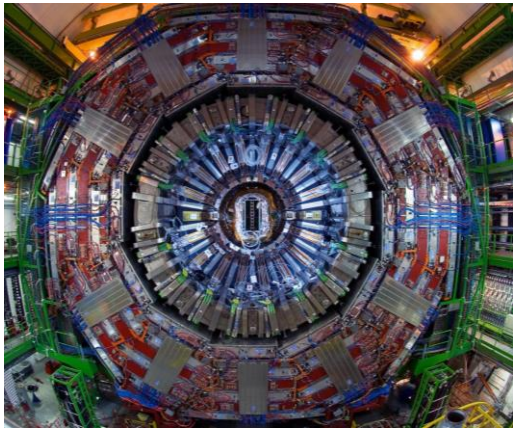
- New physics beyond the Standard Model
- BEPCII & BESIII
- New Physics search at BESIII
  - Forbidden processes
  - Rare decays
  - Exotics
- Summary and Future

New Physics beyond Standard Model

Search for …

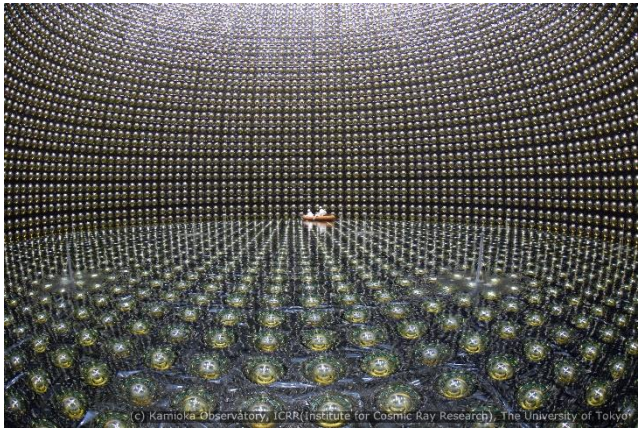
Energy Frontier

Direct search for new particles



Intensity Frontier

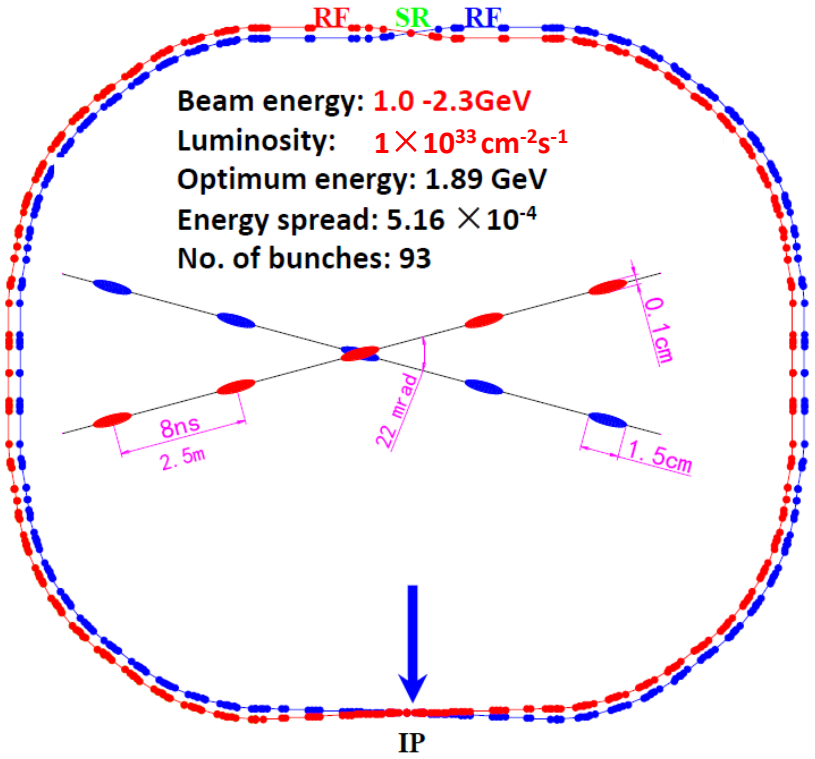
Search for rare processes



BEPCII and BESIII

Beijing Electron Positron Collider II

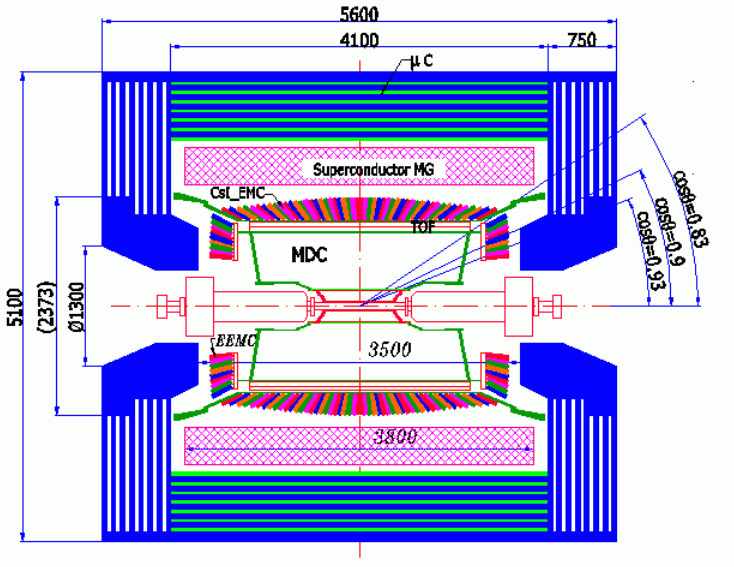
Charm Factory



BESIII Detector

MDC: p 0.5%@ 1GeV/c
dE/dx: 6%

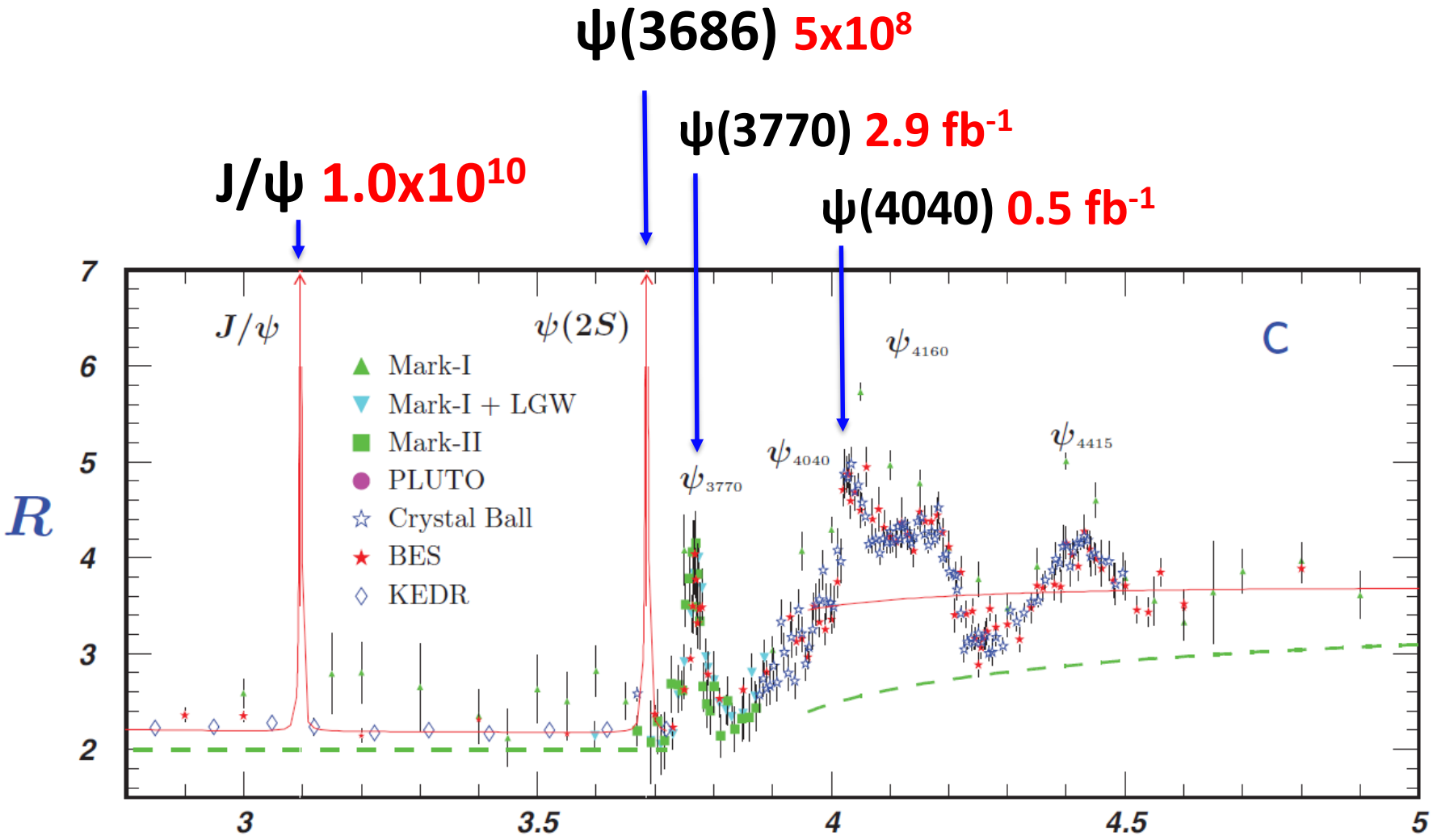
EMC: CsI (Tl) 2.5% (5.0%)
barrel (endcap) @ 1GeV



TOF: σT=80(70) ps
barrel (endcap)

MUC: RPC 9 (8) layers
barrel (endcap)

Charmonium Data at BESIII



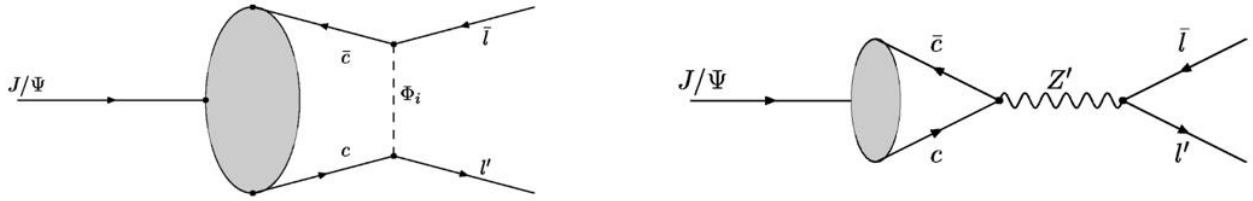
New Physics Search with Charmonium at BESIII

- BESIII new physics publications

Physics		Processes	Publication	
Forbidden Processes	Lepton Flavor Violation	J/ψ→eμ	PRD 87, 112007 (2013)	
	Lepton Number Violation	**J/ψ→Λc e**	**PRD 99, 072006 (2019**)	**New**
	Baryon Number Violation	J/ψ→ΛΛbar		
	C/P/CP	J/ψ→γγ, J/ψ→γϕ	PRD 90, 092002 (2014)	
Rare Decays	FCNC	J/ψ and ψ(3686)→D0e+e-	PRD 96, 111101(R) (2017)	
	Weak Decays	J/ψ→Ds e υ	PRD 90, 112014 (2014)	
		J/ψ→Ds ρ	PRD 89, 071101(R) (2014)	
	E.M.	**J/ψ→ϕe+e-**	**PRD 99, 052010 (2019)**	**New**
Exotics	Dark Photons	e+e-→γ(e+e-/μ+μ-)γ' ISR	PLB 774 (2017) 252	
		J/ψ→ηA' (A'->e+e-)	**PRD 99, 012006 (2019)**	**New**
		J/ψ→η'γ' (γ'->e+e-)	**PRD 99, 012013 (2019)**	**New**
	Little Higgs, Dark Higgs	J/ψ→γX (X→μ+μ-)	PRD 85, 092012 (2012)	
		J/ψ→γA0 (A0→μ+μ-)	PRD 93, 052005 (2016)	
	Invisible Decays	J/ψ→ϕη	PRD 87, 012009 (2013)	
		J/ψ → Vη V(=ω , ϕ)	**PRD 98, 032001 (2018)**	**New**

Forbidden Processes

- SM convservation law violated
  - Lepton Flavor Violation (LFV)
  - Lepton Number violation (LNV)
  - Baryon Number violation (BNV)
  - Lepton Universality (LU)
  - C/P/CP violation



PRD.67.114001

Lepton Flavor Violation

- A useful probe for new physics beyond SM
- Sensitive to new physics with effective energy up to 10^4 TeV
- Intensity frontier

  advantages over

  energy frontier

Process	Current Limit	Next Generation exp
$\tau \rightarrow \mu\eta$	BR < 6.5 E-8	
$\tau \rightarrow \mu\gamma$	BR < 6.8 E-8	10^{-9} - 10^{-10} (Belle II)
$\tau \rightarrow \mu\mu\mu$	BR < 3.2 E-8	
$\tau \rightarrow eee$	BR < 3.6 E-8	
$K_L \rightarrow e\mu$	BR < 4.7 E-12	
$K^+ \rightarrow \pi^+e^-\mu^+$	BR < 1.3 E-11	
$B^0 \rightarrow e\mu$	BR < 7.8 E-8	
$B^+ \rightarrow K^+e\mu$	BR < 9.1 E-8	
$\mu^+ \rightarrow e^+\gamma$	BR < 4.2 E-13	10^{-14} (MEG)
$\mu^+ \rightarrow e^+e^+e^-$	BR < 1.0 E-12	10^{-16} (PSI)
$\mu N \rightarrow eN$	$R_{\mu e}$ < 7.0 E-13	10^{-17} (Mu2e, COMET)

LFV measurements at BESIII

- Search for LFV process physics with Charmonium
- J/ψ→eμ with the 225.3x10^6 J/ψ events at BESIII

$$\boldsymbol{B(J/\Psi \to e\mu) < 1.6 \times 10^{-7}}\ (90\%\ C.L.)$$

BESIII, PRD 87, 112007 (2013)

- Expect more with the 1x10^{10} J/ψ collected
  - J/ψ→eμ
  - J/ψ→eτ, J/ψ→μτ
  - J/ψ→γeτ, J/ψ→γμτ

PRD.67.114001

Search for BNV & LNV process $J/\psi \to \Lambda_c^+ e^-$

- Matter anti-matter asymmetry (Sakharov conditions)
  - Baryon number violation
  - C & CP violation
  - Interactions out of thermal equilibrium

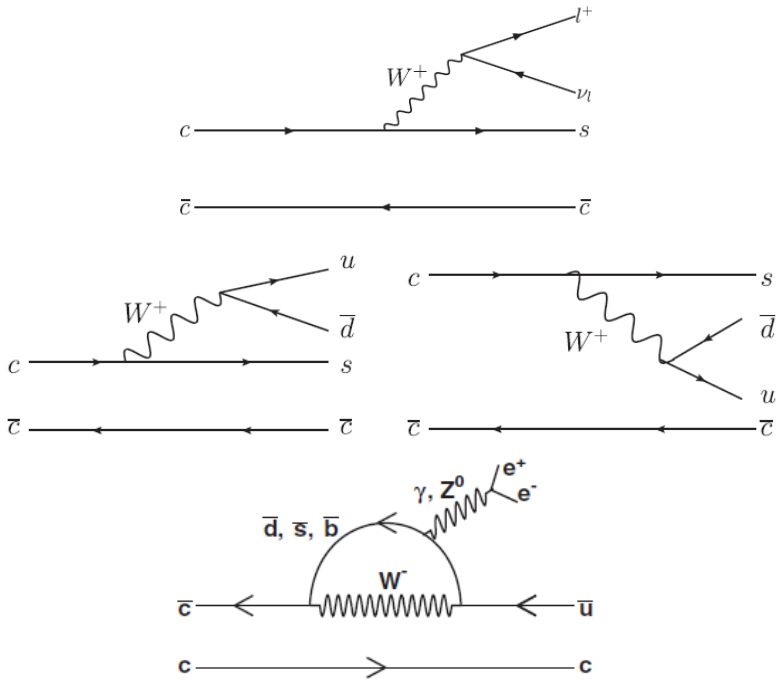
PRL 32 (1974) 438-441

- BSM Theory allows BNV
  - GUT, X&Y bosons

Recent BESIII result on the process will be introduced in the talk "**Charmonium rare decays at BESIII**" by Bo ZHENG on 5/16

Rare Decays

- Allowed in SM, but highly suppressed
  - FCNC (Loop, GIM, <10^{-9})
  - Rare weak decays ($c \to s$, $c \to d$)
  - Highly suppressed E.M. processes



Weak

$B(J/\Psi \to D_s^- e^+ \nu_e + c.c.) < 1.3 \times 10^{-6}$

$B(J/\Psi \to D_s^{*-} e^+ \nu_e + c.c.) < 1.8 \times 10^{-6}$

BESIII, PRD 90, 112014 (2014)

Weak

$B(J/\Psi \to D_s^- \rho^+ + c.c.) < 1.3 \times 10^{-5}$

$B(J/\Psi \to \bar{D}^0 \bar{K}^{*0} + c.c.) < 2.5 \times 10^{-6}$

BESIII, PRD 89, 071101(R) (2014)

FCNC

$B(J/\Psi \to D^0 e^+ e^- + c.c.) < 8.5 \times 10^{-8}$

$B(\Psi(3686) \to D^0 e^+ e^- + c.c.) < 1.4 \times 10^{-7}$

BESIII, PRD 96, 111101(R) (2017)

Search for rare decay $J/\psi \to \Phi e^+ e^-$

- SM suppressed E.M. process
  - SM predicts the BF at 10^{-8} (a) and 10^{-11} (b) level
  - If excess, new particle in the intermediate process (dark photon, glueball)
  - J/ψ from $\psi(3686)$ for background control

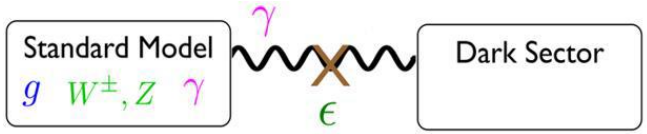
Recent BESIII result on the process will be introduced in the talk "**Charmonium rare decays at BESIII**" by Bo ZHENG on 5/16

Exotic

- Dark Photon search
  - New light neutral spin-1 gauge boson – dark photon (U/γ’/A’)
  - Mass range MeV – GeV
- Dark Matter search through invisible decays
  - Assuming the U boson can decay into a light dark matter pair
  - Invisible to detector
  - Search for the U boson from invisible decays with ISR
- Other Exotic
  - Axion-Like Particles
  - Low energy probe of inflation

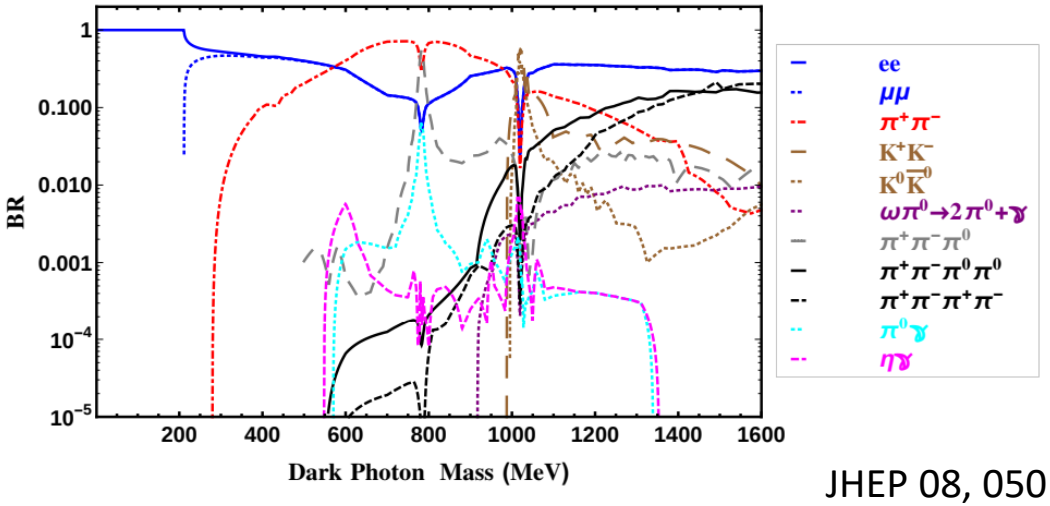
Dark Photon

- Dark Photon
  - Can kinetically mix with the SM EW force carrier
  - Mixing strength ε: 10^{-2} – 10^{-5}
  - Can couple to SM fermions $q\bar{q}, l^+l^-, \nu\bar{\nu}$ …
- Possible decays
  - $\gamma' \rightarrow e^+e^-/\mu^+\mu^-$



ordinary photon & can mix

$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$ "Kinetic Mixing"



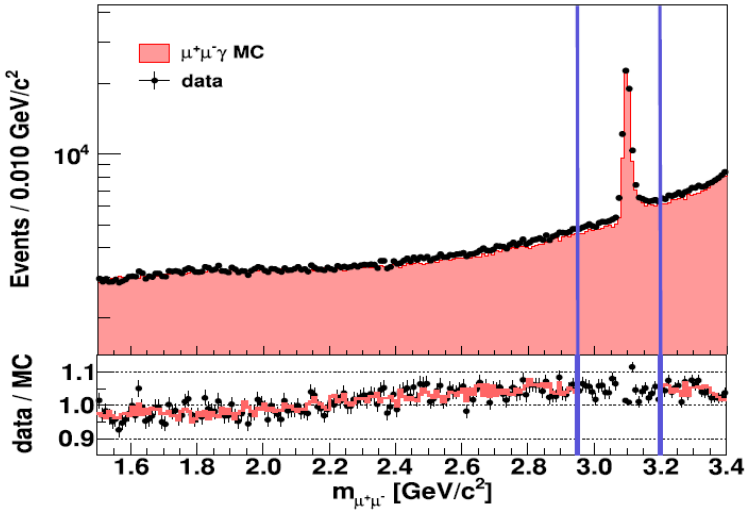
JHEP 08, 050 (2015)

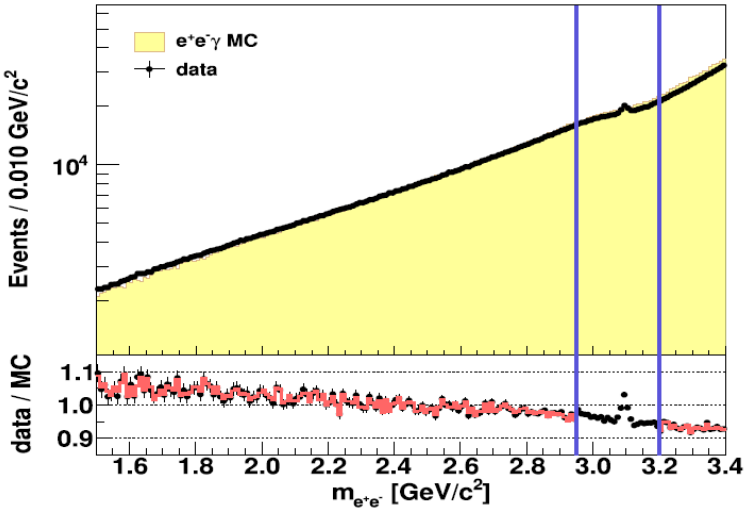
Search for Dark photon with $e^+e^- \to \gamma\gamma'$

- Dark photon search
  - 2.93 fb^{-1} data from √s=3.773 GeV
  - Search for γ' with mass range 1.5 ~ 3.4 GeV/c^2
  - Set ε upper limit between 10^{-3} – 10^{-4}
  - $e^+e^- \to \gamma_{ISR}\gamma'(\to e^+e^-/\mu^+\mu^-)$

No obvious enhancement observed

BESIII, PLB 774 (2017) 252

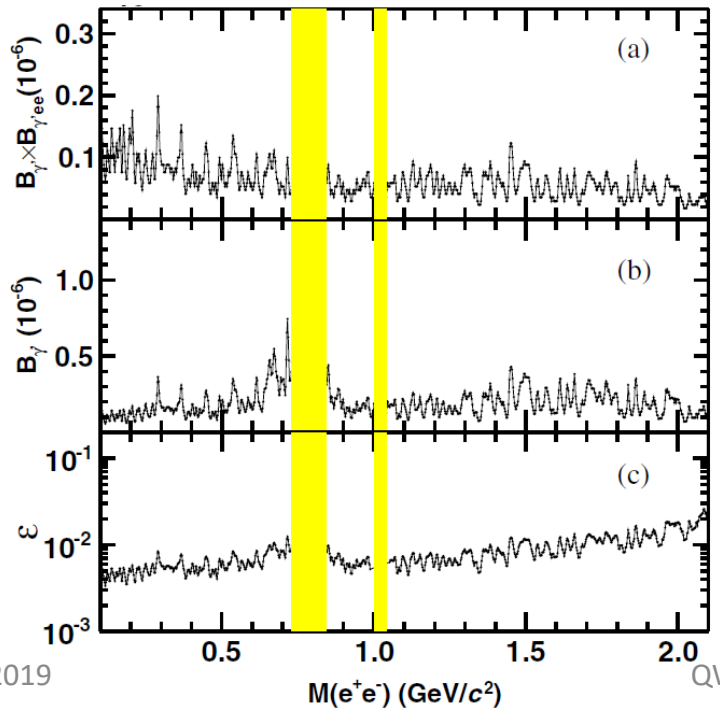




Search for Dark photon with $J/\Psi \to \eta'\gamma'$

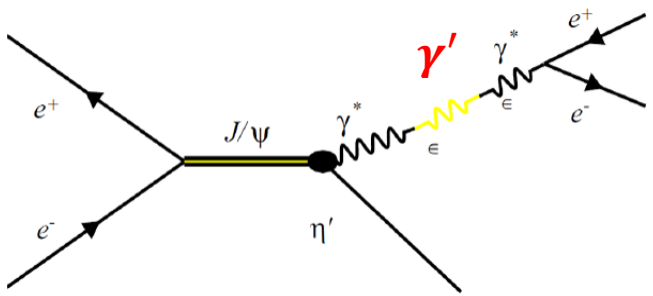
- Dark photon search
  - 1.3106x10^9 J/ψ events
  - No signal in the mass range 0.1 – 2.1 GeV/c^2, excluding ϕ/ω range
  - Set ε upper limit between 3.4×10^{-3} – 2.6×10^{-2}
  - $\boldsymbol{J/\Psi \to \eta'\gamma'(\gamma' \to e^+e^-)}$

NEW



$\boldsymbol{B(J/\Psi \to \eta'\gamma') \times B(\gamma' \to e^+e^-) < 5.7\times10^{-8} - 7.4\times10^{-7}}$

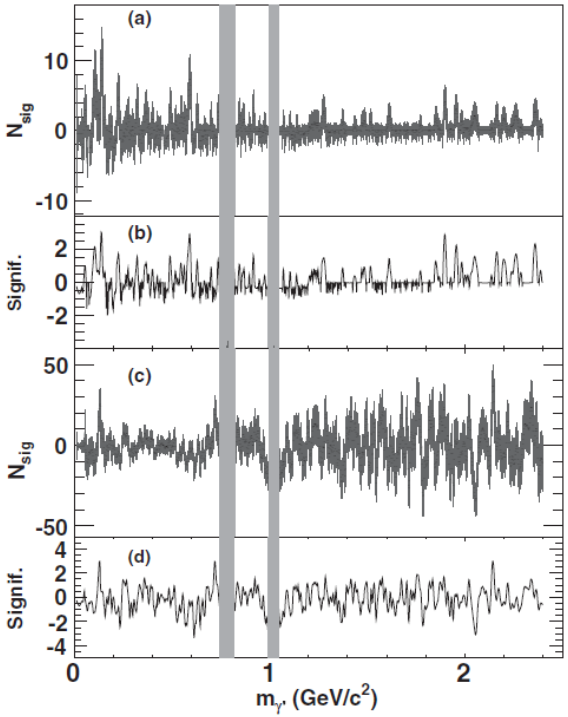
BESIII, PRD 99, 012013 (2019)



Search for Dark photon with $J/\Psi \to e^+e^-\eta$

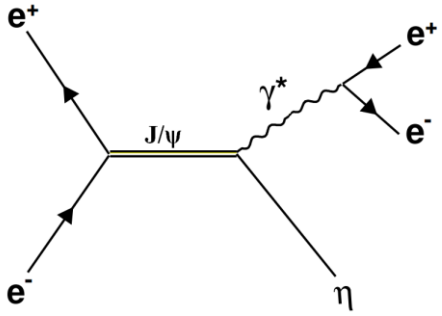
- Dark photon search
  - 1.3106x10^9 J/ψ events
  - No signal in the mass range 0.01 – 2.4 GeV/c^2, excluding ϕ/ω range
  - Set mixing strength ε upper limit between 10^{-2} – 10^{-3}
  - $J/\Psi \to \eta\gamma'(\gamma' \to e^+e^-)$

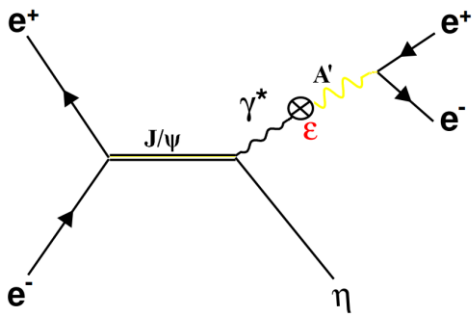
NEW



$$B(J/\Psi \to \gamma'\eta) \times B(\gamma' \to e^+e^-) < (1.9 - 91.1) \times 10^{-8}$$

BESIII, PRD 99, 012006 (2019)



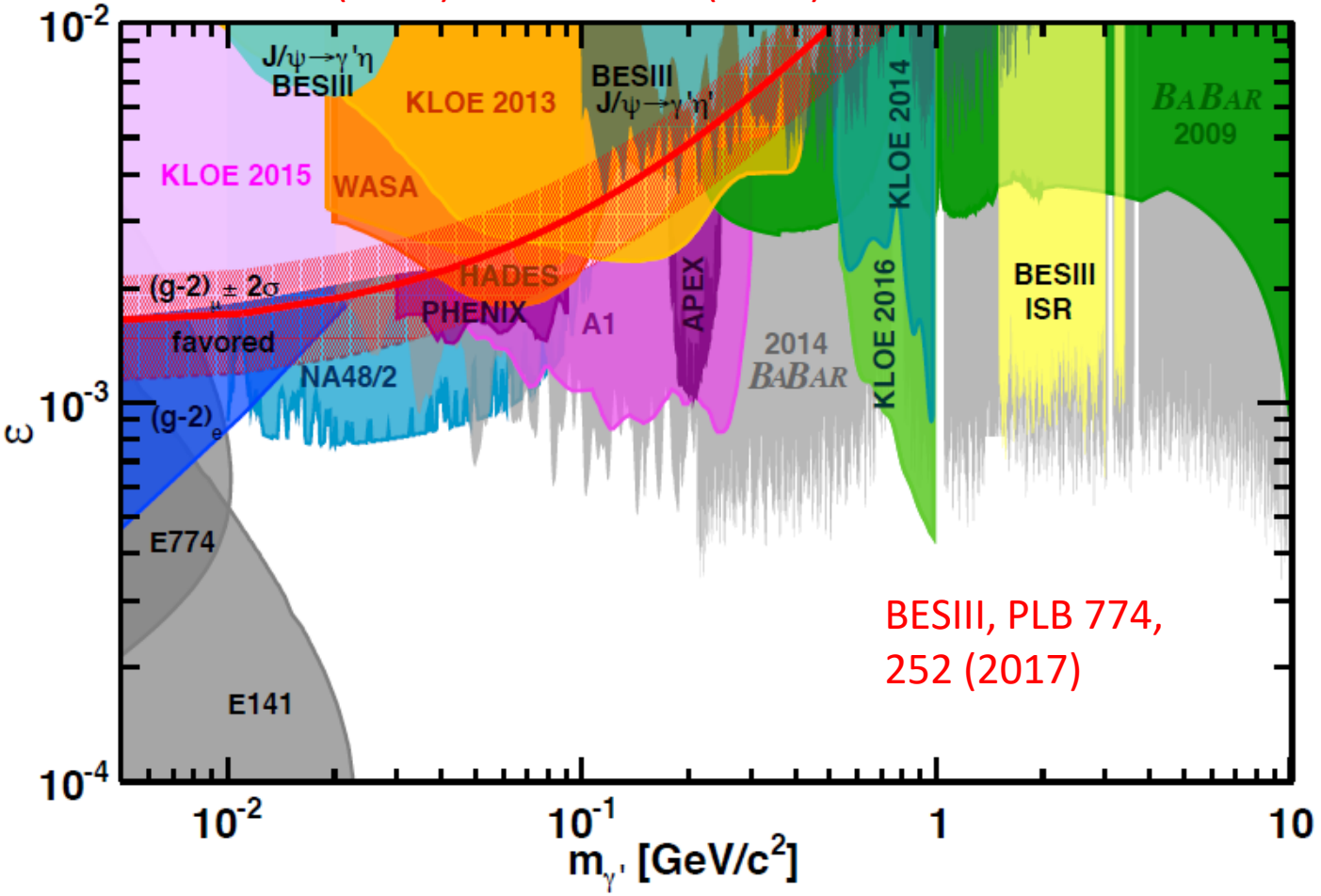


Dark Photon searches

- Dark photon mixing strength ε vs. dark photon mass

BESIII, PRD 99, 012006 (2019)

BESIII, PRD 99, 012013 (2019)

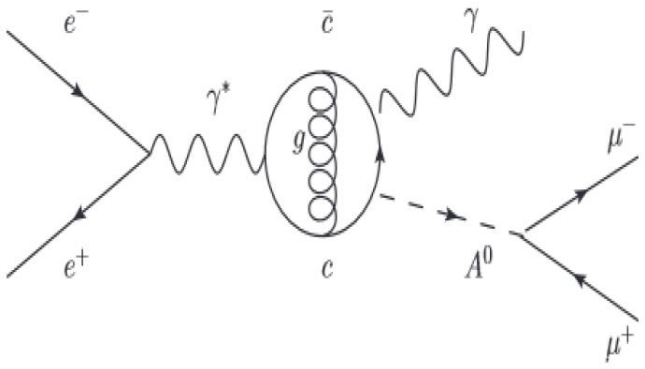


Higgs-like Boson

- NMSSM model
  - Predict a light CP-odd Higgs like boson A^0
  - Couples to a fermion anti-fermion pair
  - Stronger coupling of $\boldsymbol{A^0\mu^+\mu^-}$ than $\boldsymbol{A^0e^+e^-}$

PRD 76, 051105 (2017)

- Possible decays
  - $\boldsymbol{J/\Psi \to \gamma A^0 \quad A^0 \to \mu^+\mu^-}$



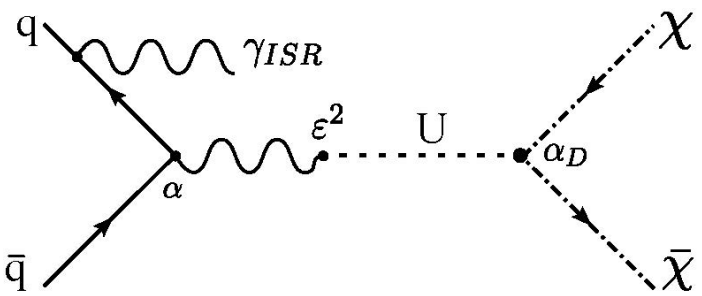
$\boldsymbol{B(J/\Psi \to \gamma A^0, A^0 \to \mu^+\mu^-) < 4 \times 10^{-7}\ to\ 2.1 \times 10^{-5}}$
BESIII, PRD 85, 092012 (2012)

$\boldsymbol{B(J/\Psi \to \gamma A^0, A^0 \to \mu^+\mu^-) < (2.8 - 495.3) \times 10^{-8}}$
BESIII, PRD 93, 052005 (2016)

for $0.212 \leq m_{A^0} \leq 3.0 GeV/c^2$

Invisible Decays

- U boson
  - The spin-1 U boson may decay directly to a ligh dark matter pair
  - Candidate of light dark matter constituents χ
  - Invisible to the detector
- Possible decays
  - $J/\Psi \to \phi\eta, \phi\eta' \quad \eta(\eta') \to \chi\chi$



$$\frac{B(\eta \to invisible)}{B(\eta \to \gamma\gamma)} < 2.6 \times 10^{-4}$$

$$\frac{B(\eta' \to invisible)}{B(\eta' \to \gamma\gamma)} < 2.4 \times 10^{-2}$$

BESIII, PRD 87, 012009 (2013)

Search for invisible decays of ω, ϕ with J/ψ

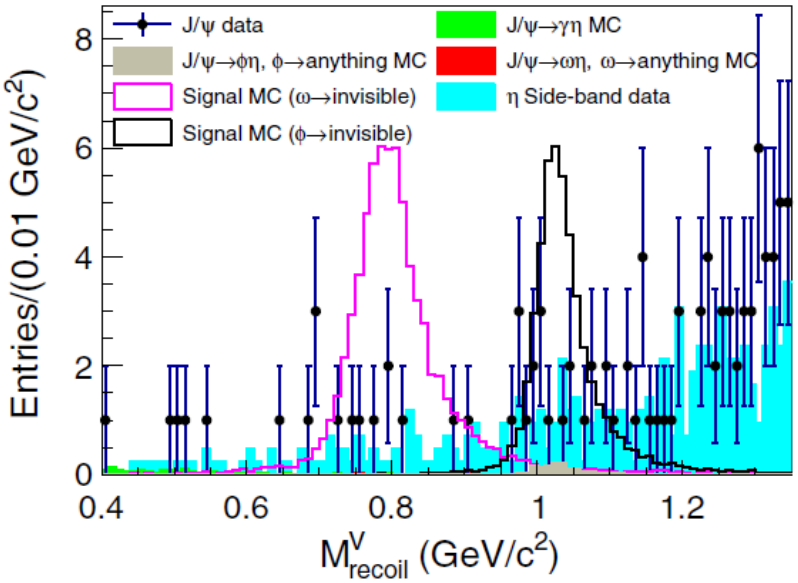
- Invisible decay search
  - 1.3106x10^9 J/ψ events
  - Search for invisible decay of a light vector meson V (ω, ϕ)
  - Tag with recoil η with $\eta \to \pi^+\pi^-\pi^0$
  - $J/\Psi \to \eta V\ (V = \omega,\ \phi)$

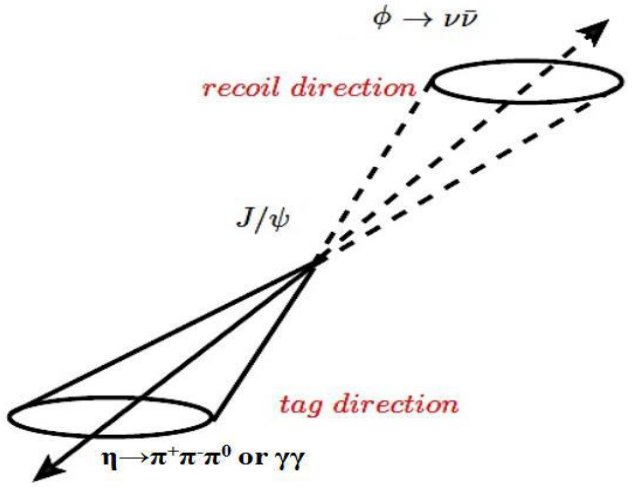
NEW

$B(\omega \to invisible) < 7.5 \times 10^{-5}$

$B(\phi \to invisible) < 1.7 \times 10^{-4}$

BESIII, PRD 98, 032001 (2018)





Summary

- Recent updates of New Physics search with Charmonium at BESIII, no signal observed
  - BNV & LNV process $J/\psi \to \Lambda_c^+ e^-$
  - Rare E.M. process $J/\psi \to \Phi e^+ e^-$
  - Dark photon search $J/\psi \to e^+ e^- \eta$, $J/\psi \to \eta' \gamma'$
  - Invisible decay $J/\psi \to \eta\omega/\Phi$
- More potential with larger data sample
  - 1×10^{10} J/ψ
  - Other Charmonium data in the future

Thank you!