

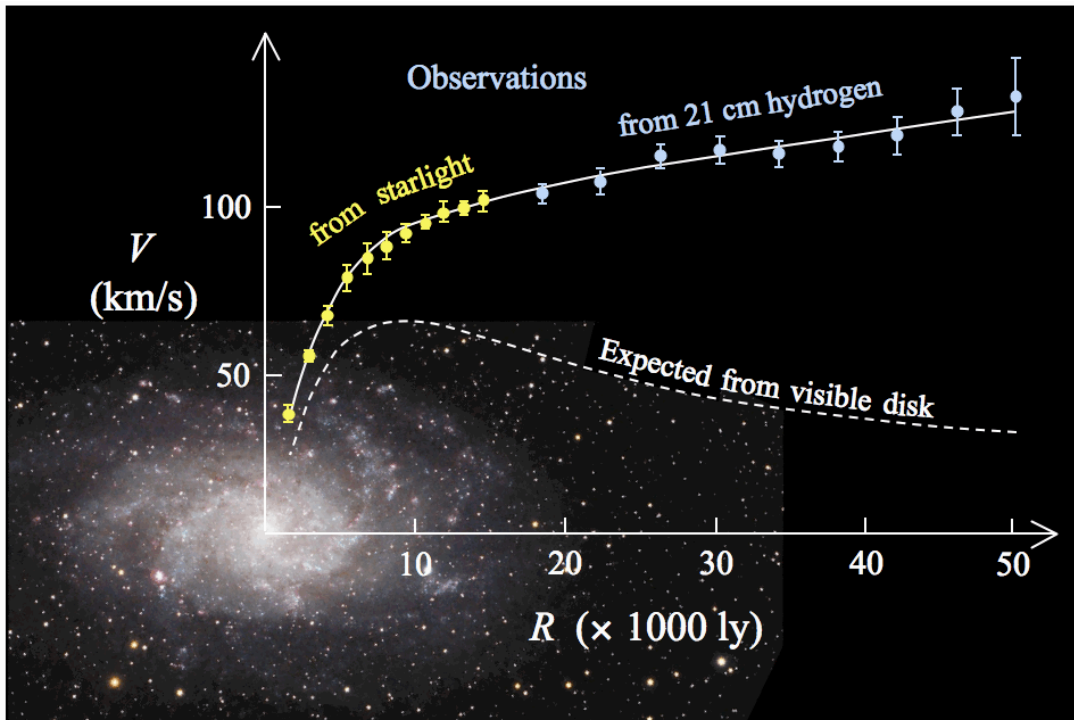
# Dark Sector Searches at BESIII

YUPING GUO

ON BEHALF OF THE  COLLABORATION

# DARK MATTER

Rotation curve of the typical spiral galaxy M 33

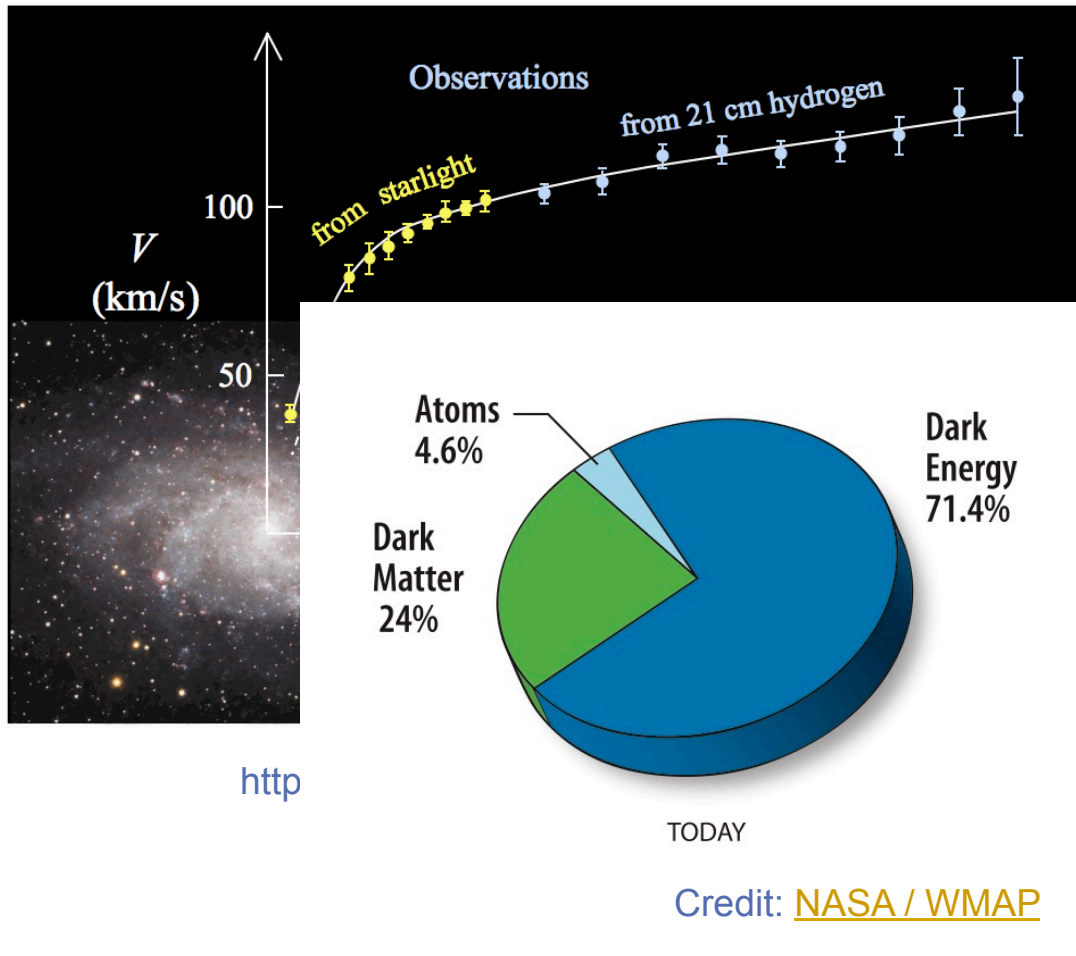


- Numerous indirect astrophysical and cosmological observations point to the presence of dark matter

[https://en.wikipedia.org/wiki/Galaxy\\_rotation\\_curve](https://en.wikipedia.org/wiki/Galaxy_rotation_curve)

# DARK MATTER

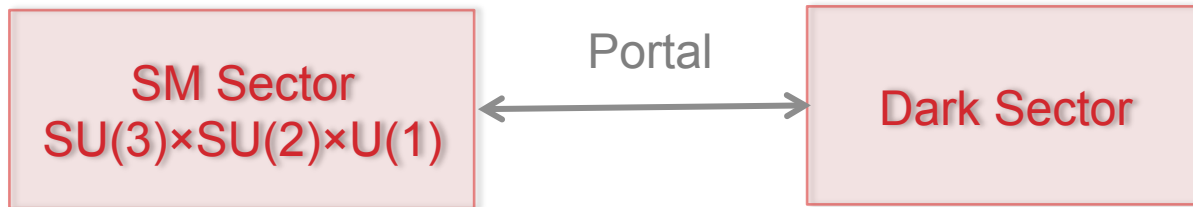
Rotation curve of the typical spiral galaxy M 33



- Numerous indirect astrophysical and cosmological observations point to the presence of dark matter
- Dark matter: a factor of 5 over normal matter
- Gravitational interaction
- Constitution remains unknown

# DARK SECTOR

Consisting of (light) particles do not interact with the known strong, weak, or electromagnetic forces



Portal	Particles	Operator(s)
“Vector”	Dark photons	$-\frac{\epsilon}{2 \cos \theta_W} B_{\mu\nu} F'^{\mu\nu}$
“Axion”	Pseudoscalars	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}, \frac{a}{f_a} G_{i\mu\nu} \tilde{G}_i^{\mu\nu}, \frac{\partial_\mu a}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$
“Higgs”	Dark scalars	$(\mu S + \lambda S^2) H^\dagger H$
“Neutrino”	Sterile neutrinos	$y_N L H N$

# DARK PHOTON ( $\gamma'$ )

- New Abelian gauge group U(1) force carrier
- Kinematic mixing with SM U(1) with mixing coefficient  $\epsilon$

B. Holdom, PLB 166,196 (1986)

- Typical mix strength:  $10^{-2} \sim 10^{-5}$ , could be smaller
- Expected mass scale:  $\text{MeV}/c^2 \sim \text{GeV}/c^2$
- Could explain large number of astrophysical anomalies

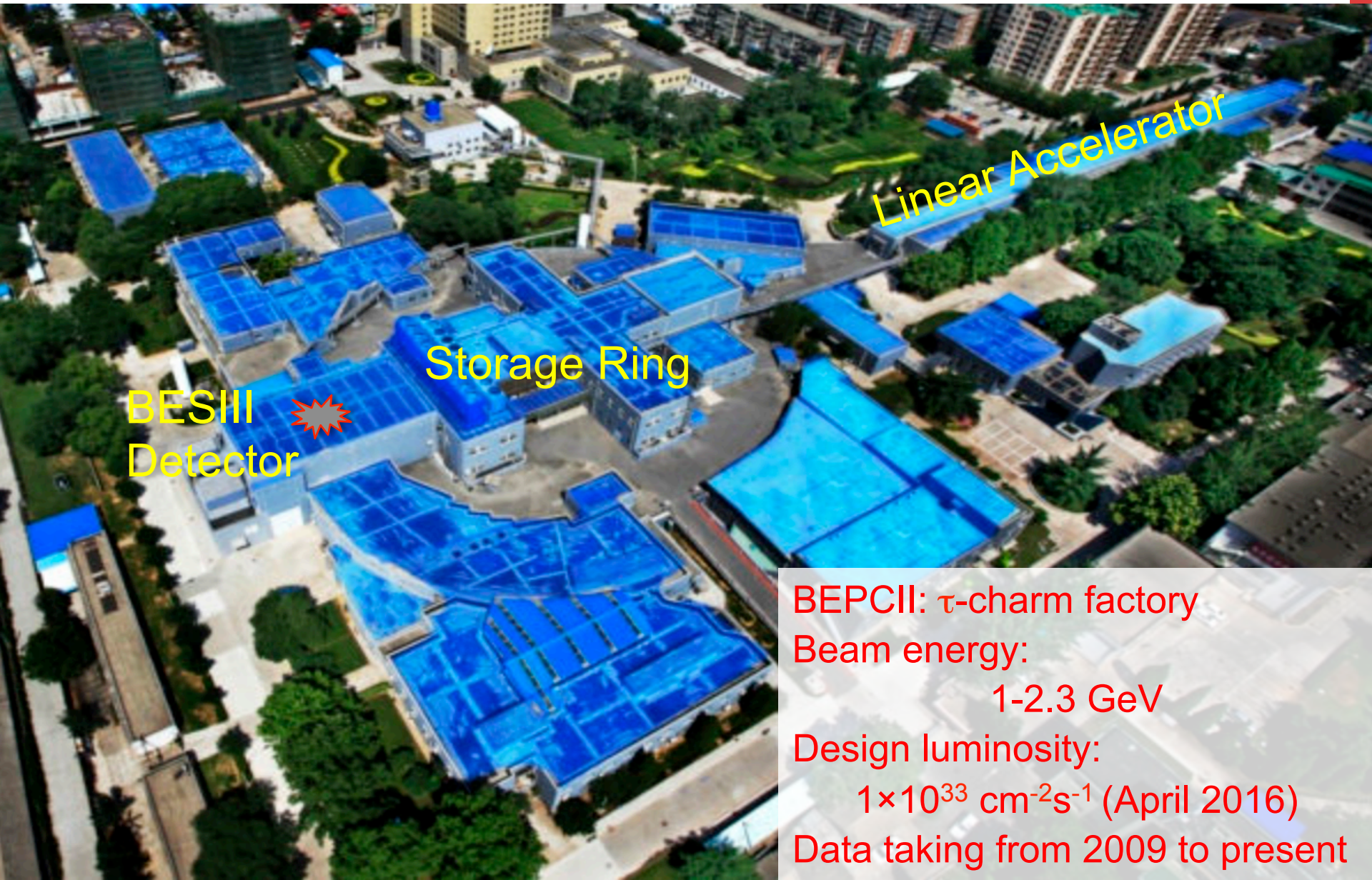
N. Arkani-Hamed et al., PRD 79, 015014 (2009)

S. Andreas, A. Ringwald arXiv:1008.4519 (2010)

Also deviation on muon anomaly  $(g-2)_\mu$

M. Pospelov, PRD 80,095002 (2009)

# Beijing Electron Positron Collider-II



Linear Accelerator

Storage Ring

BESIII  
Detector

BEPCII:  $\tau$ -charm factory

Beam energy:

1-2.3 GeV

Design luminosity:

$1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$  (April 2016)

Data taking from 2009 to present

# Beijing Electron Positron Collider-II

SC Magnet: 1Tesla

Magnet yoke

TOF: ( $\sigma_T$ )

80 ps / 70 ps

Beam pipe

MDC:

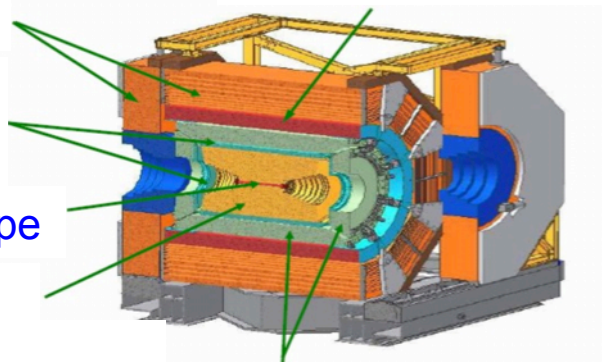
$\sigma_p/p$ : 0.5% at 1GeV/c

dE/dx: 6%

CsI calorimeter:

$\Delta E/E$ : 2.5% / 5.0% at 1 GeV;

$\sigma_z$ : 0.6 cm/ $\sqrt{E}$



Linear Accelerator

BEPCII:  $\tau$ -charm factory

Beam energy:

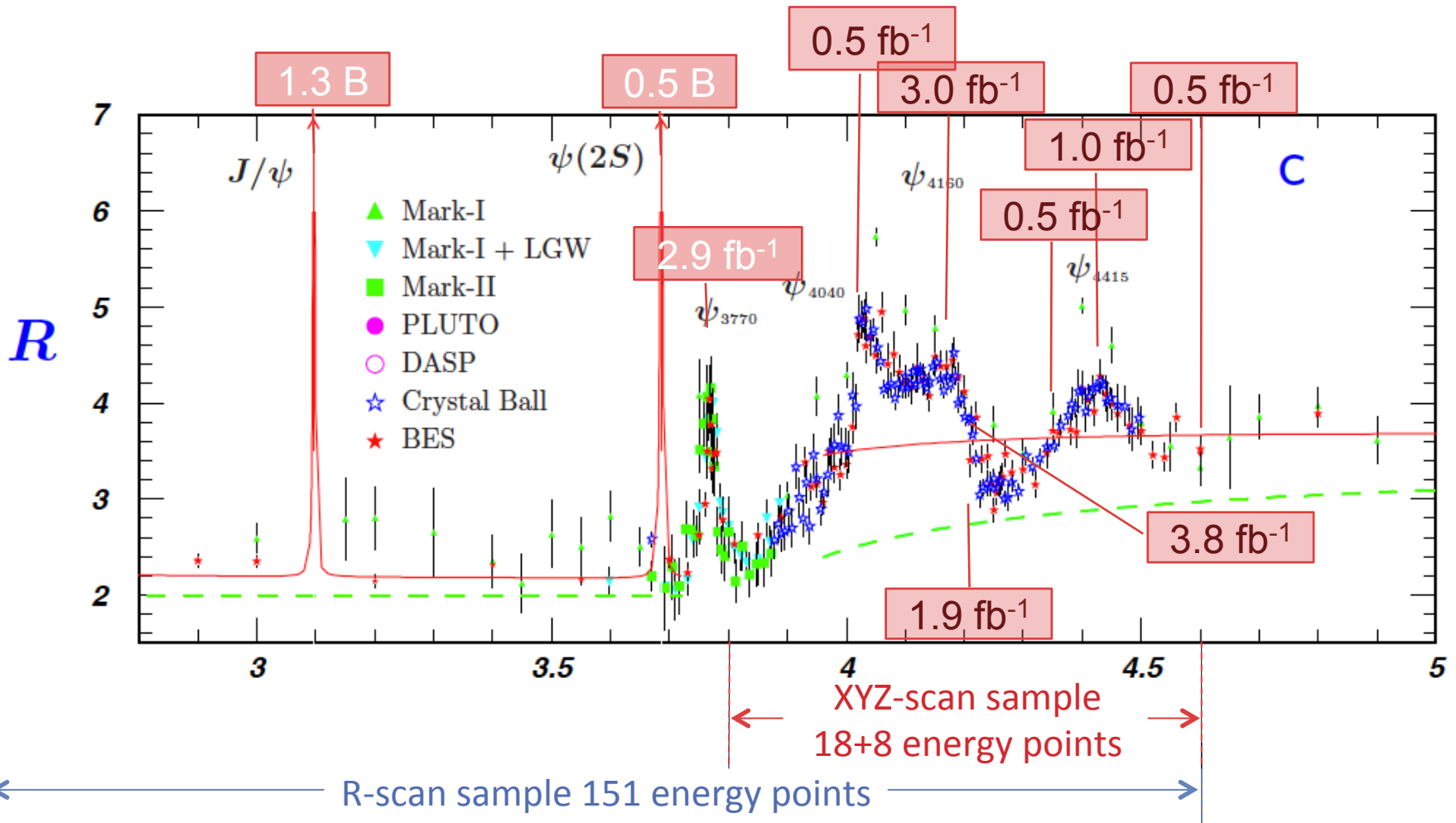
1-2.3 GeV

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Data taking from 2009 to present

# BESIII DATA SET



World largest data sample on J/ψ, ψ' ψ(3770), unique data sample at XYZ region

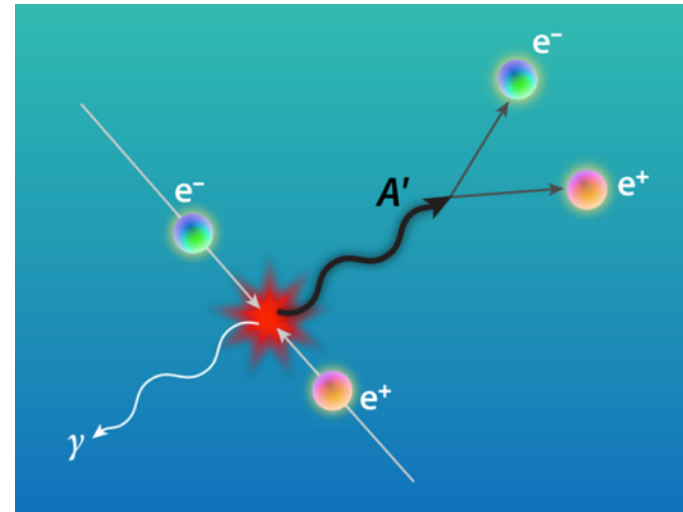


# DARK PHOTON SEARCH(I)

- 2.93 fb<sup>-1</sup>  $\psi(3770)$  data sample
- Initial State Radiation process:

$$e^+e^- \rightarrow \gamma_{ISR}\gamma' \rightarrow \gamma_{ISR}\mu^+\mu^-$$

$$e^+e^- \rightarrow \gamma_{ISR}\gamma' \rightarrow \gamma_{ISR}e^+e^-$$



APS/Alan Stonebreaker

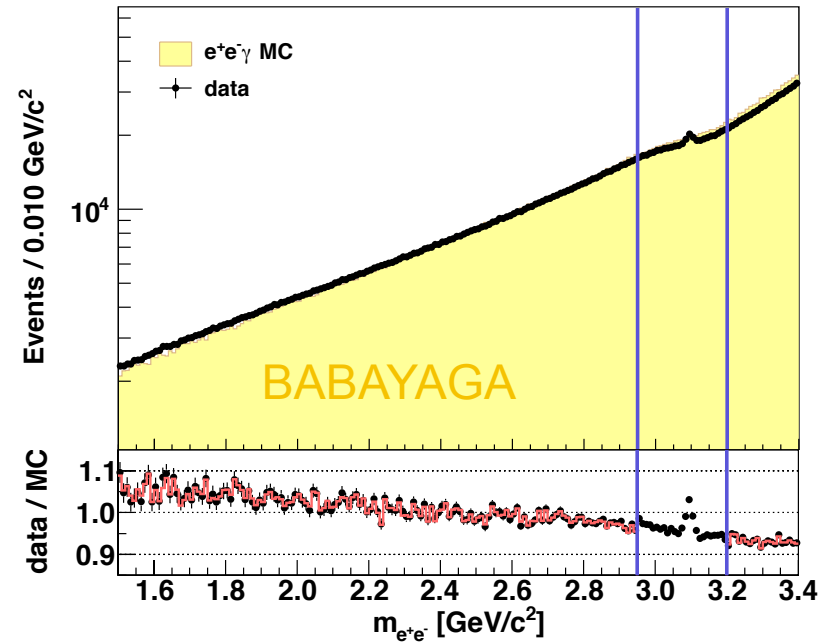
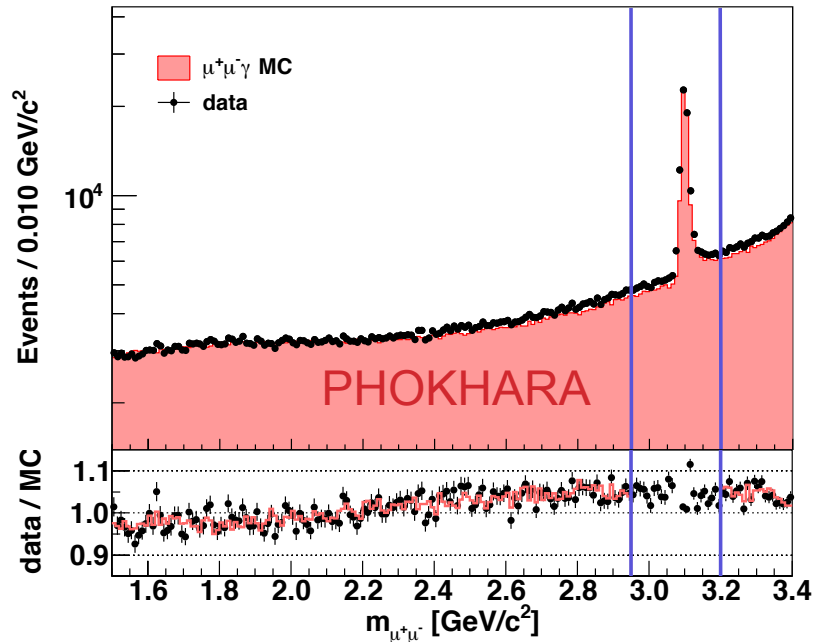
- Search for narrow structure on top of the continuum QED

background ( $e^+e^- \rightarrow \gamma_{ISR}l^+l^-$ )

BESIII, PLB 774,252 (2017)

# MASS SPECTRUM

BESIII, PLB 774,252 (2017)

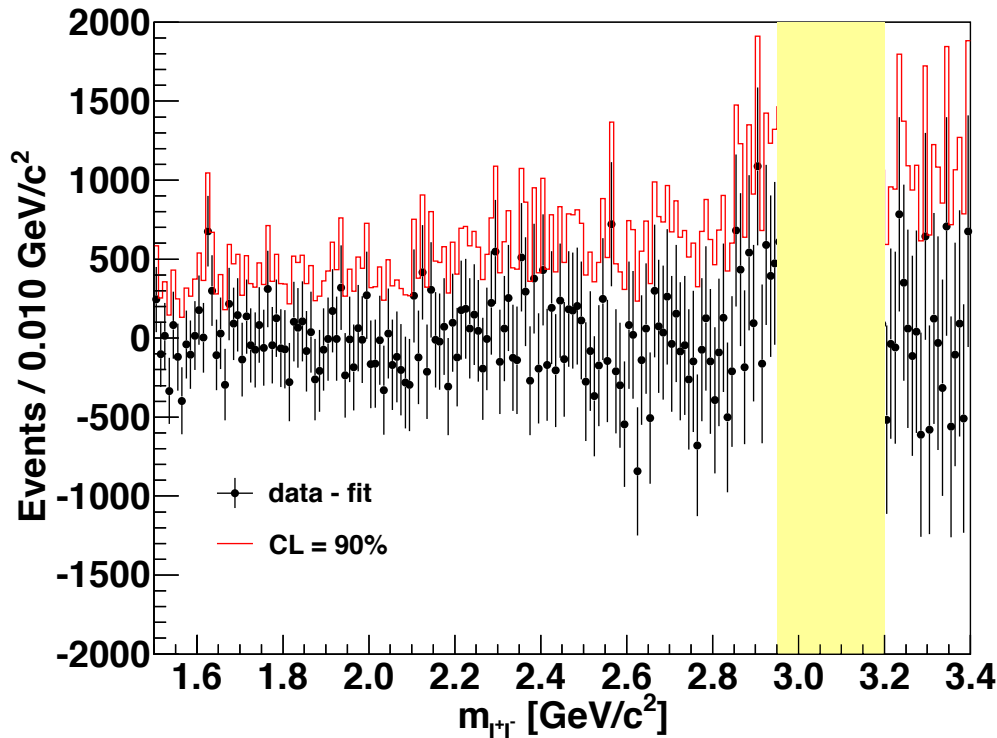


**Cover mass region: 1.5 GeV/c<sup>2</sup> ~ 3.4 GeV/c<sup>2</sup>**

- <1.5 GeV/c<sup>2</sup> :  $\pi^+\pi^-$  background dominates
- >3.4 GeV/c<sup>2</sup> : hadronic qq-bar process

# NUMBER OF SIGNAL EVENTS

BESIII, PLB 774,252 (2017)



- Fit QED background with 4<sup>th</sup> order polynomial function
- No peaking structure observed in (data-fit)
- 90% confidence level limit obtained with profile likelihood approach, systematic uncertainty included

W. Rolke et al., NIM A 551, 493 (2005)

Combined statistical significance less than  $3\sigma$

# CALCULATION OF $\varepsilon$

Mixing coefficient

Dark photon mass

Number of dark photon events

$$\frac{\sigma_i(e^+e^- \rightarrow \gamma' \gamma_{\text{ISR}} \rightarrow l^+l^- \gamma_{\text{ISR}})}{\sigma_i(e^+e^- \rightarrow \gamma^* \gamma_{\text{ISR}} \rightarrow l^+l^- \gamma_{\text{ISR}})} = \frac{3\pi}{2N_f^{l^+l^-}} \cdot \frac{\varepsilon^2}{\alpha} \cdot \frac{m_{\gamma'}}{\delta_m^{l^+l^-}}$$

Number of QED events from annihilation process

Bin width

Ratio of possible decay channels of the dark photon and the phase space

Fine structure constant

$$N_f^{l^+l^-} = \frac{\Gamma_{\text{tot}}}{\Gamma(\gamma' \rightarrow l^+l^-)} = 1 + \frac{\Gamma_{\mu\mu}}{\Gamma_{ee} + \Gamma_{\mu\mu}} \cdot (1 + R(\sqrt{s}))$$

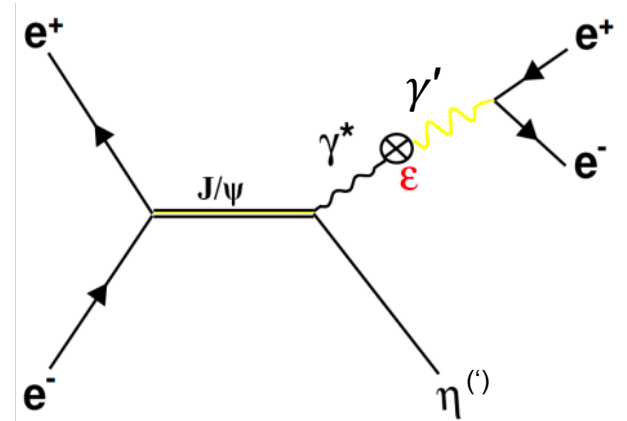
J. D. Bjorken, R. Essig, P. Schuster, N. Toro, PRD 80, 075018 (2009)

# DARK PHOTON SEARCH(II)

- $(1310.6 \pm 7.0) \times 10^6$   $J/\psi$  events
- Electromagnetic (EM) Dalitz decay:

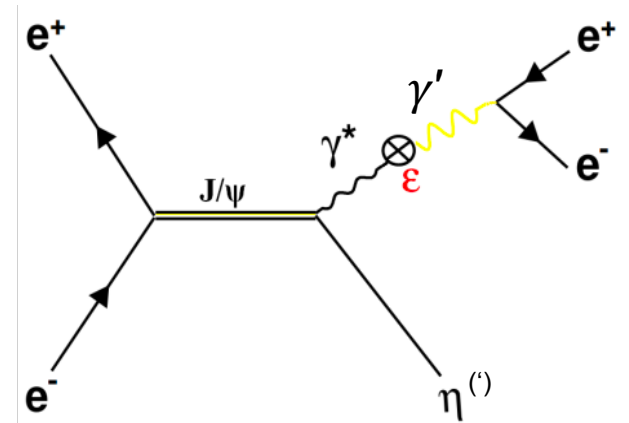
- $J/\psi \rightarrow \gamma' \eta \rightarrow e^+ e^- \eta$   
 $\eta \rightarrow \gamma\gamma$  or  $\eta \rightarrow \pi^+ \pi^- \pi^0$

- $J/\psi \rightarrow \gamma' \eta' \rightarrow e^+ e^- \eta'$   
 $\eta' \rightarrow \gamma \pi^+ \pi^-$  or  $\eta' \rightarrow \eta \pi^+ \pi^-$



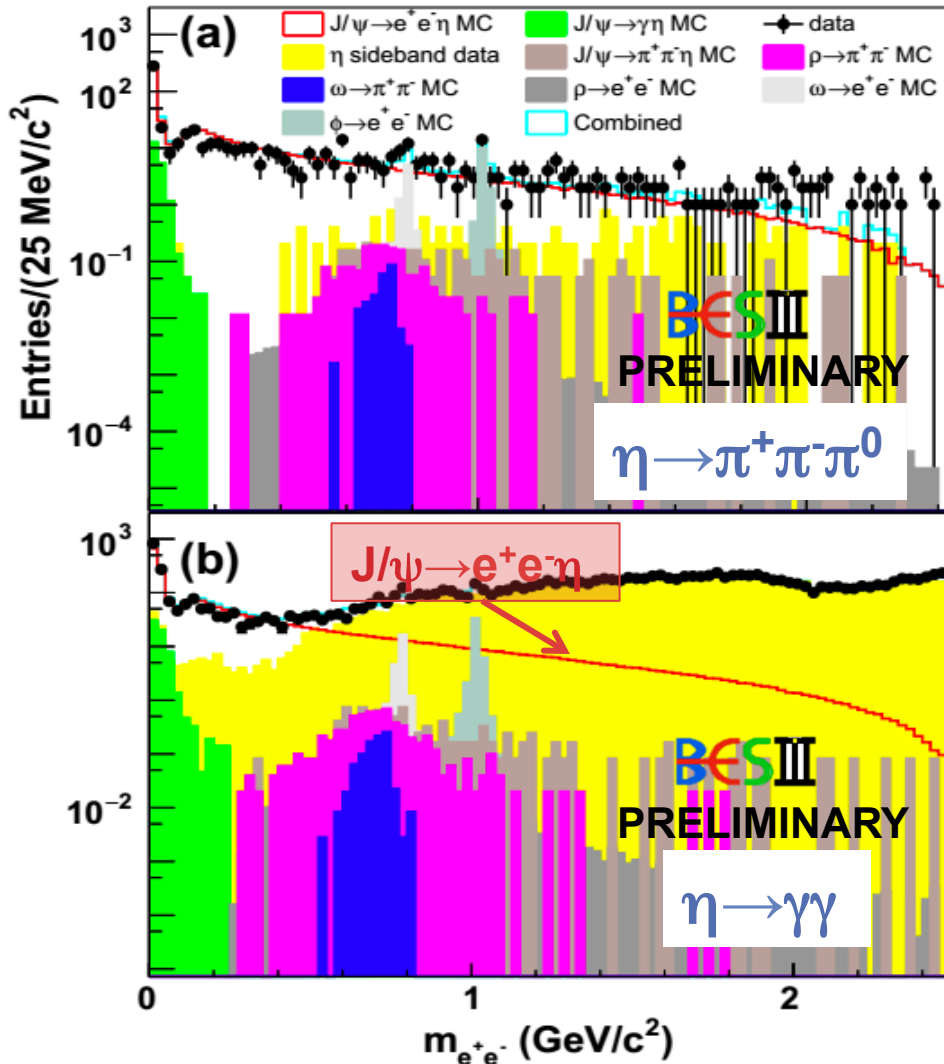
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  - $J/\psi \rightarrow \gamma' \eta' \rightarrow e^+ e^- \eta'$   
 $\eta' \rightarrow \gamma \pi^+ \pi^-$  or  $\eta' \rightarrow \eta \pi^+ \pi^-$



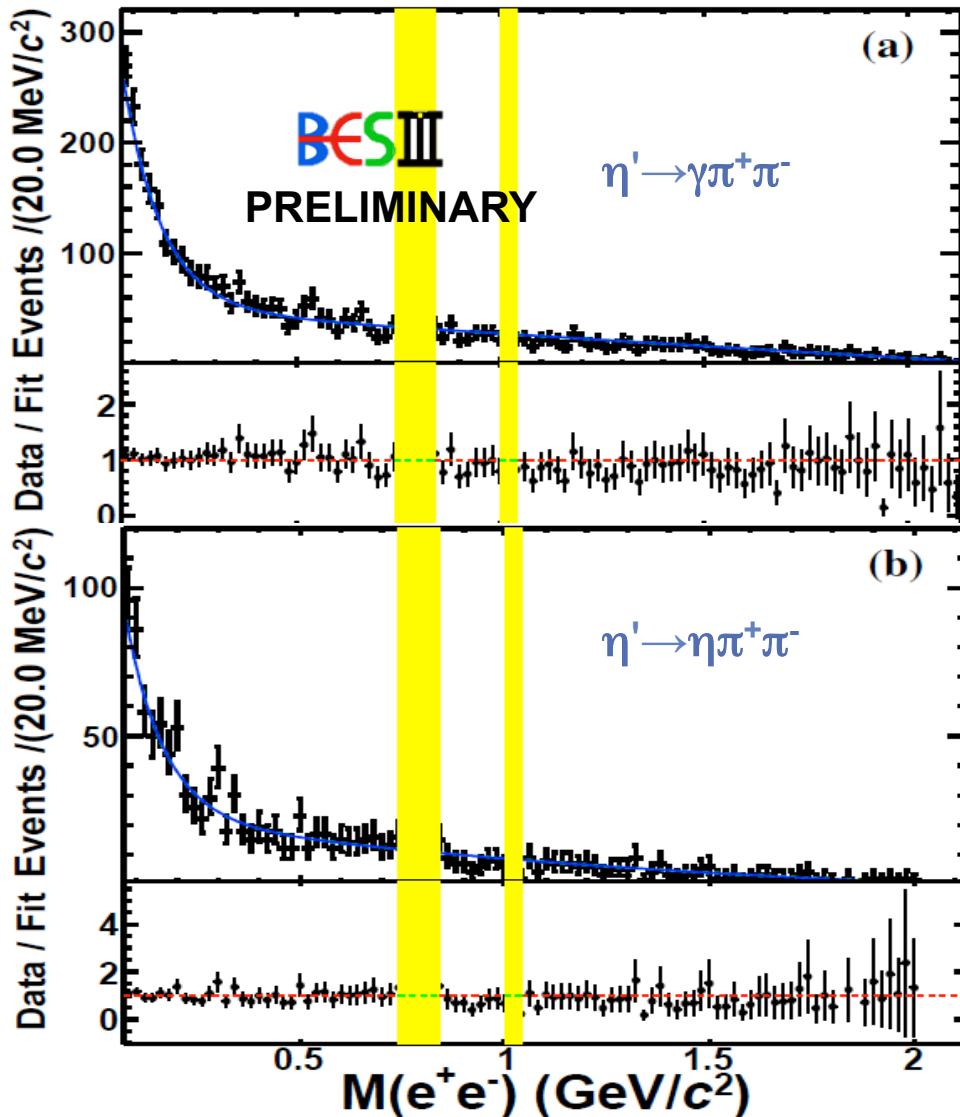
All particles reconstructed,  $\eta$  mass window:  $[0.52, 0.57]$   $\text{GeV}/c^2$   
 $\eta'$  mass window:  $[0.93, 0.98]$   $\text{GeV}/c^2$

# MASS SPECTRUM $\eta$



- Fit  $M(e^+e^-)$  spectrum:
  - 0.01-2.40  $\text{GeV}/c^2$
  - Signal:
    - two Crystal Ball functions (2MeV step)
  - Background:
    - Chebyshev polynomial + Exponential functions
- Exclude  $\rho/\omega$  and  $\phi$  mass regions
- No clear peaking structure observed

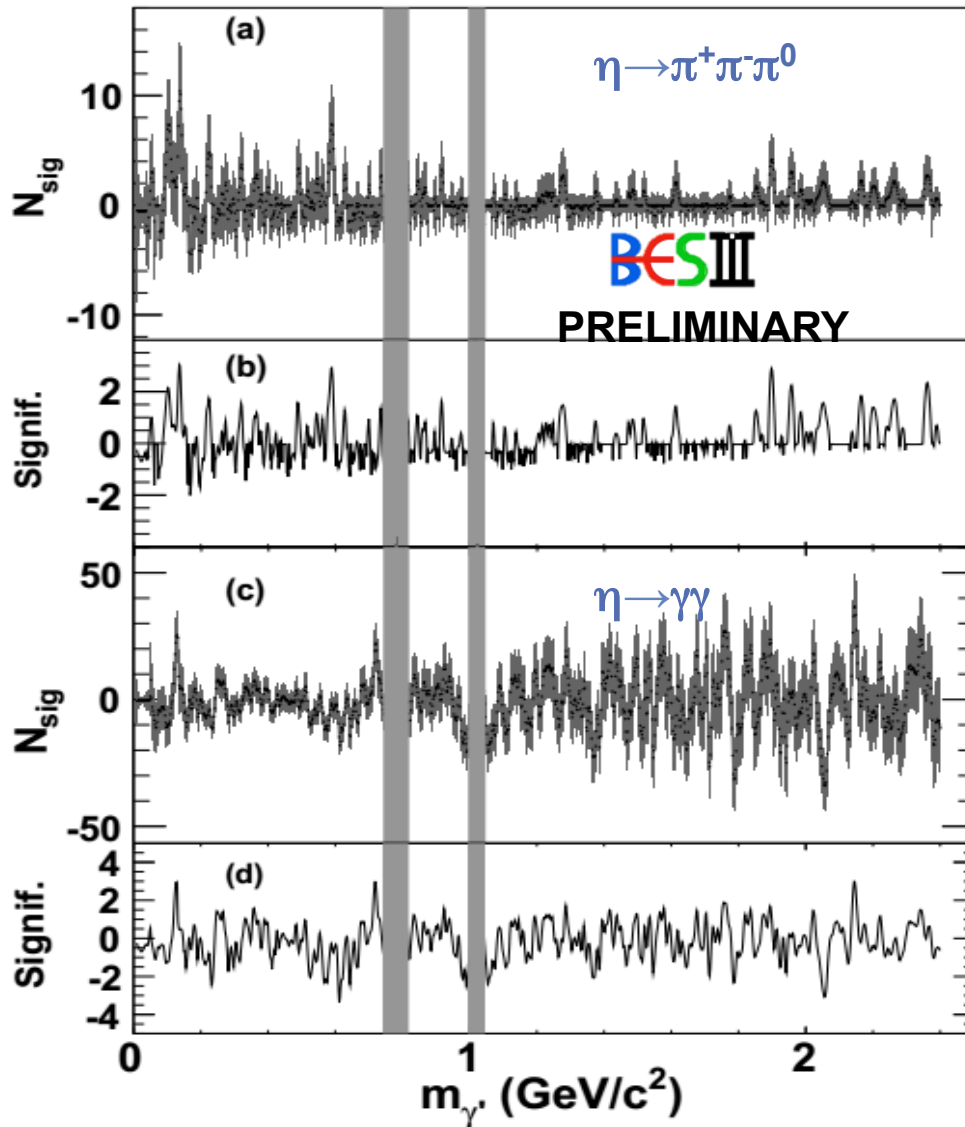
# MASS SPECTRUM $\eta'$



- Fit  $M(e^+e^-)$  spectrum:
  - 0.1-2.1  $\text{GeV}/c^2$
  - Signal:
    - two Crystal Ball functions (2MeV step)
  - Background:
    - Chebyshev polynomial + Exponential functions
- Exclude  $\rho/\omega$  and  $\phi$  mass regions
- No clear peaking structure observed

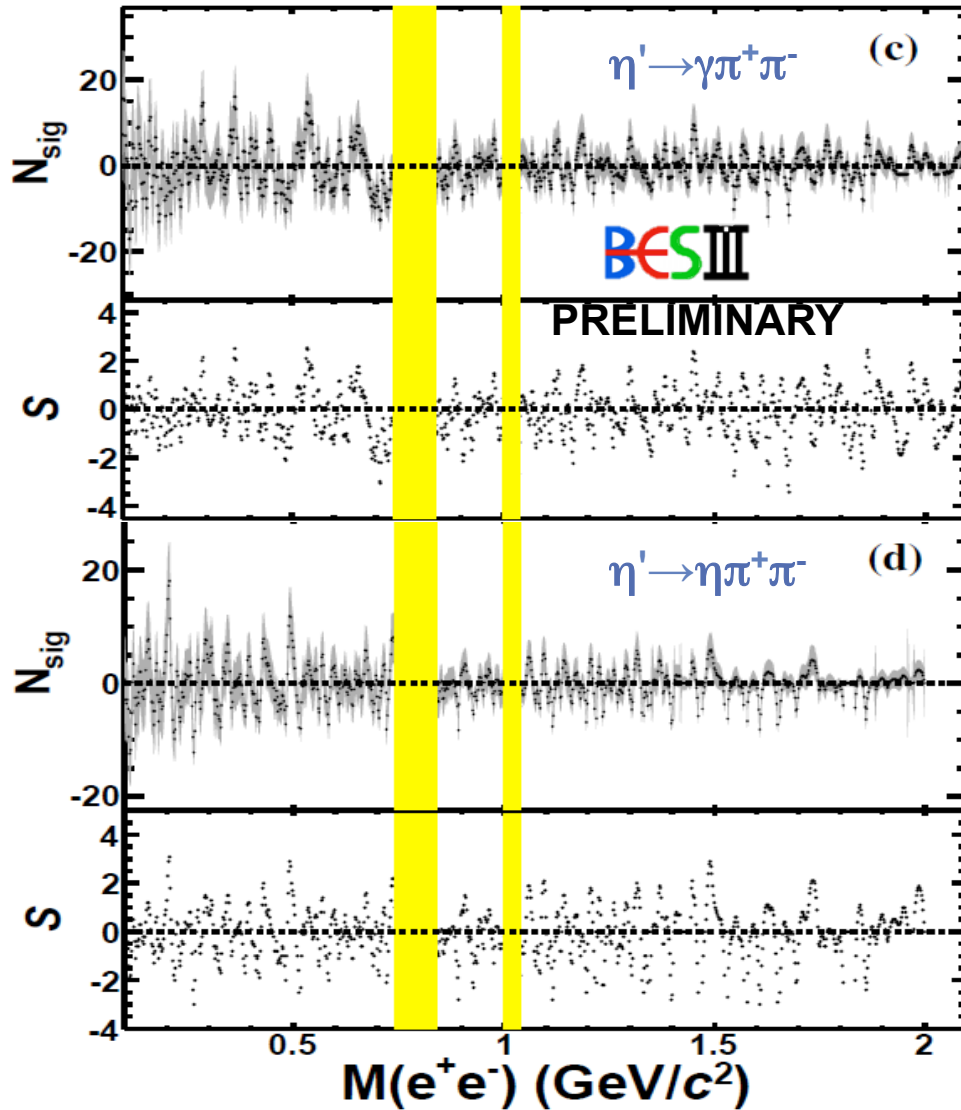


# NUMBER OF SIGNAL $\eta$



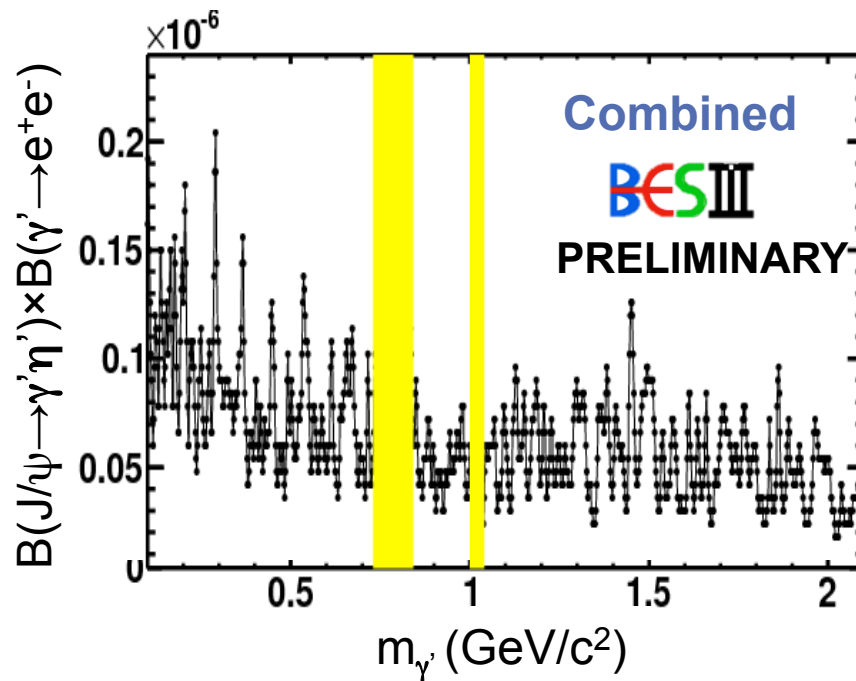
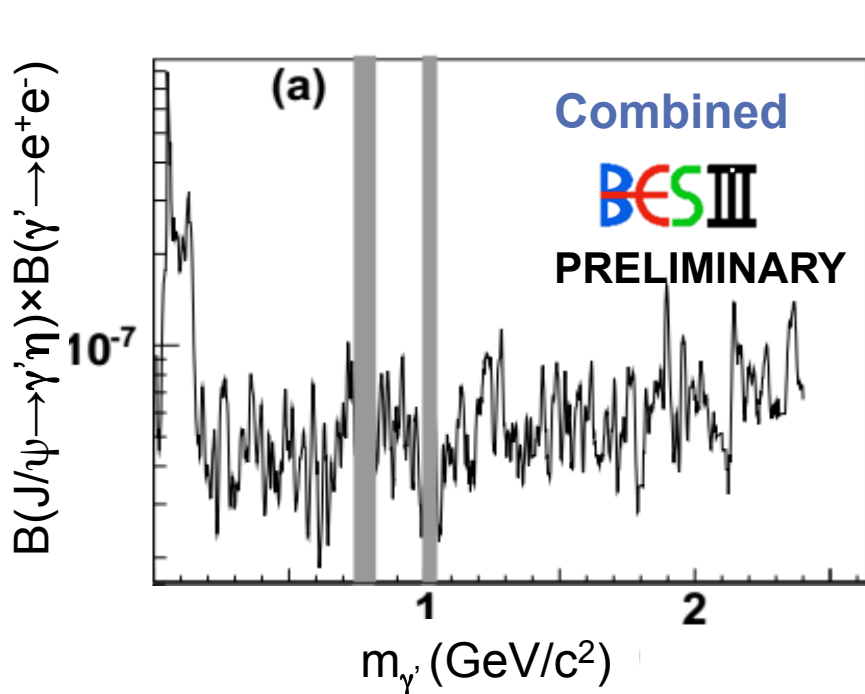
- Local significance less than  $3\sigma$  in each mass point

# NUMBER OF SIGNAL $\eta'$

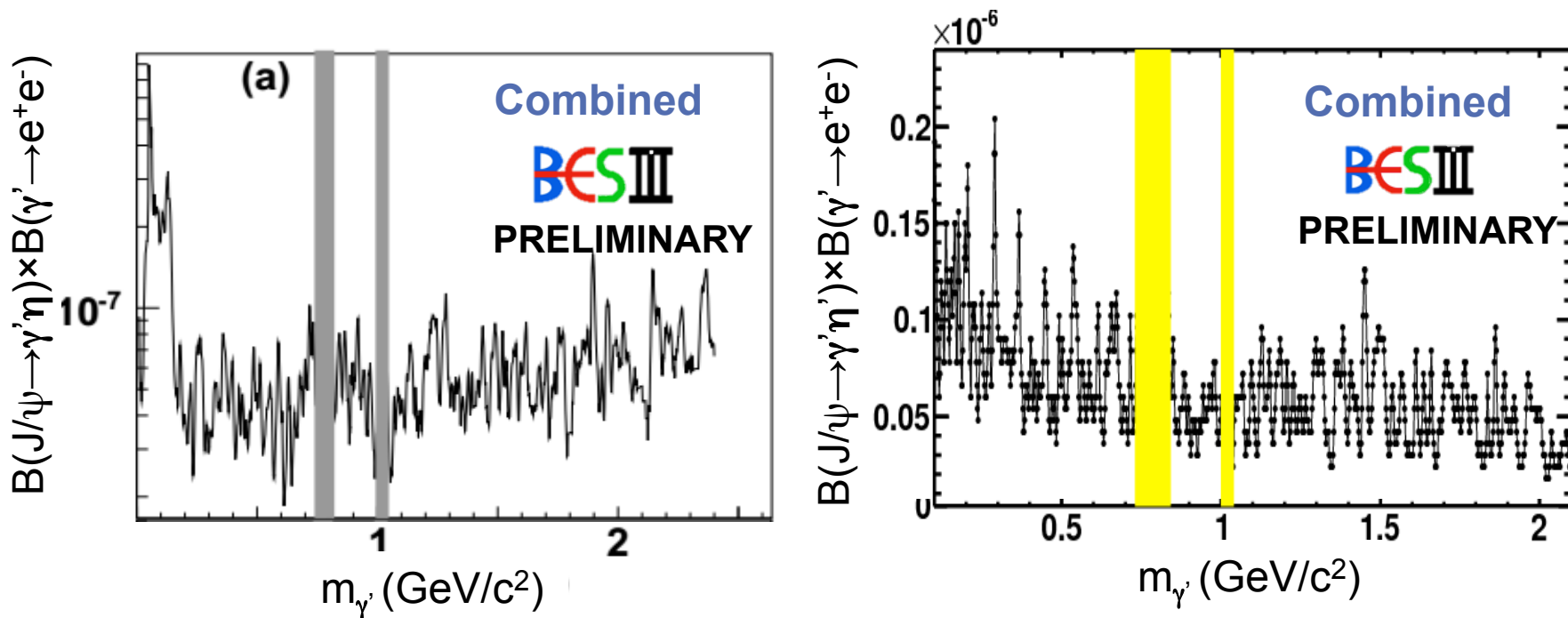


- Maximum local significance  $3.1\sigma$

# UPPER LIMIT OF PRODUCT BR @ 90% C.L.



# UPPER LIMIT OF PRODUCT BR @ 90% C.L.



Divide out  $B(\gamma' \rightarrow e^+ e^-) = \frac{\Gamma_{ee}}{\Gamma_{\text{tot}}} = \frac{\Gamma_{ee}}{\Gamma_{ee} + \Gamma_{\mu\mu} \cdot (1 + R(\sqrt{s}))}$

B. Batell, M. Pospelov, and A. Ritz  
PRD 79, 115008 (2009)

# CALCULATION OF $\varepsilon$

Branching fraction of  $J/\psi \rightarrow \gamma' \eta^{(\prime)}$

Dark photon mass

Mixing coefficient

$$\frac{B(J/\psi \rightarrow \gamma' \eta^{(\prime)})}{B(J/\psi \rightarrow \gamma \eta^{(\prime)})} = \varepsilon^2 |F_{J/\psi \eta^{(\prime)}}(m_{\gamma'}^2)|^2 \cdot \frac{\Lambda^{3/2}(m_{J/\psi}^2, m_{\eta^{(\prime)}}^2, m_{\gamma'}^2)}{\Lambda^{3/2}(m_{J/\psi}^2, m_{\eta^{(\prime)}}^2, 0)}$$

Branching fraction of  $J/\psi \rightarrow \gamma \eta^{(\prime)}$

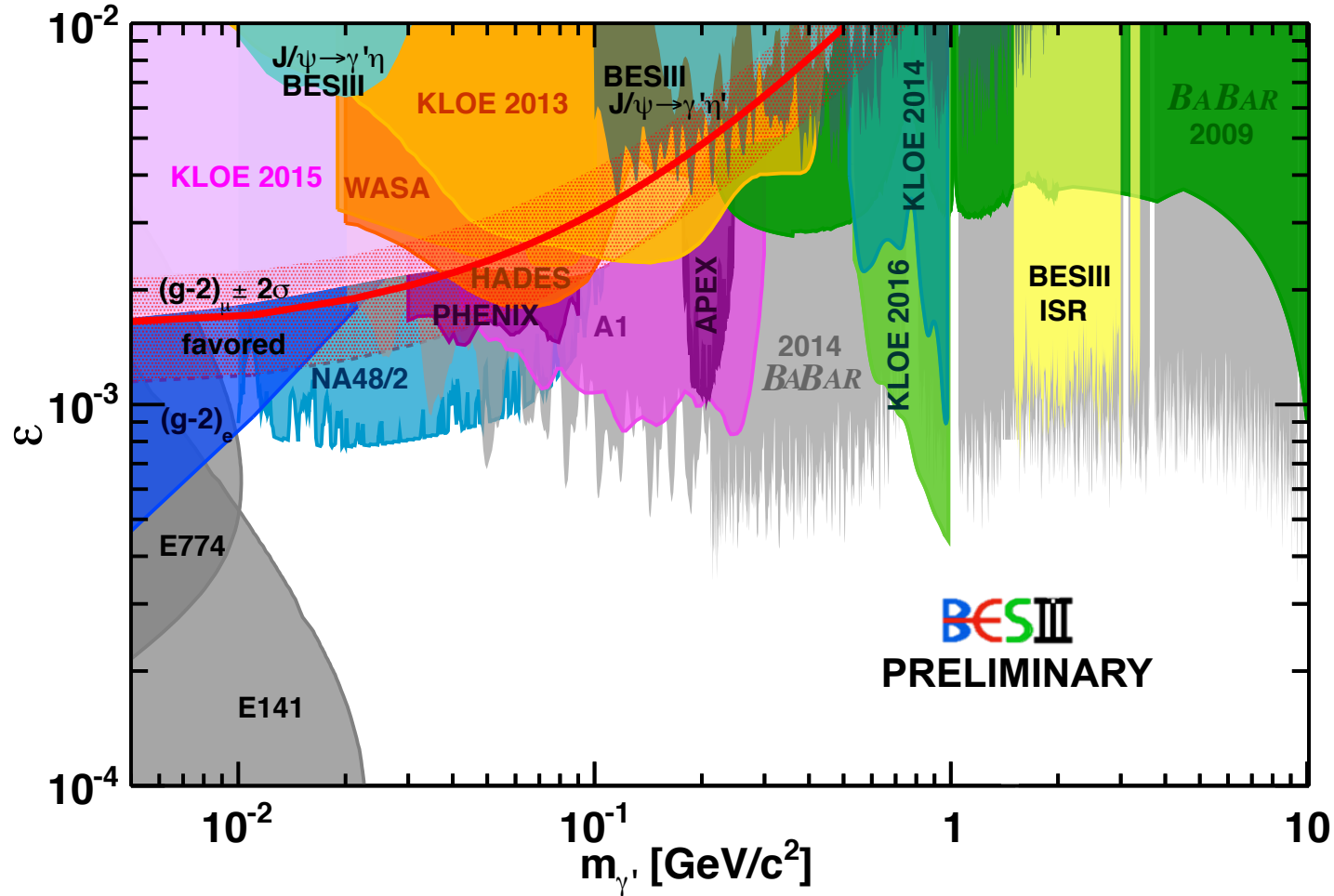
$$\Lambda^{3/2}(m_1^2, m_2^2, m_3^2) = \left(1 + \frac{m_3^2}{m_1^2 - m_2^2}\right)^2 - \frac{4m_1^2 m_3^2}{(m_1^2 - m_2^2)^2}$$

Form factor for  $J/\psi \rightarrow \gamma^* \eta^{(\prime)}$  transition  
evaluated at  $\gamma'$  mass

$$|F_{J/\psi \eta^{(\prime)}}(m_{\gamma'}^2)|^2 = \frac{\Lambda^2}{\Lambda^2 - m_{\gamma'}^2} \quad \Lambda^2 = m_{\psi(2S)}$$

M. Reece and L. T. Wang  
JHEP07, 051 (2009)

# CALCULATION OF $\varepsilon$



# SUMMARY

- Dark photon search at BESIII:
  - ISR process and EM Dalitz decay process
  - In  $0.01 \text{ GeV}/c^2 \sim 3.4 \text{ GeV}/c^2$ , significance less than  $3\sigma$
  - Mixing parameters:  $10^{-2}$ - $10^{-4}$
- More study related to dark sector
  - Invisible decay of  $\eta^{(\prime)}$ ,  $\omega$ ,  $\phi$  meson study [PRD 87, 012009 \(2013\)](#)
  - CP-odd Higgs boson search through radiative decay of  $J/\psi$   
[PRD 93, 052005 \(2016\)](#)  
[PRD 85, 092012 \(2012\)](#)

**THANK YOU!**