

Search for Dark Sector at BESIII

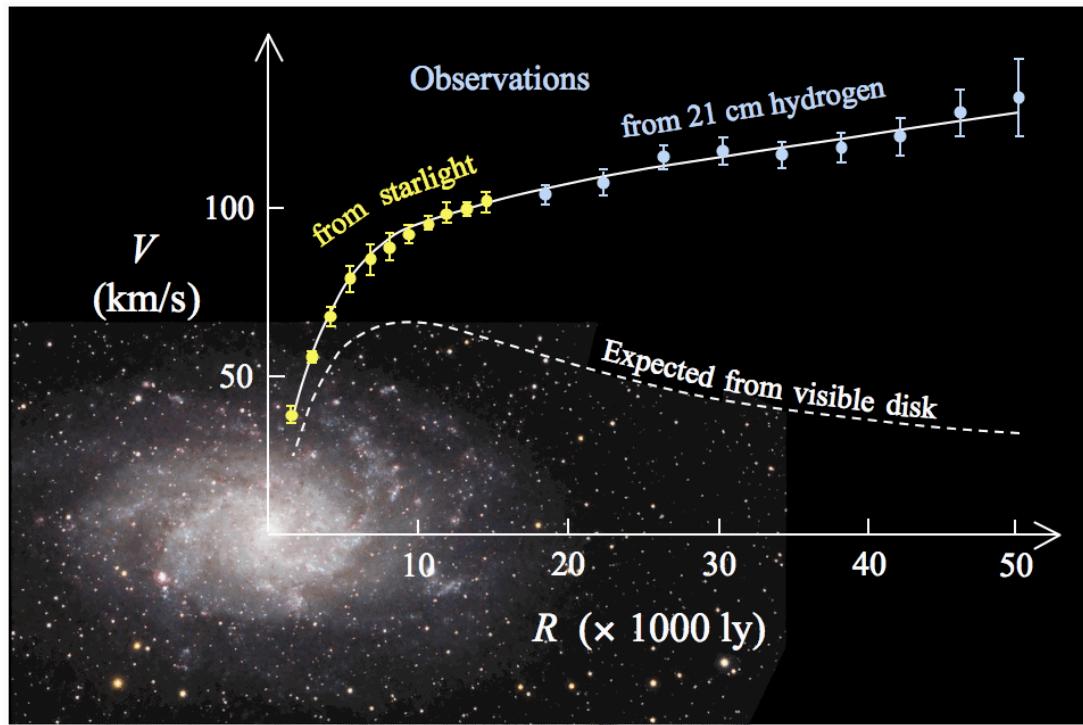
YUPING GUO

ON BEHALF OF THE BESIII COLLABORATION



DARK MATTER

Rotation curve of the typical spiral galaxy M 33

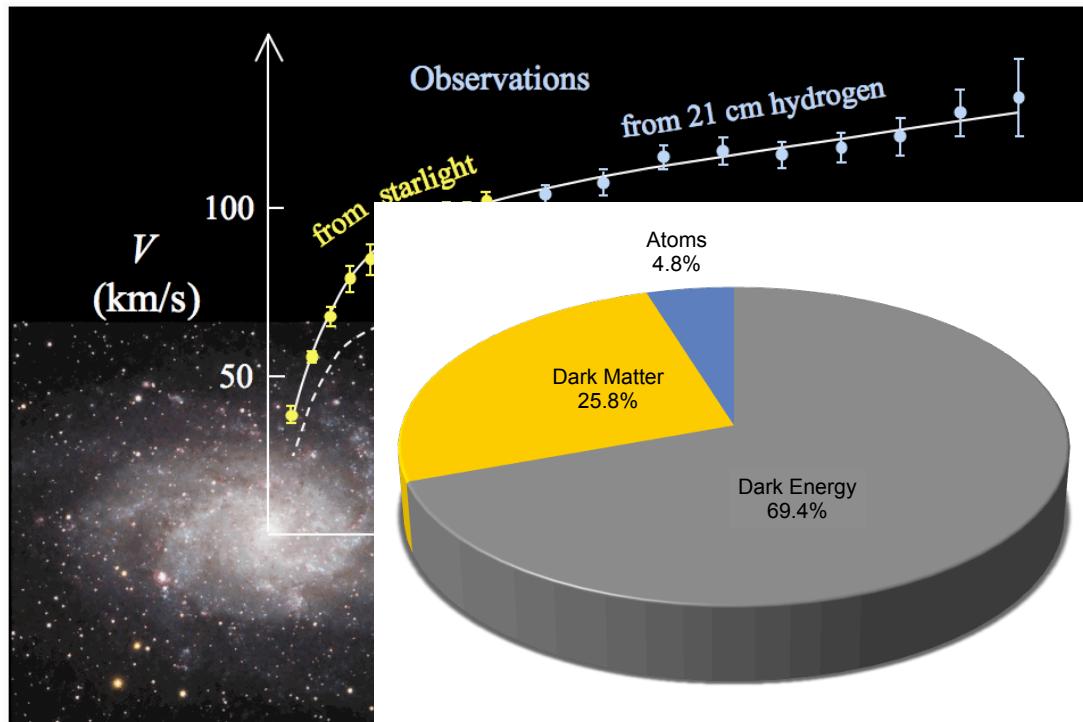


https://en.wikipedia.org/wiki/Galaxy_rotation_curve

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

DARK MATTER

Rotation curve of the typical spiral galaxy M 33



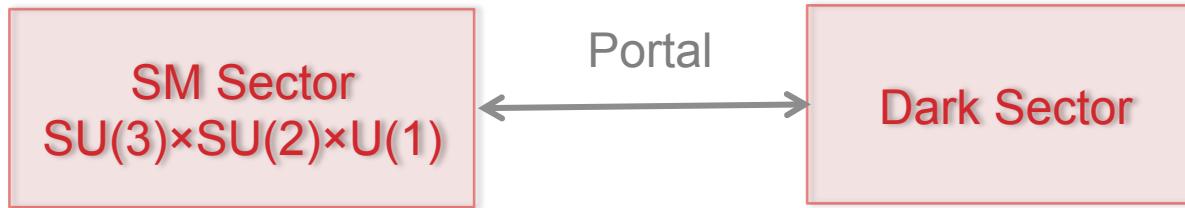
<https://e>

Planck satellite, arXiv:1502.01589

- 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 keep unknown

DARK SECTOR

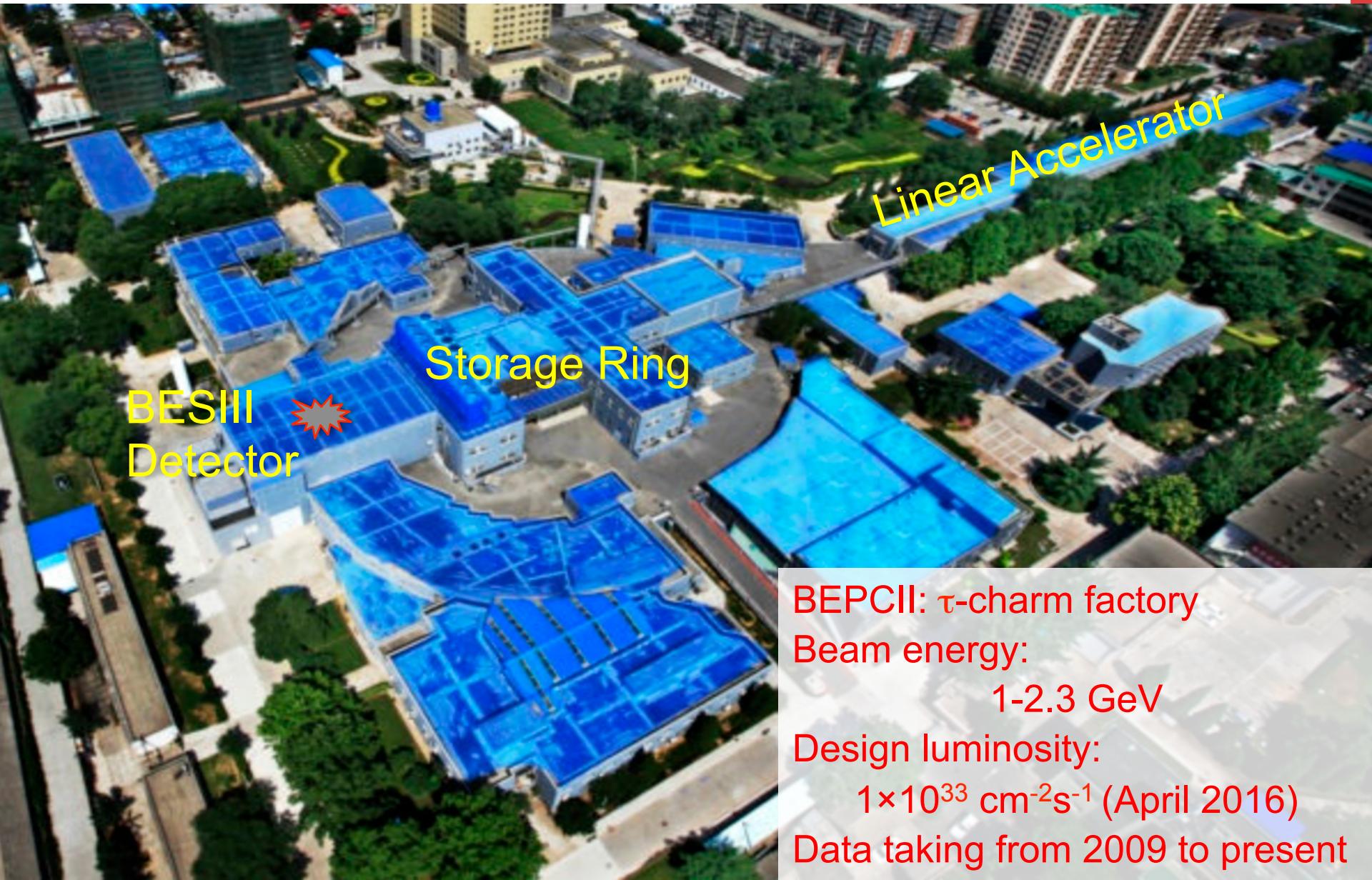
Consisting of (light) particles do not interact with the known strong, weak, or electromagnetic forces



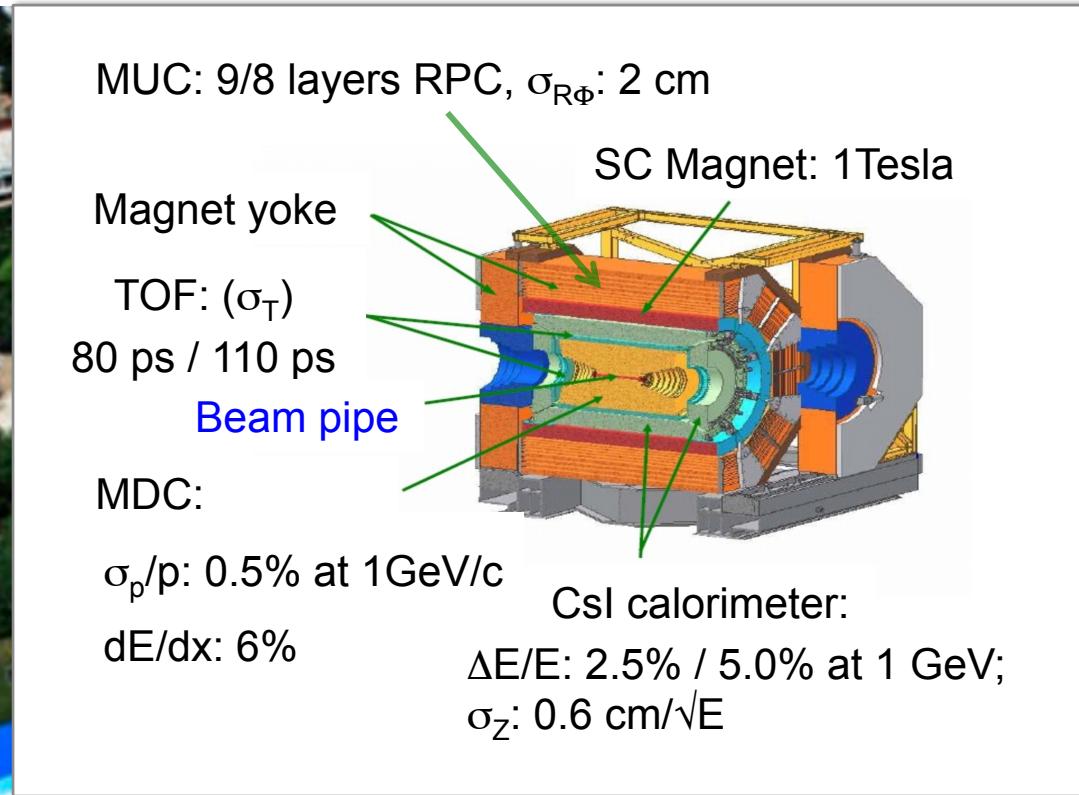
| Portal | Particles | Operator(s) |
|------------|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| “Vector” | Dark photons | $-\frac{\epsilon}{2 \cos \theta_W} B_{\mu\nu} F'^{\mu\nu}$ |
| “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 | $y_N LHN$ |

R. Essig, et al, arXiv:1311.0029

Beijing Electron Positron Collider-II



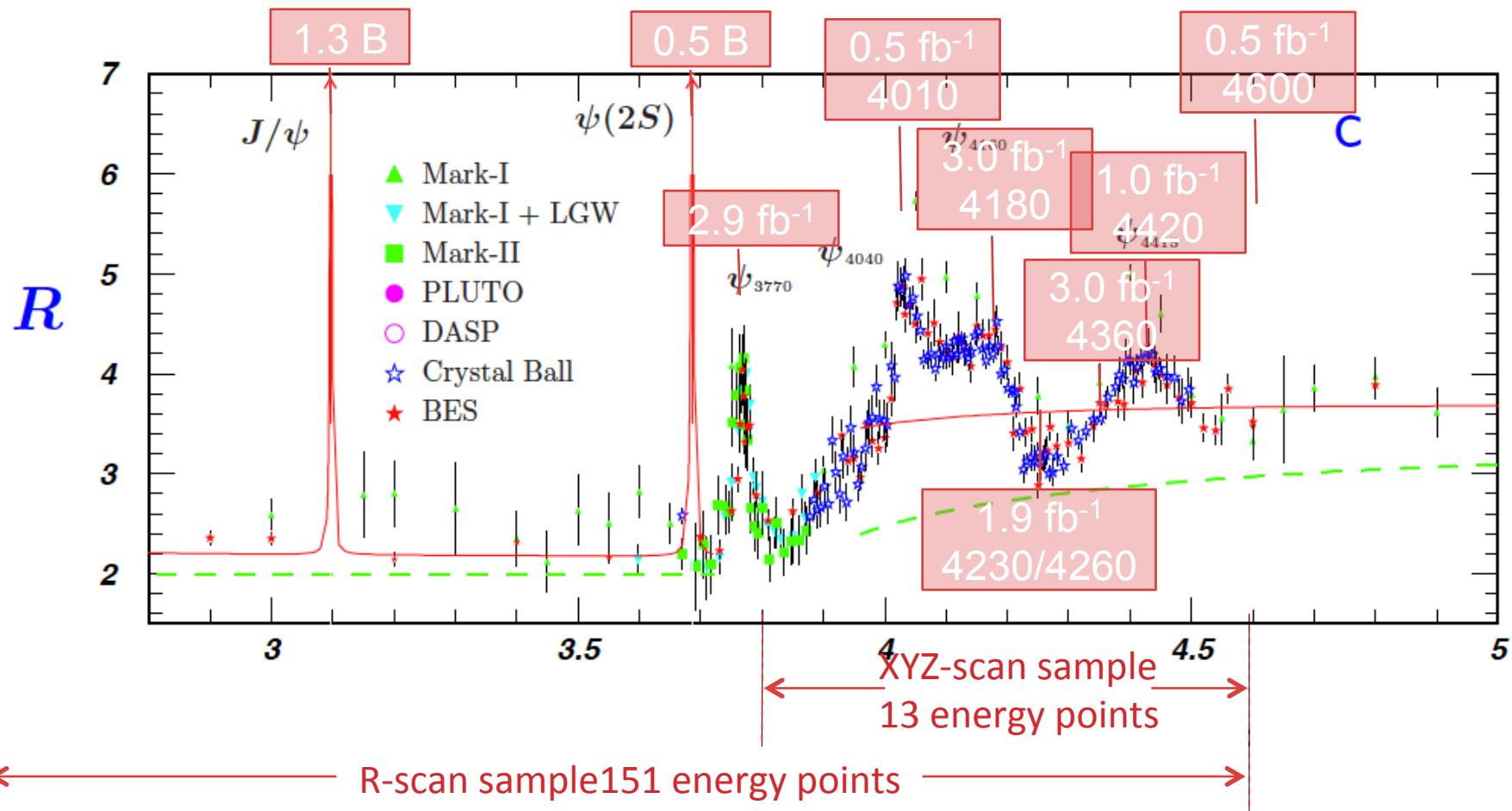
Beijing Electron Positron Collider-II



BEPCII: τ -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

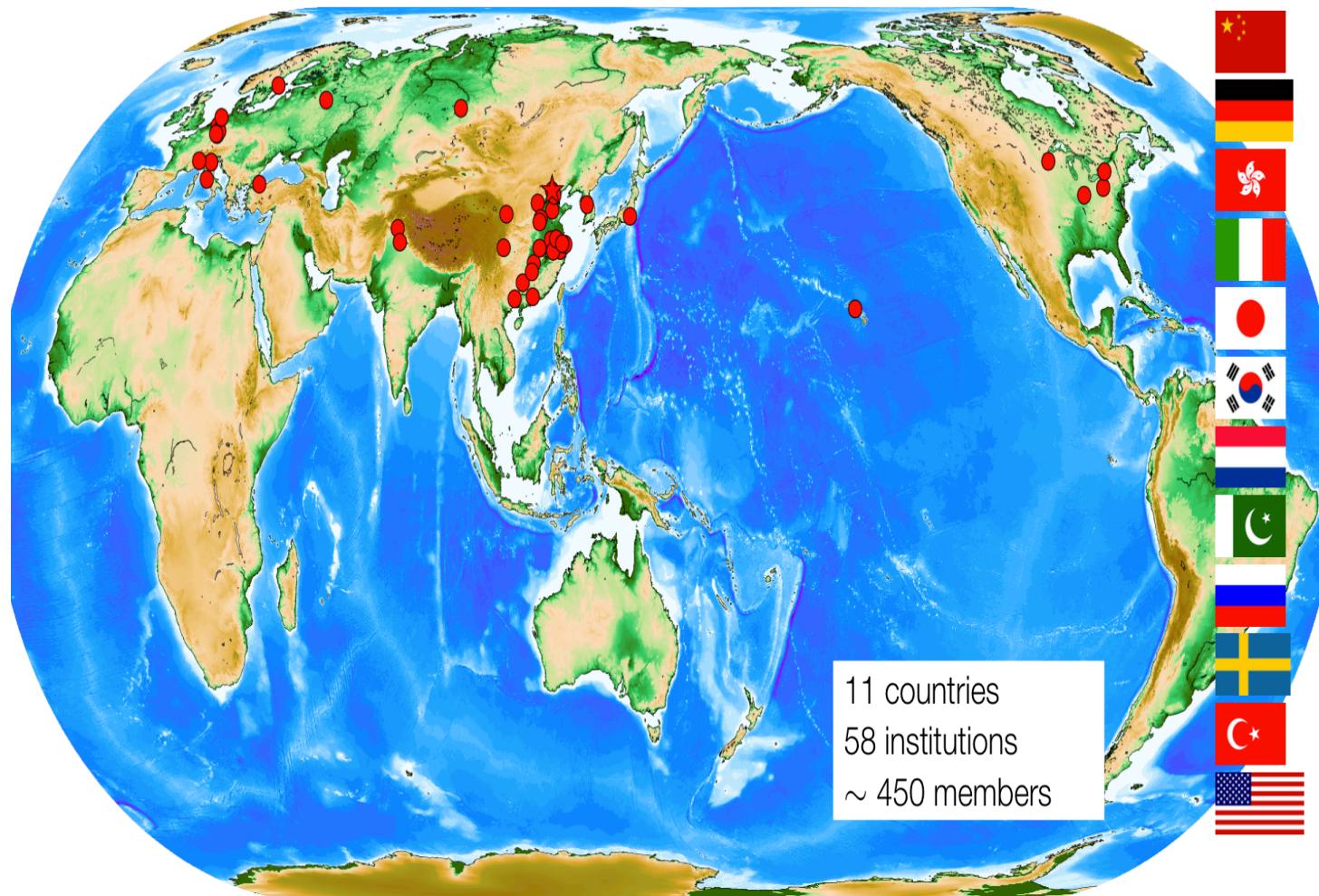


BESIII DATA SET



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

BESIII COLLABORATION



ACTIVITIES AT BESIII

- **Search for dark photon**
- **Search for meson invisible decays**
- **Search for CP-odd light Higgs**

DARK PHOTON (γ')

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

B. Holdom, PLB 166,196 (1986)

- Typical mix strength: $\epsilon 10^{-2} \sim 10^{-5}$, 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 $(g-2)_\mu$

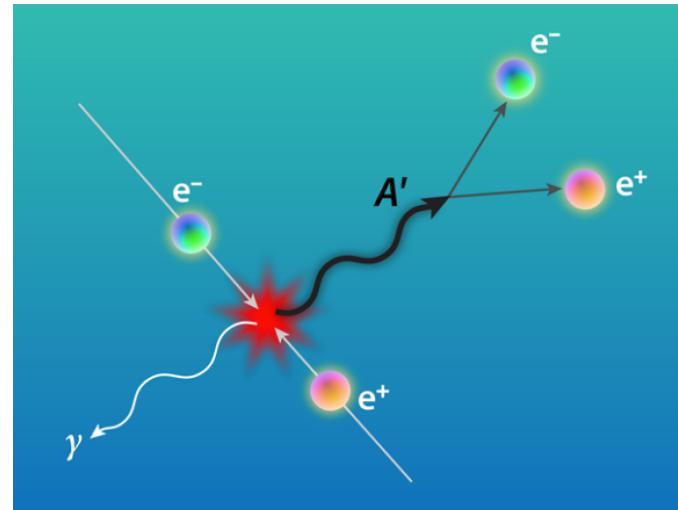
M. Pospelov, PRD 80,095002 (2009)

DARK PHOTON SEARCH

- $2.9 \text{ fb}^{-1} \psi(3770)$ data sample
- Initial State Radiation process:

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

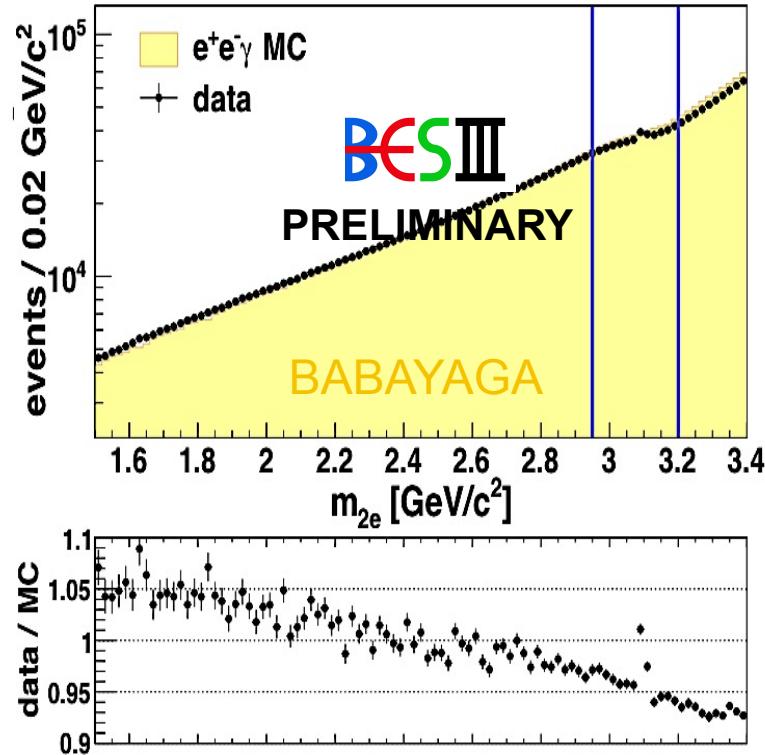
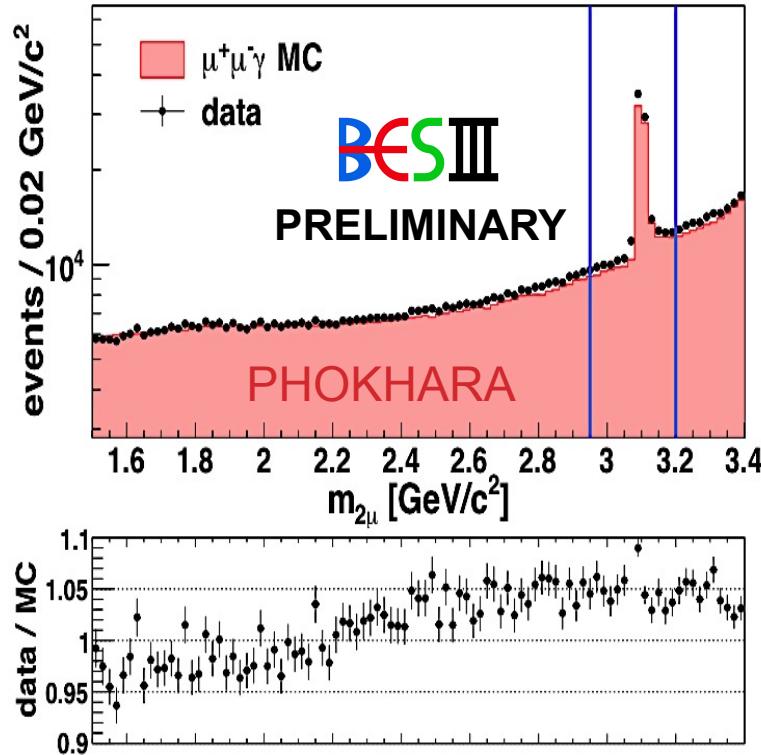
$$e^+ e^- \rightarrow \gamma_{ISR} \gamma' \rightarrow \gamma_{ISR} e^+ e^-$$



APS/Alan Stonebreaker

- Search for narrow structure on top of the continuum QED background ($e^+ e^- \rightarrow \gamma_{ISR} l^+ l^-$)

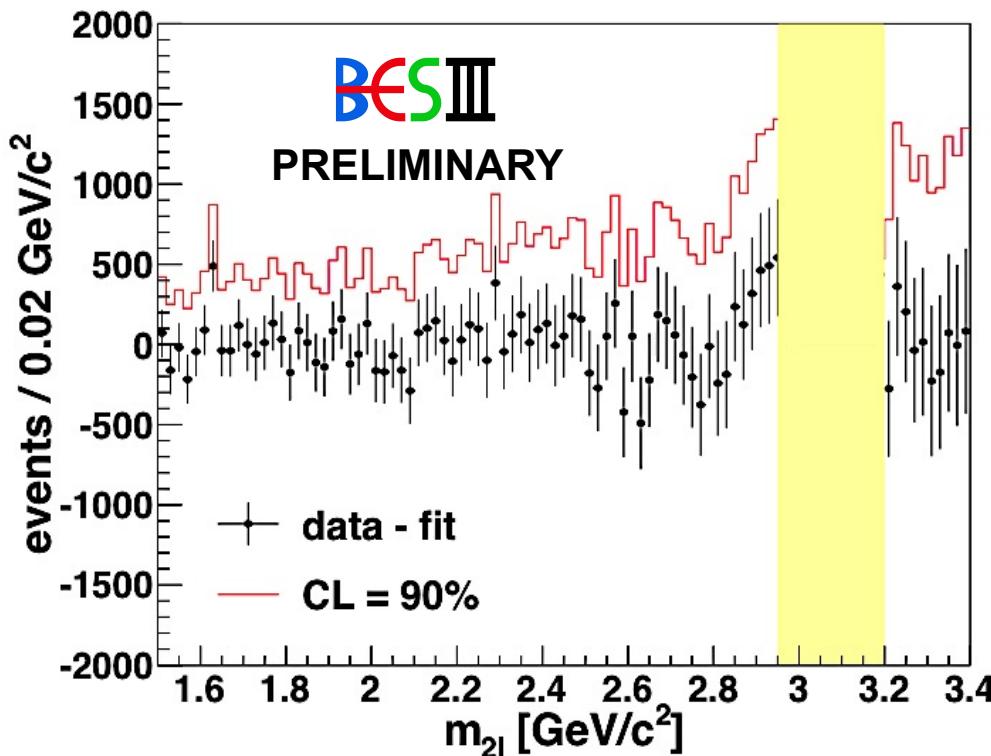
MASS SPECTRUM



Cover mass region: $1.5\text{ GeV}/c^2 \sim 3.4\text{ GeV}/c^2$

- $<1.5\text{ GeV}/c^2$: $\pi^+\pi^-$ background dominates
- $>3.4\text{ GeV}/c^2$: hadronic $q\bar{q}$ -bar process

NUMBER OF SIGNAL EVENTS



- Fit QED background with 4th 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 σ

CALCULATION OF ϵ

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

Mixing coefficient

Number of dark photon events

Number of QED events from annihilation process

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

Mass resolution

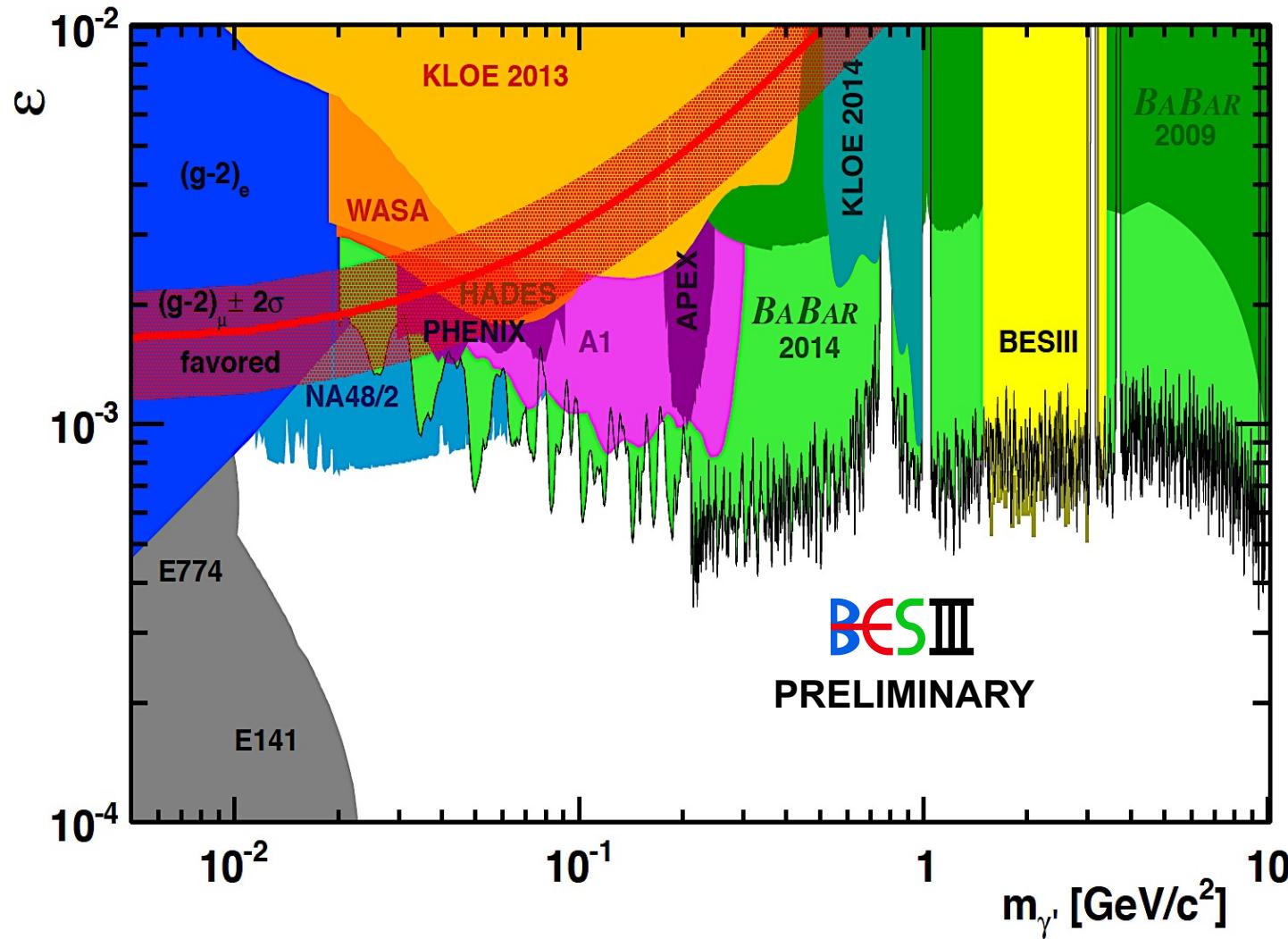
Fine structure constant

Dark photon mass

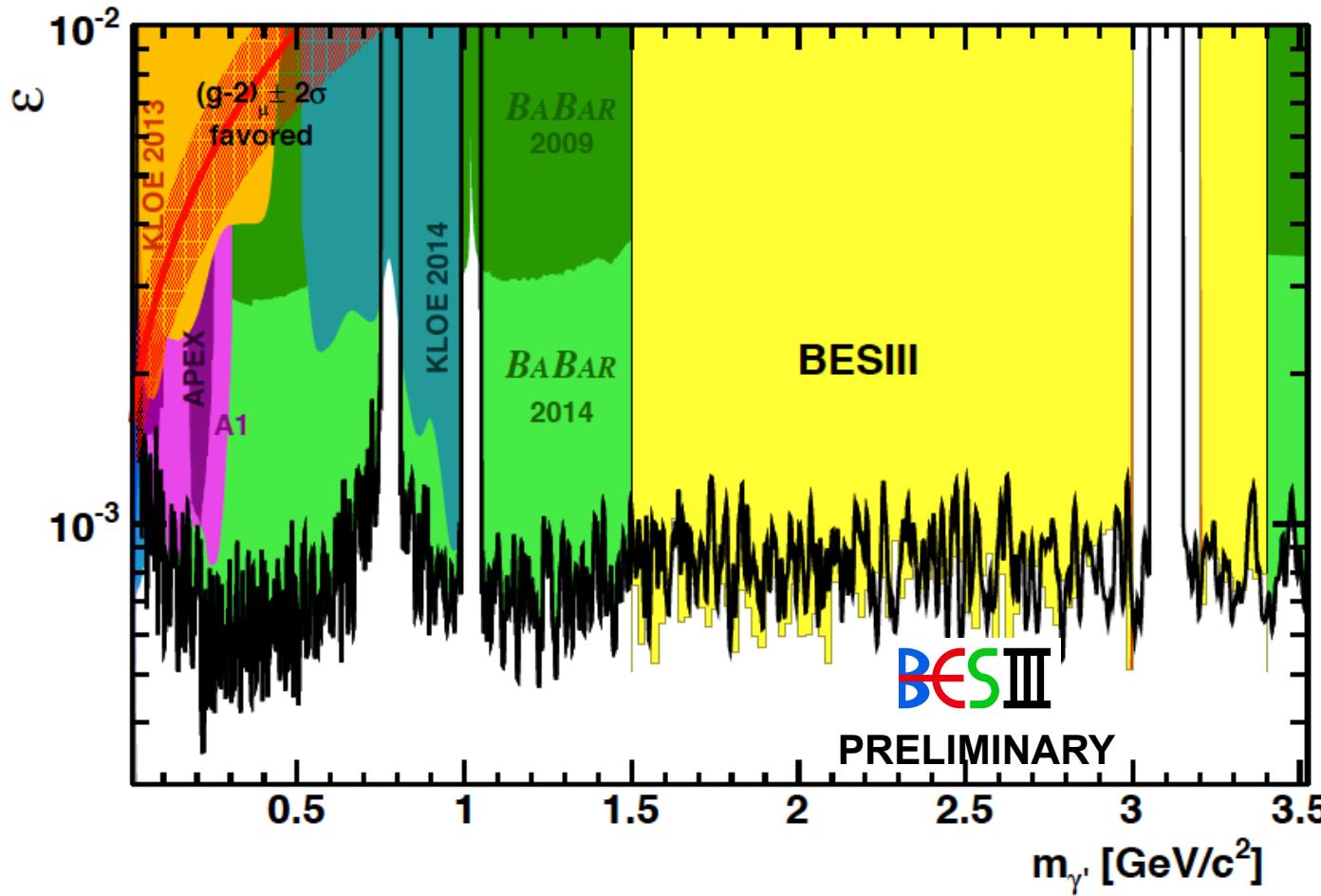
$$N_f^{l^+l^-} = \frac{\Gamma_{\text{tot}}}{\Gamma(\gamma' \rightarrow l^+l^-)} = 1 + \frac{\Gamma_{\mu\mu}}{\Gamma_{ee} + \Gamma_{\mu\mu}} \cdot (1 + R(\sqrt{s}))$$

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

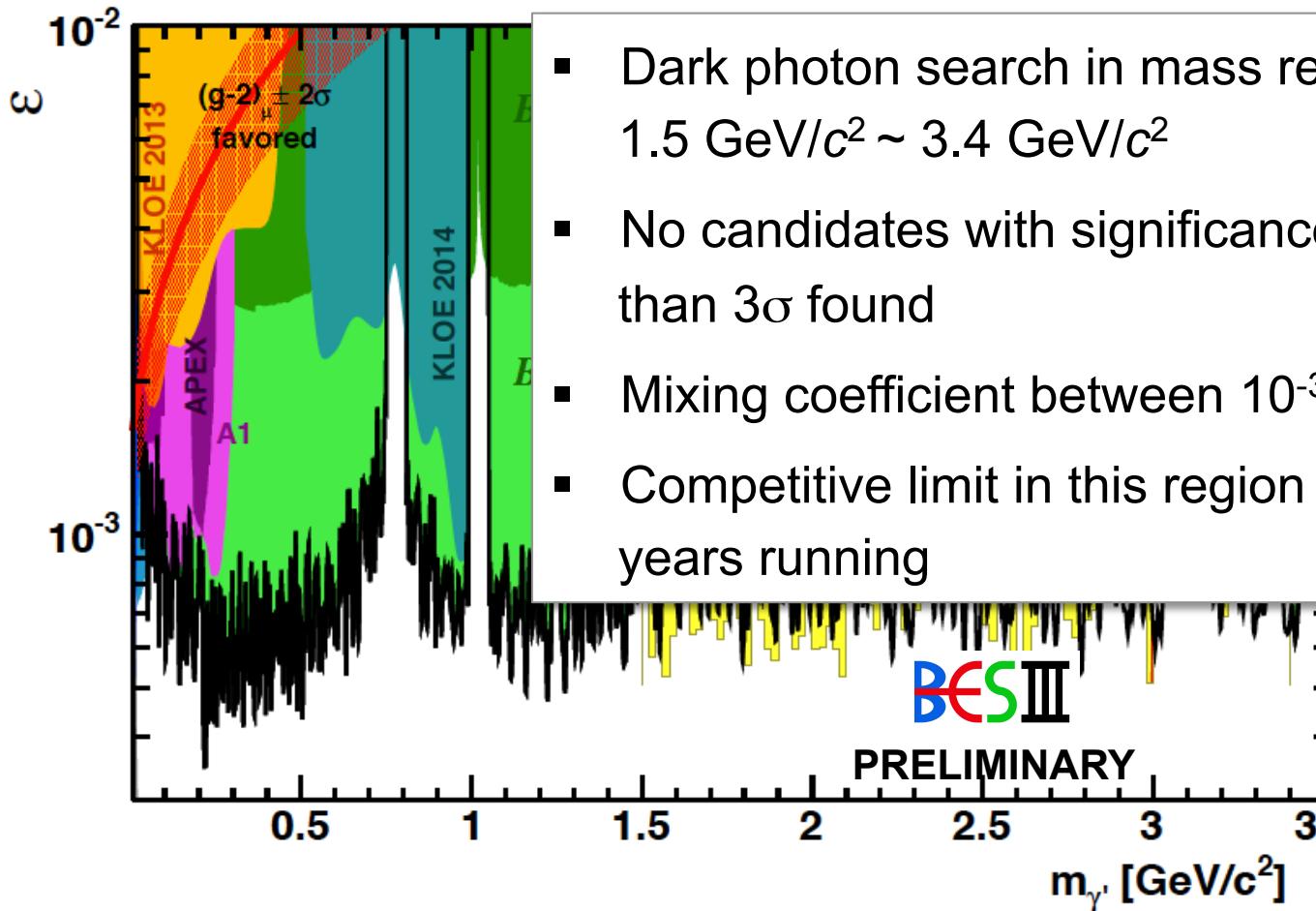
CALCULATION OF ϵ



CALCULATION OF ϵ



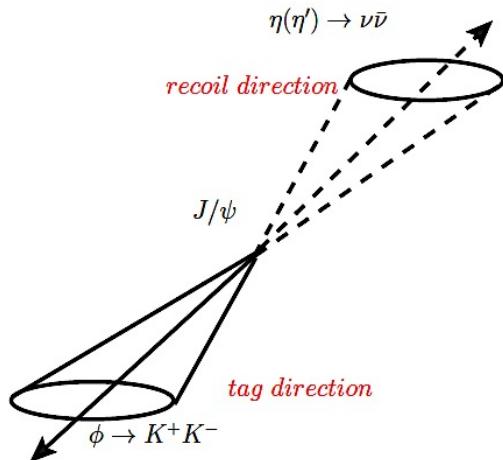
CALCULATION OF ϵ



INVISIBLE DECAY OF $\eta^{(')}$

- Tiny in Standard Model due to helicity suppression: $\sim 10^{-11}$ (η)
- Any enhanced signal of invisible decay may indicate New Physics
- Possible through new gauge boson U(1)

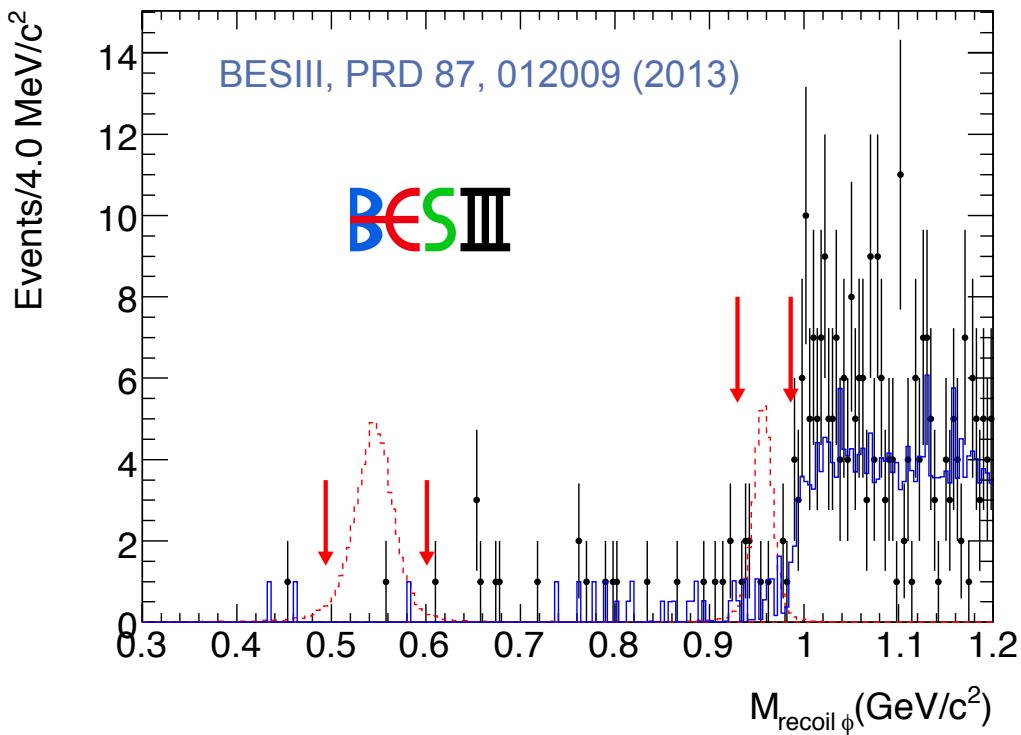
A. R. Fazely, et al., PRD81, 117101(2010)



- 0.22 B J/ψ sample
- $J/\psi \rightarrow \phi \eta^{(')}$, tag ϕ with K^+K^-
 - $8.2 \times 10^4 \eta$
 - $4.4 \times 10^4 \eta'$

BESIII, PRD 87, 012009 (2013)

INVISIBLE DECAY OF $\eta^{(')}$



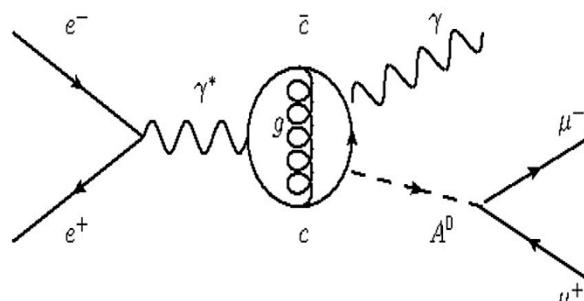
- No signal events observed
- $B(\eta \rightarrow \text{invisible})/B(\eta \rightarrow \gamma\gamma) < 2.6 \times 10^{-4}$
- $B(\eta' \rightarrow \text{invisible})/B(\eta' \rightarrow \gamma\gamma) < 2.4 \times 10^{-2}$
- $B(\eta \rightarrow \text{invisible}) < 1.0 \times 10^{-4}$
- $B(\eta' \rightarrow \text{invisible}) < 5.3 \times 10^{-4}$

- Improved upper limits in both cases
- Theory estimate: $B(\eta^{(')} \rightarrow \chi\chi) \sim 7.4(8.1) \times 10^{-5(7)}$

B. McElrath, PRD 72, 103508 (2005)

CP-ODD LIGHT HIGGS

- Coupling of fermions and the CP-odd Higgs (A^0) in Next-to-Minimal Supersymmetry Standard Model (NMSSM):

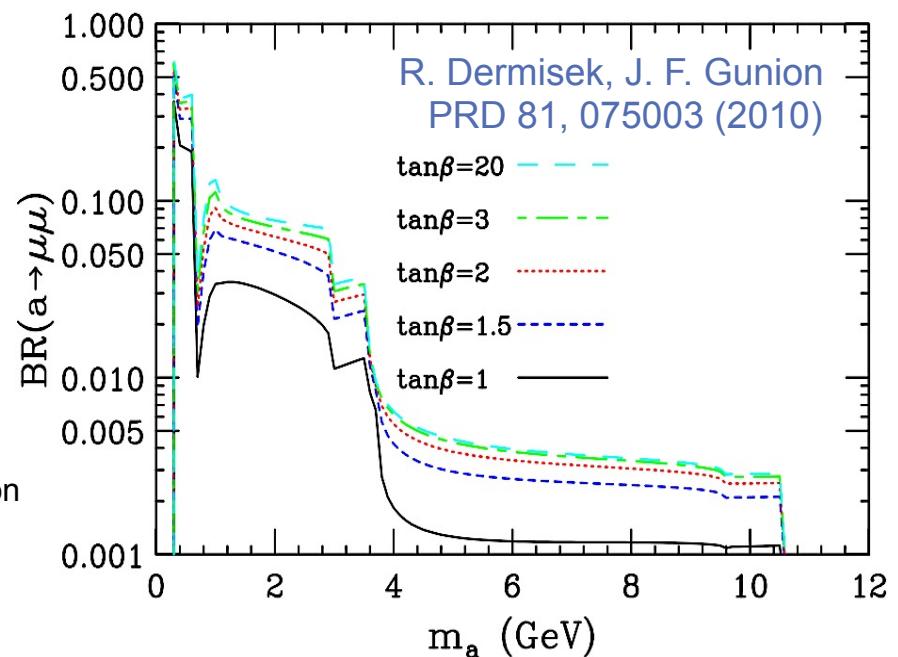


$$\mathcal{L}_{int}^{\bar{f}f} = -X_f \frac{A^0}{v} m_f \bar{f}(i\gamma_5)f$$

X_f : the coupling of the A^0 field to up (down) type fermion pairs, proportional to $\cos\theta_A \cot\beta$ ($\cos\theta_A \tan\beta$)

θ_A : the mixing angle between the CP-odd singlet and doublet component of the A^0

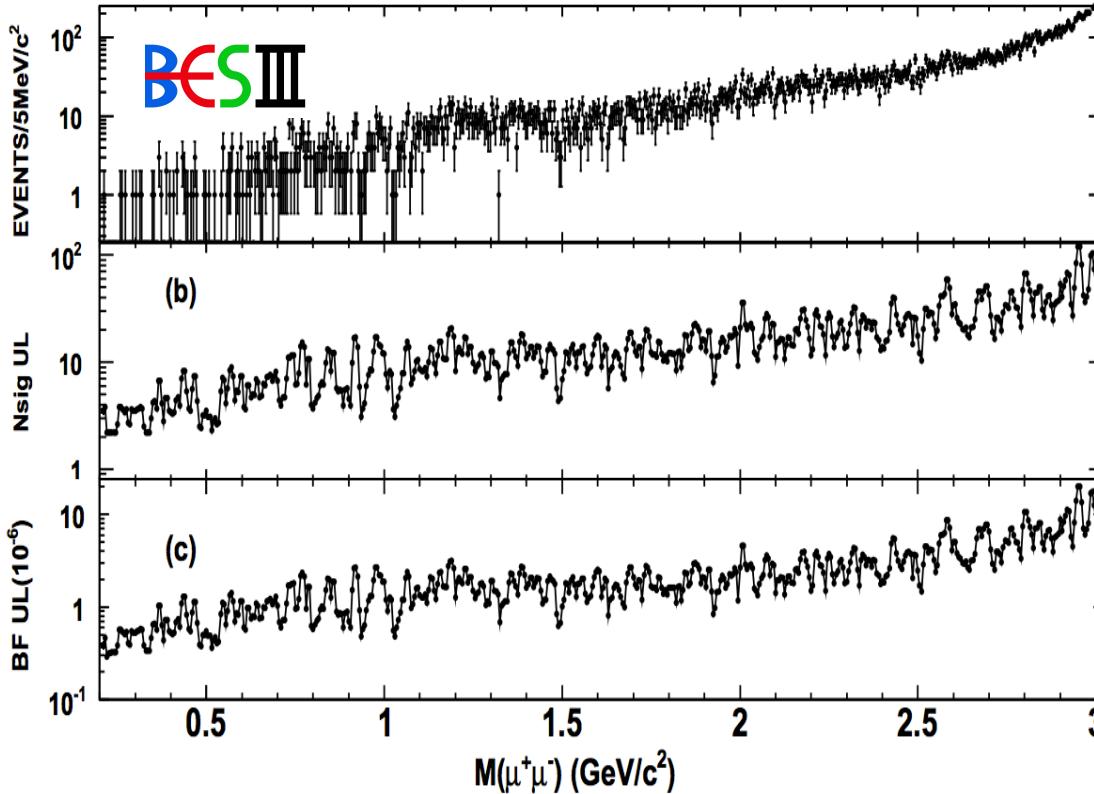
$\tan\beta$: the ratio of the vacuum expectation values of the up and down type Higgs doublets



RESULT OF ψ' DATA

$\psi' \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$

BESIII PRD 85, 092012 (2012)



1.06 M ψ' events

Expected $B(J/\psi \rightarrow \gamma A^0)$:
 $\sim 10^{-9}$ to 10^{-7} level

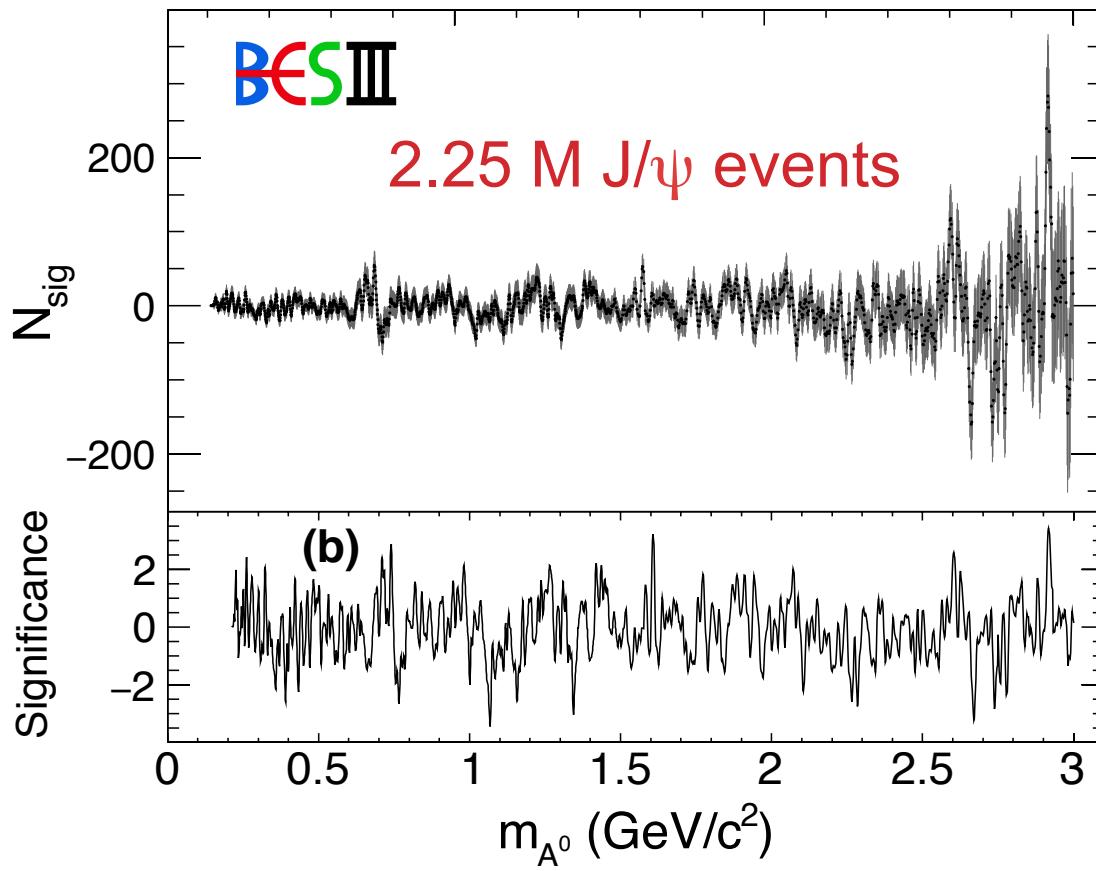
R. Dermisek, J. F. Gunion,
B. McElrath
PRD 76, 051105 (2007)

- No evidence is observed
- Upper limits on $B(J/\psi \rightarrow \gamma A^0) \times B(A^0 \rightarrow \mu^+ \mu^-)$: $4 \times 10^{-7} \sim 2.1 \times 10^{-5}$

RESULT OF J/ ψ DATA

$J/\psi \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$

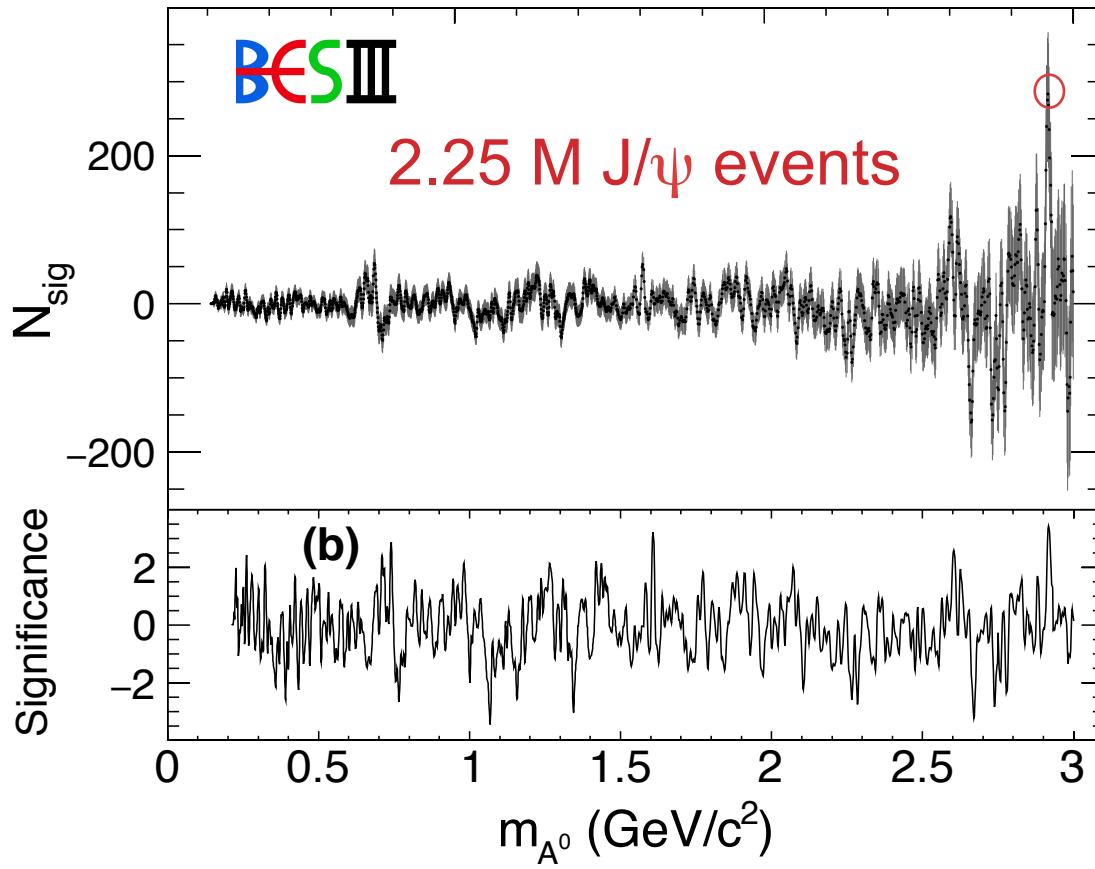
BESIII PRD 93, 052005 (2016)



RESULT OF J/ ψ DATA

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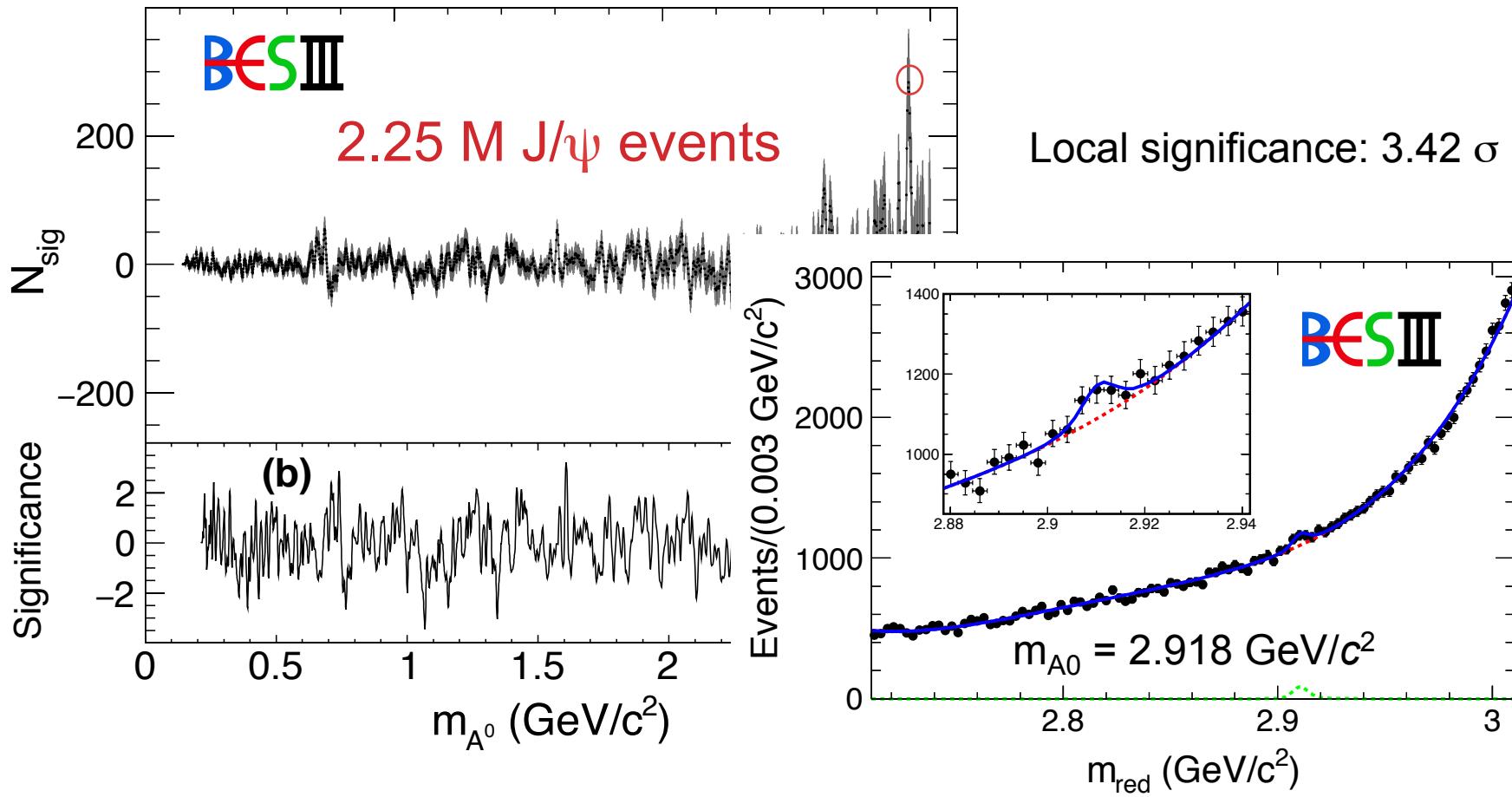
BESIII PRD 93, 052005 (2016)



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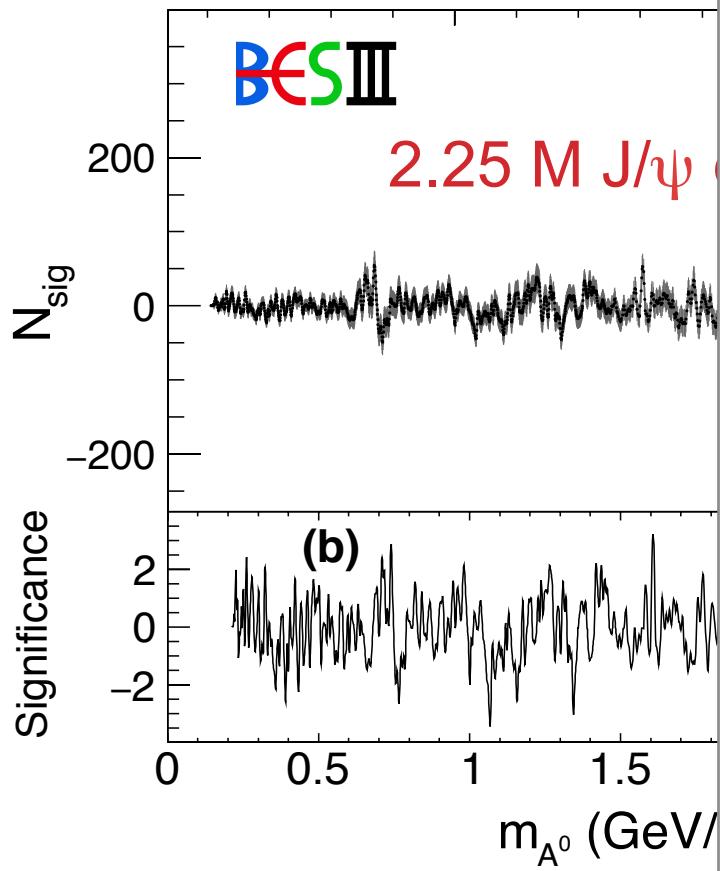
BESIII PRD 93, 052005 (2016)



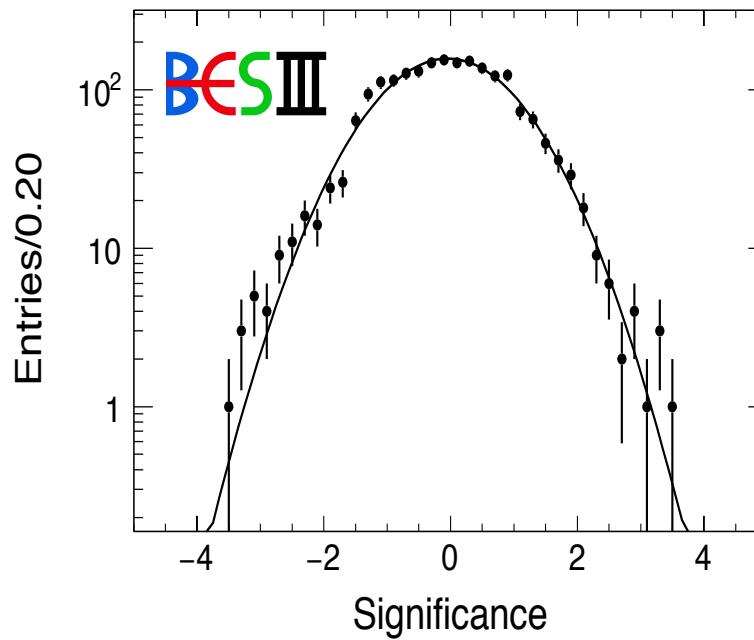
RESULT OF J/ ψ DATA

$J/\psi \rightarrow \gamma A^0, A^0 \rightarrow \mu^+ \mu^-$

BESIII PRD 93, 052005 (2016)



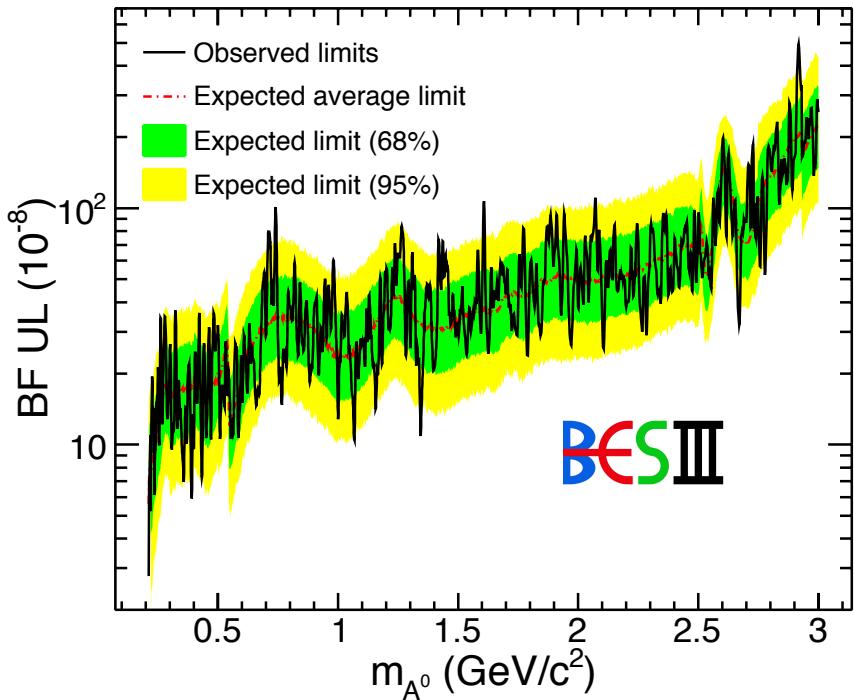
The distribution of significance ($\sqrt{-2\ln(\mathcal{L}_0/\mathcal{L}_{\max})}$)



Consistent with the normal distribution under
the null hypothesis

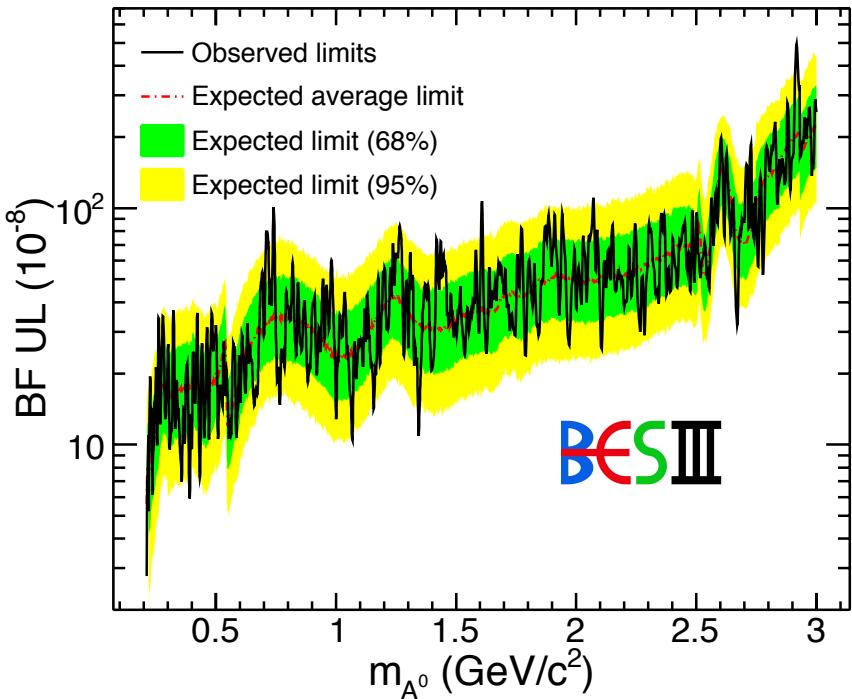
RESULT OF J/ ψ DATA

BESIII PRD 93, 052005 (2016)



New upper limits are five times below
BESIII previous result (ψ' data)

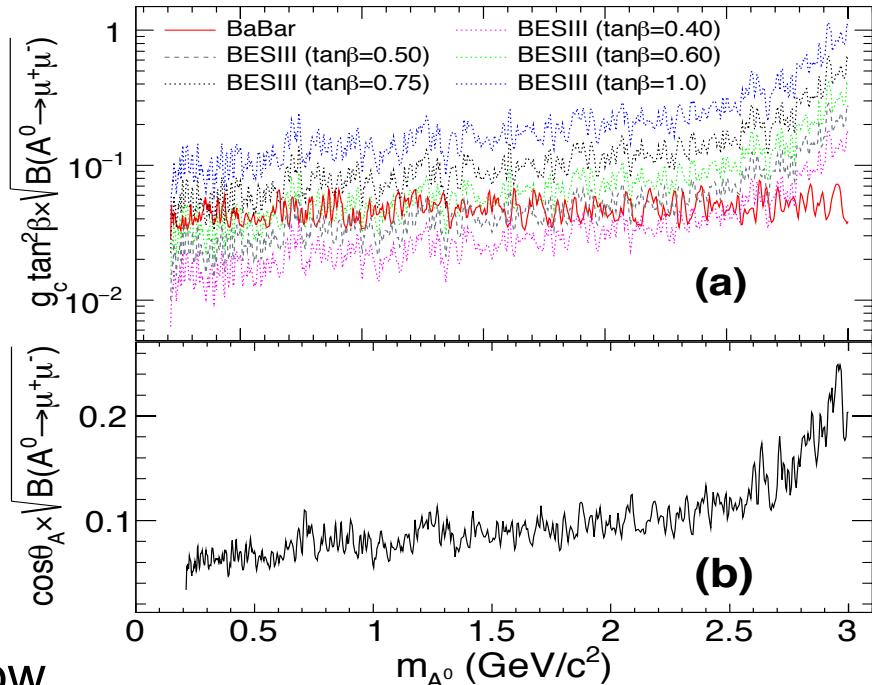
RESULT OF J/ ψ DATA



New upper limits are five times below
BESIII previous result (ψ' data)

BESIII PRD 93, 052005 (2016)

Compare with BaBar result



BaBar PRD 98, 031102(R) (2013)

SUMMARY

- Activities related to dark sector at BESIII:
 - Dark photon search through ISR process in $1.5 \text{ GeV}/c^2 \sim 3.4 \text{ GeV}/c^2$, significance less than 3σ
 - Invisible decay of $\eta^{(\prime)}$ meson study
 - CP-odd Higgs boson search through radiative decay of J/ψ
- More study related to dark sector with larger data sample to be expected

THANK YOU!