Light Meson Decays at BESIII

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Outline

- η/η' **Samples at BESIII**

- η/η' **Physics**

- **Recent results on η' decay at BESIII**

  $\eta' \to \pi^0\pi^0\pi^0\pi^0$ Precision measurement of the branching fractions of η' decays

  $\eta' \to \gamma\gamma\eta$ $\eta' \to \gamma\pi^+\pi^-$ $\eta' \to \eta\pi^+\pi^-$ $\eta' \to \eta\pi^0\pi^0$

  $\eta' \to \pi^+\pi^- e^+ e^-$ $\eta' \to \gamma\omega$ $\eta' \to \gamma\gamma$
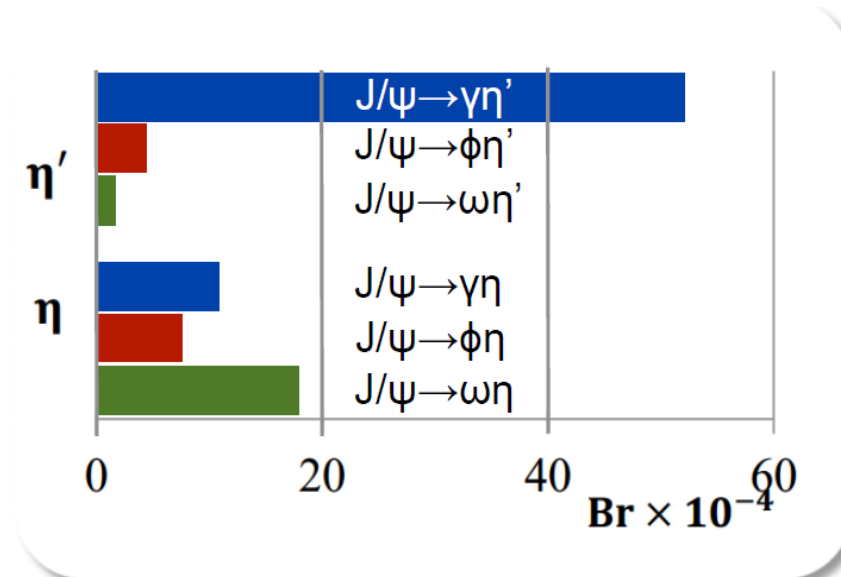
  $\eta' \to \pi^+\pi^- \mu^+ \mu^-$

- **Summary**

Beijing Electron and Positron Collider(BEPCII)

- 2004: BEPCII/BESIII construction

- Double-ring e^+e^- collider running in τ-charm energy region

- Beam energy: 1-2.3 GeV(1-2.47 GeV since 2019)

- Design luminosity: 1×10^{33} cm^{-2}s^{-1}

- 2009-today: BESIII physics runs

η/η' from J/ψ Decays at BESIII

- 1.3 billion J/ψ events (collected in 2009 and 2012)

  η/η' from J/ψ radiative decays: $6.8 \times 10^6 \, \eta'$, $1.4 \times 10^6 \eta$

  η/η' from J/ψ hadronic decays: $8.5 \times 10^5 \, \eta'$, $3.3 \times 10^6 \eta$

- More date collected since 2018, 10 billion J/ψ events in total now

η/η' Physics

- Both η and η' play an important role in understanding the low energy QCD theory
- Decays of the η/η' probe a wide variety of physics issues, such as $\pi^0 - \eta$ mixing, light quark masses and $\pi - \pi$ scattering
- In particular the η' meson, much heavier than the Goldstone bosons of broken chiral symmetry, plays a special role as the predominant singlet state arising from the strong axial U(1) anomaly
- The decay of both η and η' are used to search for processes beyond the SM and to test fundamental discrete symmetries

η decay mode	physics highlight	η' decay mode	physics highlight
$\eta \to \gamma\gamma\pi^0$	ChPT	$\eta' \to \pi\pi$	CPV
$\eta \to \gamma B$	Leptophobic dark boson	$\eta' \to \gamma\gamma$	Chiral anomaly
$\eta \to \pi^0\pi^0\pi^0$	$m_u - m_d$	$\eta' \to \gamma\pi\pi$	Box anomaly, Form factor
$\eta \to \pi^+\pi^-\pi^0$	$m_u - m_d$, CV	$\eta' \to \pi^+\pi^-\pi^0$	$m_u - m_d$, CV
$\eta \to \gamma\gamma$	CPV	$\eta' \to \pi^0\pi^0\eta$	Cusp effect

$\eta' \to \pi^0\pi^0\pi^0\pi^0$

- Suppressed due to S-wave CP-violation
- CP-conserving higher order contributions

  D-wave pion loop

  Production of two f_2 tensor mesons

- D-wave contribution[1]

  At the level of 10^{-8}

  Based on ChPT and VMD models

- Upper limits obtained by GAMS-4π[2]
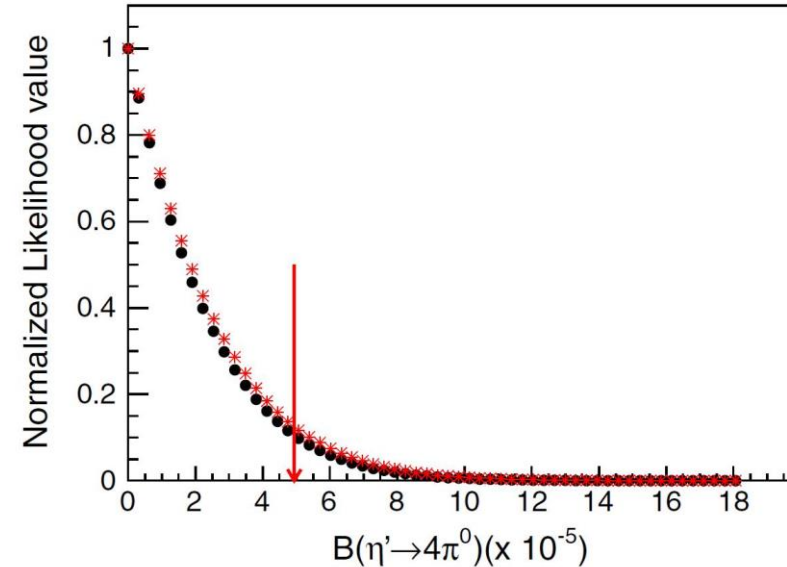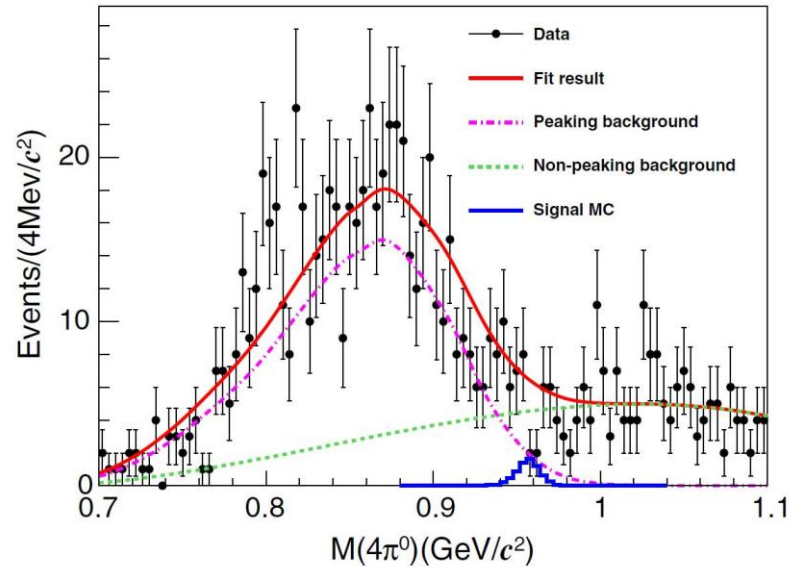
  3.2×10^{-4} at the 90% C.L.

(a)

(b)
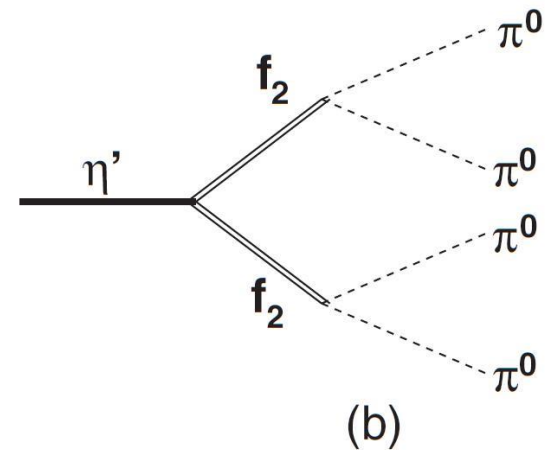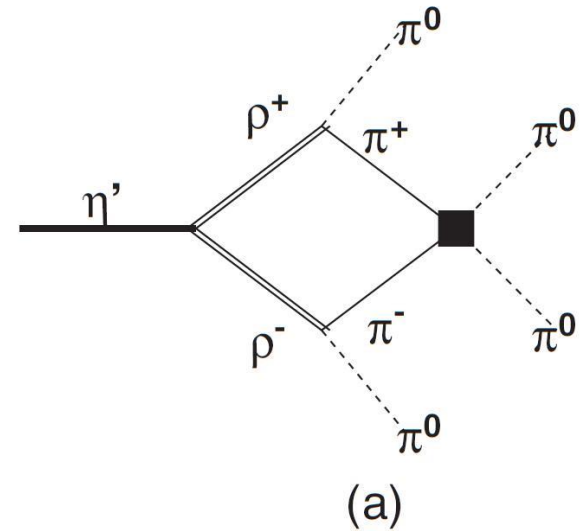
[1]F.K. Guo, B. Kubis, and A. Wirzba, Phys. Rev. D 85, 014014 (2012)
[2]S.V. Donskov *et al.*, Mod. Phys. Lett. A 29, 1450213 (2014)

$\eta' \to \pi^0 \pi^0 \pi^0 \pi^0$

Phys. Rev. D 101, 032001(2020)
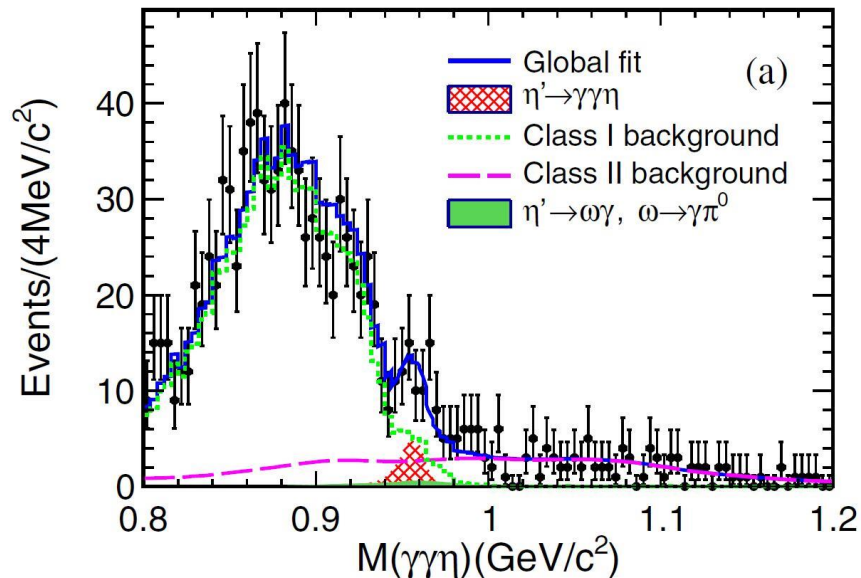

With 1.3 billion J/ψ events at BESIII

- $J/\psi \to \gamma\eta', \eta' \to 4\pi^0$
- Signal contribution negligible
- Upper limit: 4.94×10^{-5} at the 90% C.L.
- Approximately a factor of six smaller than the previous most stringent result

$\eta' \to \gamma\gamma\eta$

- Branching fraction of $\eta' \to \gamma\gamma\eta$ is predicted to be 2.0×10^{-4} within the frameworks of linear σ model and the VMD model[3,4]

- Upper limit reported by GAMS-4π[5]: 8×10^{-4} at the 90% C.L.

Phys. Rev. D 100, 052015(2019)

With 1.3 billion J/ψ events at BESIII
- $J/\psi \to \gamma\eta', \eta' \to \gamma\gamma\eta, \eta \to \gamma\gamma$
- $B(\eta' \to \gamma\gamma\eta) = (8.25 \pm 3.41 \pm 0.72) \times 10^{-5}$
- Statistical significance: 2.6σ
- Upper limit: 1.33×10^{-4} at the 90% C.L.

[3]R. Jora, Nucl. Phys. B, Proc. Suppl. 207, 224 (2010)
[4]R. Escribano *et al.,* Phys. Rev. D 102, 034026 (2020)
[5]S.V. Donskov *et al.,* Phys. At. Nucl. 78, 1043 (2015)
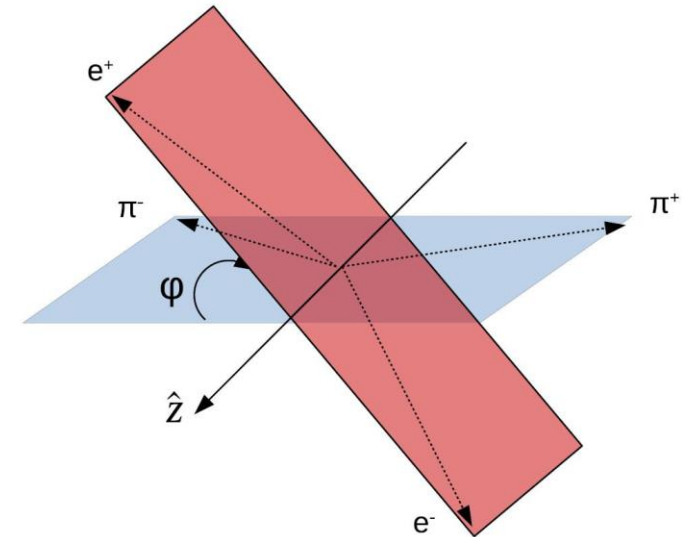
$\eta' \to \pi^+\pi^- e^+ e^-$

- Theoretical predictions of $B(\eta' \to \pi^+\pi^- e^+ e^-)$

  ChPT model[6]: $(2.13^{+0.19}_{-0.32}) \times 10^{-3}$

  Two different VMD models[7]: $(2.17 \pm 0.21) \times 10^{-3}$ and $(2.27 \pm 0.13) \times 10^{-3}$

- Previous measurement from BESIII[8]: $(2.11 \pm 0.12 \pm 0.15) \times 10^{-3}$

- Possible CP-violating contribution[9-11]

  An electric dipole type transition

  Manifest itself as an asymmetry of $\sin 2\varphi$

  $A_\varphi = \dfrac{N(\sin 2\varphi > 0) - N(\sin 2\varphi < 0)}{N(\sin 2\varphi > 0) + N(\sin 2\varphi < 0)}$

  Previous measurement of A_φ: consistent with zero

[6]B. Borasoy and R. Nissler, Eur. Phys. J. A 33, 95 (2007).
[7]T. Petri, Ph.D. thesis, Forschungszentrum Julich, (2010), arXiv:1010.2378.
[8]M. Ablikim *et al.,* (BESIII Collaboration), Phys. Rev. D 87, 092011 (2013).
[9]C.Q. Geng, J. N. Ng, and T. H. Wu, Mod. Phys. Lett. A 17, 1489 (2002).
[10]D.-N. Gao, Mod. Phys. Lett. A 17, 1583 (2002).
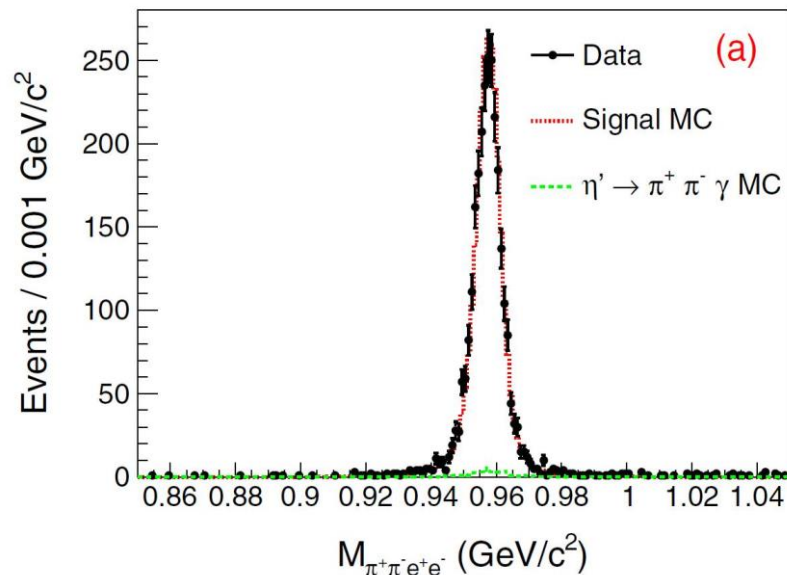[11]L. Gan, B. Kubis, E. Passemar, and S. Tulin, (2020), arXiv:2007.00664.

$\eta' \to \pi^+\pi^- e^+ e^-$

- To cancel the impact of systematic effects due to the number of J/ψ, tracking and charged particle identification of π and photon reconstruction

$$B(\eta' \to \pi^+\pi^- e^+ e^-) = B(\eta' \to \pi^+\pi^-\gamma) \times \frac{N_{\eta' \to \pi^+\pi^- e^+ e^-} \times \varepsilon_{\eta' \to \pi^+\pi^-\gamma}}{N_{\eta' \to \pi^+\pi^-\gamma} \times \varepsilon_{\eta' \to \pi^+\pi^- e^+ e^-}}$$

- The $B(\eta' \to \pi^+\pi^-\gamma)$ is referred from PDG

BESIII Phys. Rev. D 103, 092005(2021)

With 1.3 billion J/ψ events at BESIII
- Signal region: $\left| M(\pi^+\pi^- e^+ e^-) - m_{\eta'} \right| < 0.02$ GeV
- Signal purity: 98%
  based on MC simulations of $\eta' \to \pi^+\pi^-\gamma$
- $B(\eta' \to \pi^+\pi^- e^+ e^-) = (2.42 \pm 0.05 \pm 0.08) \times 10^{-3}$
  consistent with the predictions

$\eta' \to \pi^+\pi^- e^+ e^-$

Measurement of A_φ

- Due to the limited momentum resolution, some events with a true value $\sin 2\varphi < 0$ are reconstructed with a value $\sin 2\varphi > 0$. The fraction of such events, α is estimated with signal MC sample

- Corrected A_φ

$$A_{\varphi,corr} = \frac{A_{\varphi,rec}}{1 - 2\alpha}$$

- Result: $A_\varphi = (2.9 \pm 3.7 \pm 1.1)\%$, consistent with zero

$\eta' \to \pi^+\pi^-\mu^+\mu^-$

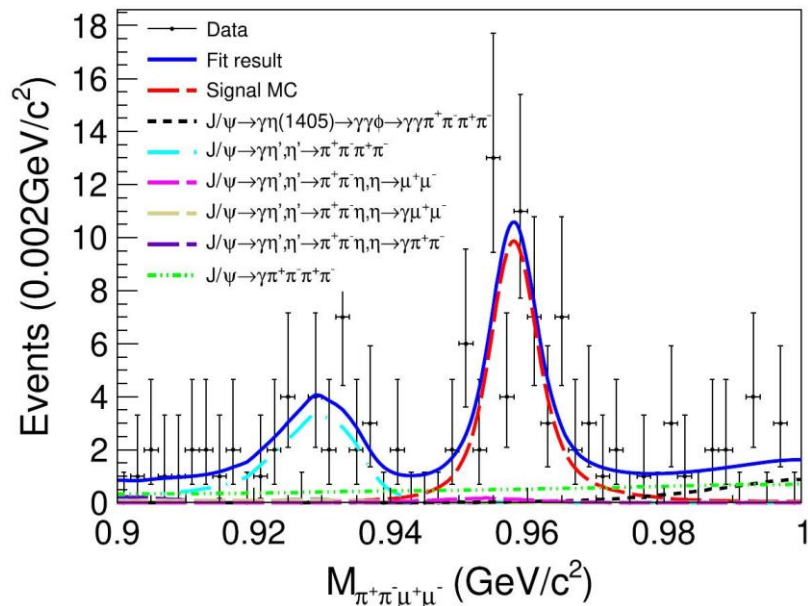- Theoretical predictions of $B(\eta' \to \pi^+\pi^-\mu^+\mu^-)$

  ChPT model[6]: $(1.57^{+0.96}_{-0.75}) \times 10^{-5}$

  Two different VMD models[7]: $(2.20 \pm 0.30) \times 10^{-5}$ and $(2.41 \pm 0.25) \times 10^{-5}$

- No significant signal has been observed before this work

- Previous measurement from BESIII[8]

  $B(\eta' \to \pi^+\pi^-\mu^+\mu^-) < 2.9 \times 10^{-5}$ at the 90% C.L.

BESⅢ Phys. Rev. D 103, 072006(2021)

With 1.3 billion J/ψ events at BESIII

- $B(\eta' \to \pi^+\pi^-\mu^+\mu^-) = (1.97 \pm 0.33 \pm 0.18) \times 10^{-5}$
- Statistical significance: 8σ
- In good agreement with theoretical predications
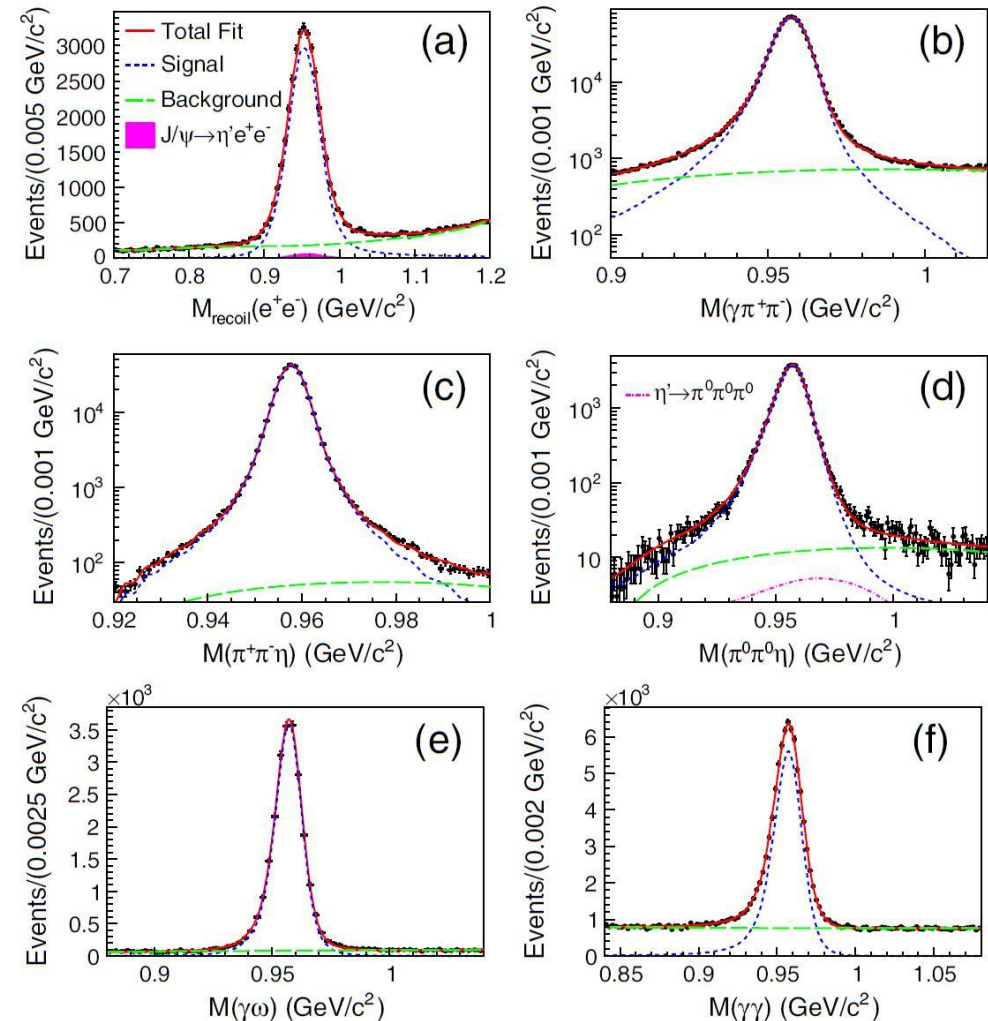

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Precision measurement of the BFs of η' decays

- No absolute branching fractions of η' decays have yet been measured due to difficulty of tagging its inclusive decays

- Tag the $J/\psi \to \gamma\eta'$ inclusive decays with γ conversions to e^+e^-
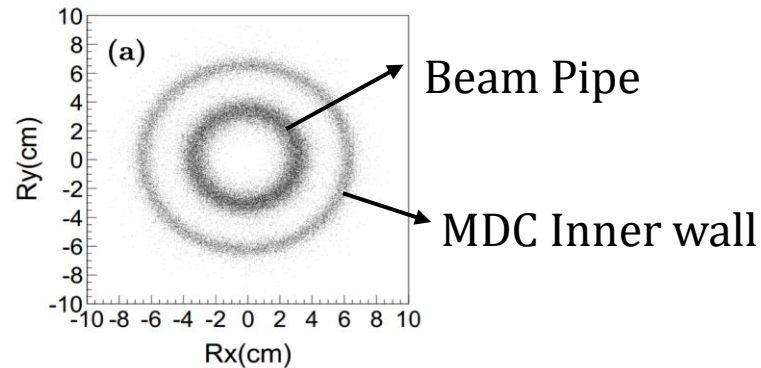
- Precision measurements by $J/\psi \to \gamma\eta'$ with the radiative photon detected by electromagnetic calorimeter(EMC)

$$\eta' \to \gamma\pi^+\pi^-, \eta' \to \eta\pi^+\pi^-,$$
$$\eta' \to \eta\pi^0\pi^0, \eta' \to \gamma\omega, \eta' \to \gamma\gamma$$

Precision measurement of the BFs of η' decays

Decay mode	$N^{obs}_{\eta' \to X}$	$\varepsilon_{\eta' \to X}(\%)$	$B(\eta' \to X)(\%)$	
			This work	PDG
$\eta' \to \gamma\pi^+\pi^-$	913106 ± 1052	44.11	$29.90 \pm 0.03 \pm 0.55$	28.9 ± 0.5
$\eta' \to \eta\pi^+\pi^-$	312275 ± 570	27.75	$41.24 \pm 0.08 \pm 1.24$	42.6 ± 0.7
$\eta' \to \eta\pi^0\pi^0$	51680 ± 238	9.08	$21.36 \pm 0.10 \pm 0.92$	22.8 ± 0.8
$\eta' \to \gamma\omega$	22749 ± 163	14.98	$2.489 \pm 0.018 \pm 0.074$	2.62 ± 0.013
$\eta' \to \gamma\gamma$	70669 ± 349	43.79	$2.331 \pm 0.012 \pm 0.035$	2.22 ± 0.08

With 1.3 billion J/ψ events at BESIII
- $B(J/\psi \to \gamma\eta') = (5.27 \pm 0.03 \pm 0.05) \times 10^{-3}$
- The absolute branching fractions of the η' are measured
- In agreement with CLEO's result within two standard deviation

Summary

η' decays

- Search for rare decay $\eta' \to \pi^0\pi^0\pi^0\pi^0$ and $\eta' \to \gamma\gamma\eta$

- Search for CP violation in $\eta' \to \pi^+\pi^- e^+ e^-$

- First observation of $\eta' \to \pi^+\pi^-\mu^+\mu^-$

- Precision measurement of the branching fractions of η' decays

With 10 billion J/ψ events collected at BESIII

- A unique worldwide sample for studying light mesons with the unprecedented statistics

- More interesting results are expected

Thanks for your attention!