



Beijing Spectrometer(BESIII) Experiment



Light meson decays at BESIII

XiaoLin Kang

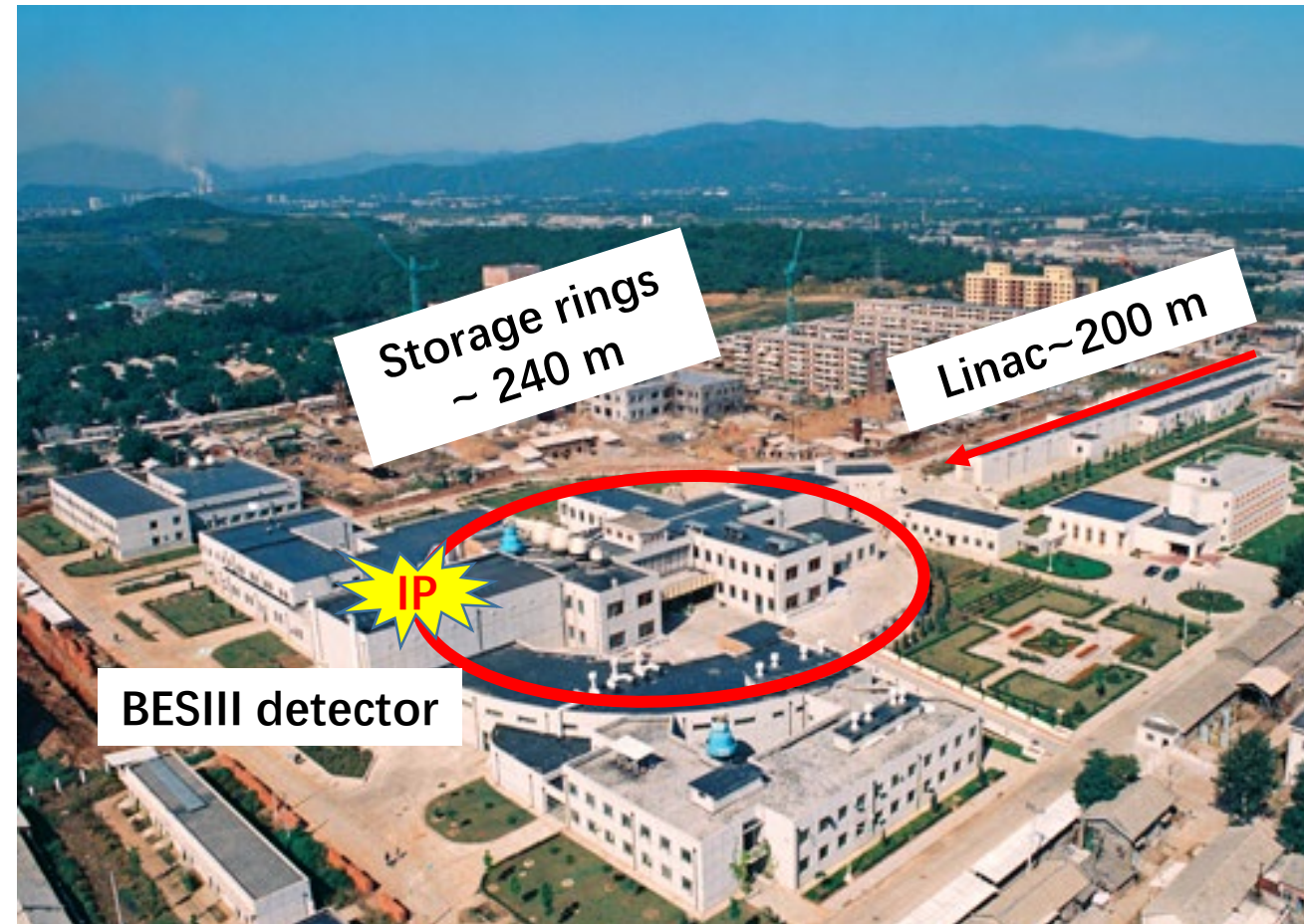
(on behalf of BESIII Collaboration)

China University of Geosciences (Wuhan) (CUG)

The 10th International Workshop on Chiral Dynamics

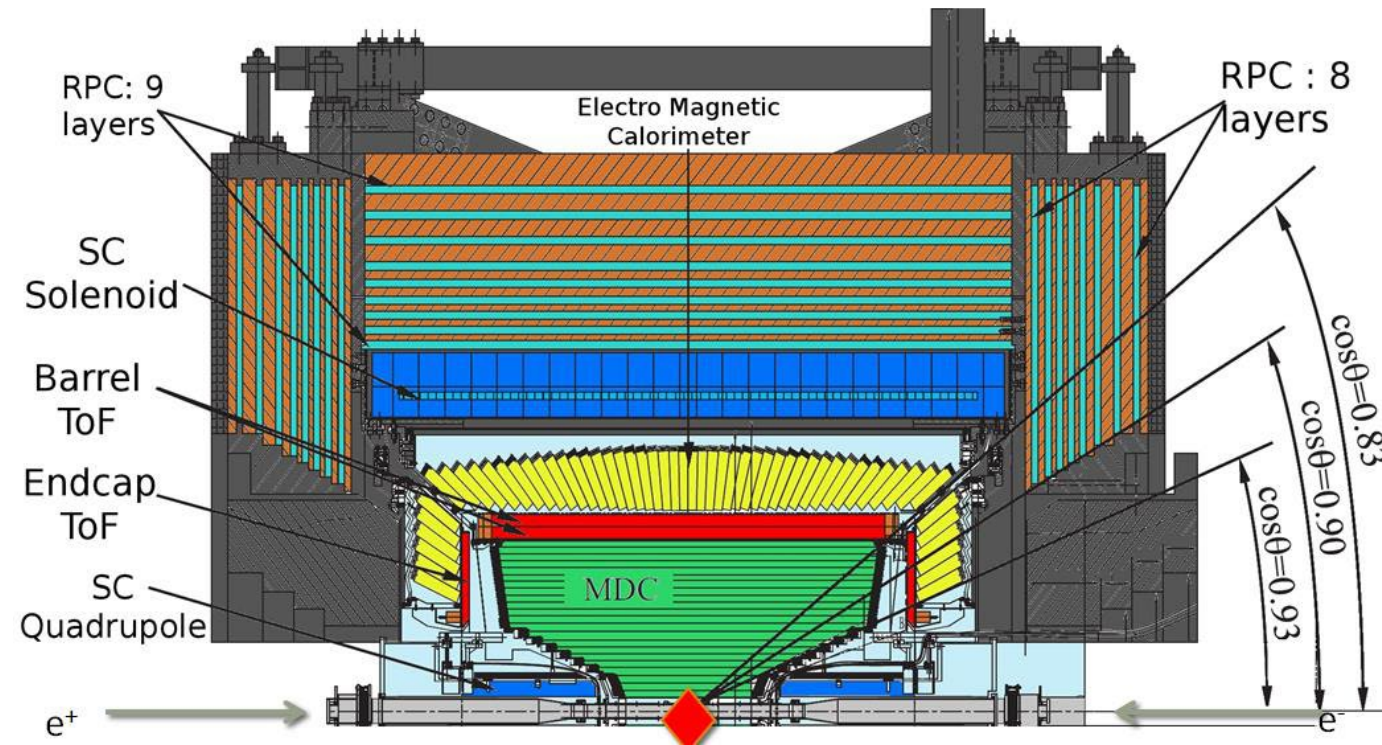
November 15 - 19, 2021, Beijing, China

Beijing Electron and Positron Collider(BEPCII)



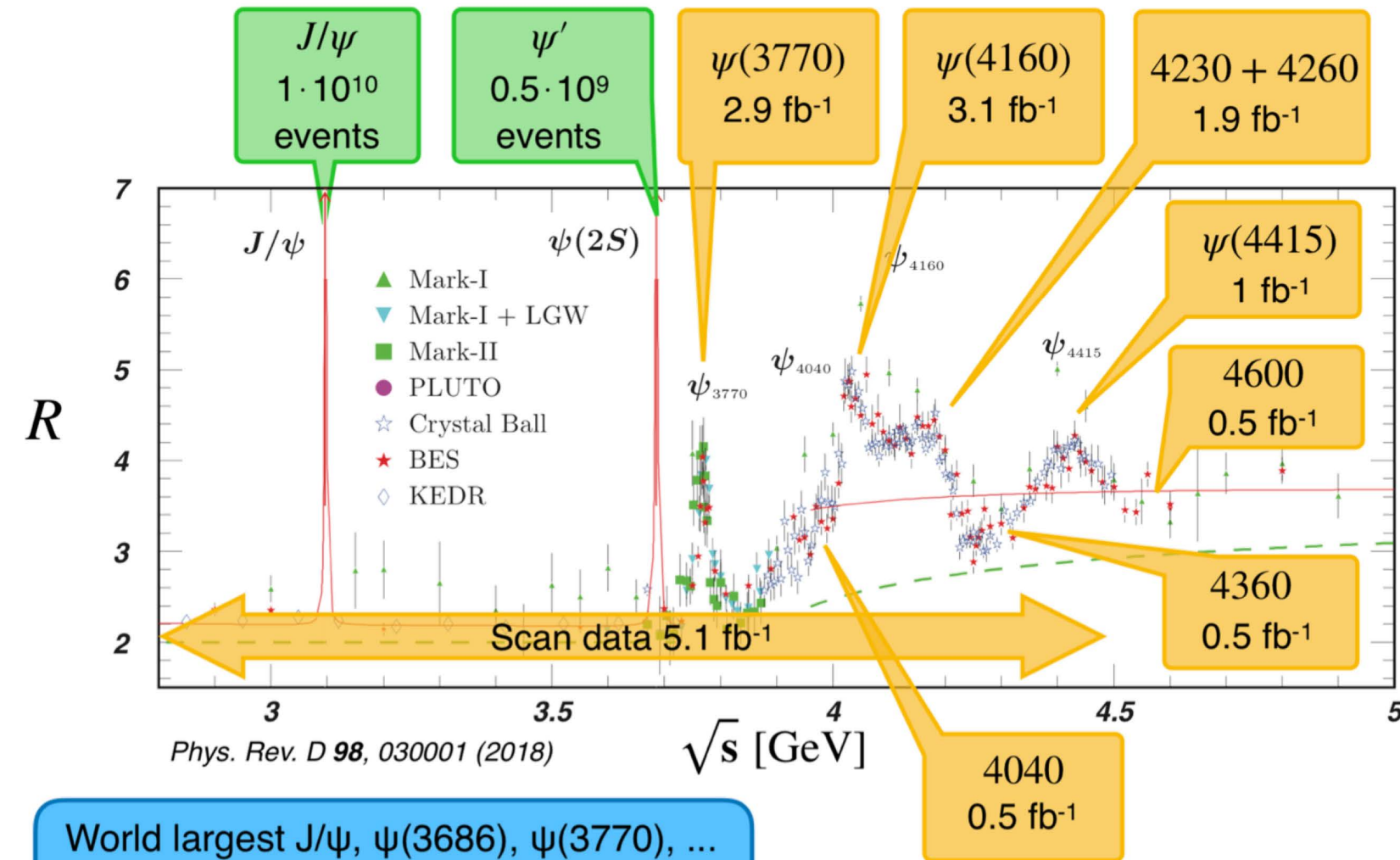
- Symmetric, double rings e^+e^- collider @ $\sqrt{s}=2-4.9\text{GeV}$
- Peak luminosity $\approx 10^{33}\text{cm}^{-2}\text{s}^{-1}$ at $\sqrt{s}=3.770\text{GeV}$
- Crab-Waist interaction scheme with the crossing angle of 11 mrad
- Top-up operation since 2018

BESIII detector



- **Acceptance: 93% of 4π**
- **Main Drift Chamber:** small cell & gas
 - ✓ $\sigma_{xy}=130\text{ }\mu\text{m}$, $\sigma_p/P=0.5\% @ 1\text{ GeV}$
 - ✓ $\sigma_{dE/dx}=6\%$
- **Time of Flight (TOF)**
 - ✓ $\sigma_T=70\text{ ps}$ for barrel layers
 - ✓ $\sigma_T=110\text{ ps}$ (65 ps with updated MRPC) for endcaps
- **Super Conducting Solenoid:** 1.0T (0.9T for 2012)
- **Electromagnetic Calorimeter:** CsI Crystals
 - ✓ $\sigma_E/E=2.5\% @ 1\text{ GeV}$
 - ✓ Position resolution 6mm@1GeV
- **RPC Muon ID:** 9 layer

Data set and Physics at BESIII



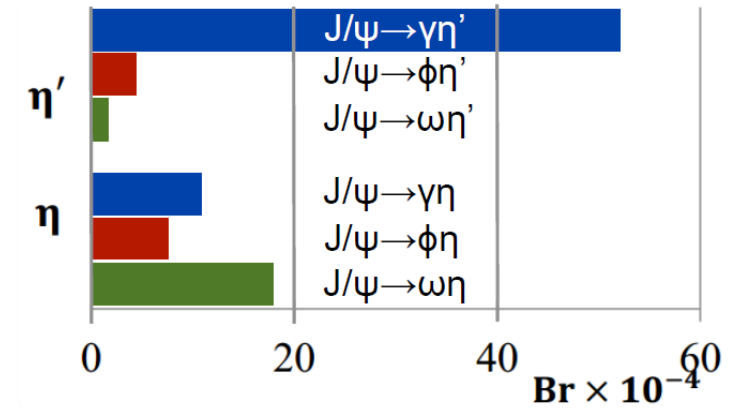
- Wide physics topics @ $\sqrt{s}=2-4.9\text{GeV}$
- Light hadron Physics
- Charmonium physics
- XYZ particles
- Discrete symmetries breaking
- Charm physics
- Physics with tau lepton
- R-value measurement
- ...

[Chin. Phys. C 44, 040001 \(2020\)](#)

η/η' sample from J/ψ decays at BESIII

- Understand the low energy QCD
- Test the predictions of ChPT
- Probe the u-d quark mass difference
- Search for discrete symmetries violation (CV, CPV) and test fundamental symmetries
- Probe physics beyond the SM

Why η/η' ???



- High production rate of η/η' in J/ψ decays
 - radiative decays: $5.2 \times 10^7 \eta'$, $1.1 \times 10^7 \eta$
 - hadronic decays: $6.5 \times 10^6 \eta'$, $2.5 \times 10^7 \eta$
- Unique opportunity to investigate the decays of η/η'

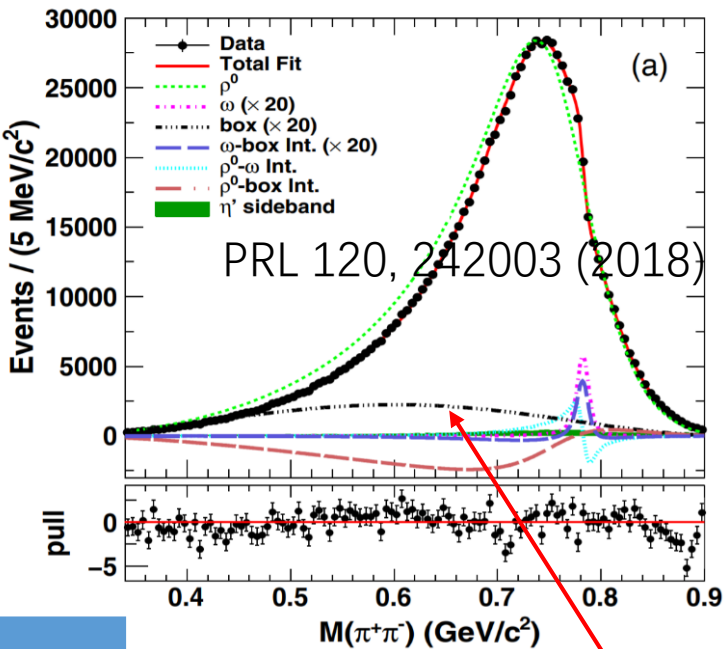
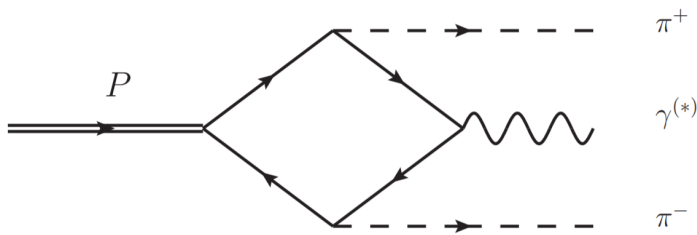
Fruitful achievements with
1.3 billion J/ψ events related
light meson decays

Hadronic decays
Radiative decays
Rare/forbidden decays

Decay channel	Physics	Publication
$\eta' \rightarrow 2(\pi^+\pi^-), \pi^+\pi^-\pi^0\pi^0$	First observation, BR	PRL112, 251801(2014)
$\eta' \rightarrow \gamma e^+e^-$	First observation, BR, TFF	PRD92, 012001(2015)
$\eta \rightarrow \pi^+\pi^-\pi^0, \eta/\eta' \rightarrow \pi^0\pi^0\pi^0$	Matrix elements, m_u-m_d , C-inv	PRD92, 012014(2015)
$\eta' \rightarrow \omega e^+e^-$	First observation, BR	PRD92, 051101(2015)
$\eta' \rightarrow K\pi$	Weak decay, UL	PRD93, 072008 (2016)
$\eta' \rightarrow \rho\pi$	First observation, BR	PRL118, 012001(2017)
$\eta' \rightarrow \gamma\gamma\pi^0$	BR, B boson	PRD96, 012005(2017)
$\eta' \rightarrow \gamma\pi^+\pi^-$	BR, decay dynamic (box anomaly)	PRL120, 242003(2018)
$\eta' \rightarrow \pi^+\pi^-\eta, \eta' \rightarrow \pi^0\pi^0\eta$	Matrix elements, cusp effect	PRD97, 012003(2018)
$\omega \rightarrow \pi^+\pi^-\pi^0$	Dalitz plot analysis	PRD98, 112007(2018)
$P \rightarrow \gamma\gamma$	BRs, chiral anomaly	PRD97, 072014(2018)
$\eta' \rightarrow \gamma\gamma\eta$	UL	PRD100, 052015(2019)
Absolute BF of η' decays	BRs	PRL122, 142002(2019)
$\eta' \rightarrow \pi^0\pi^0\pi^0\pi^0$	CP-vio, UL	PRD101, 032001(2020)
$\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$	BR, CP-viol assymm	PRD103, 092005(2021)
$\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$	BR, decay dynamic	PRD103, 072006(2021)
Absolute BF of η decays	BRs	arXiv:2109.12812

Study of $\eta' \rightarrow \pi^+ \pi^- \mu^+ \mu^-$ and $\eta' \rightarrow \pi^+ \pi^- e^+ e^-$

- $\eta' \rightarrow \pi^+ \pi^- l^+ l^-$ has similar structure of $\eta' \rightarrow \pi^+ \pi^- \gamma$, replacing the γ with an off-shell one that decays into a lepton pair
- Contributions from the box anomaly proceed



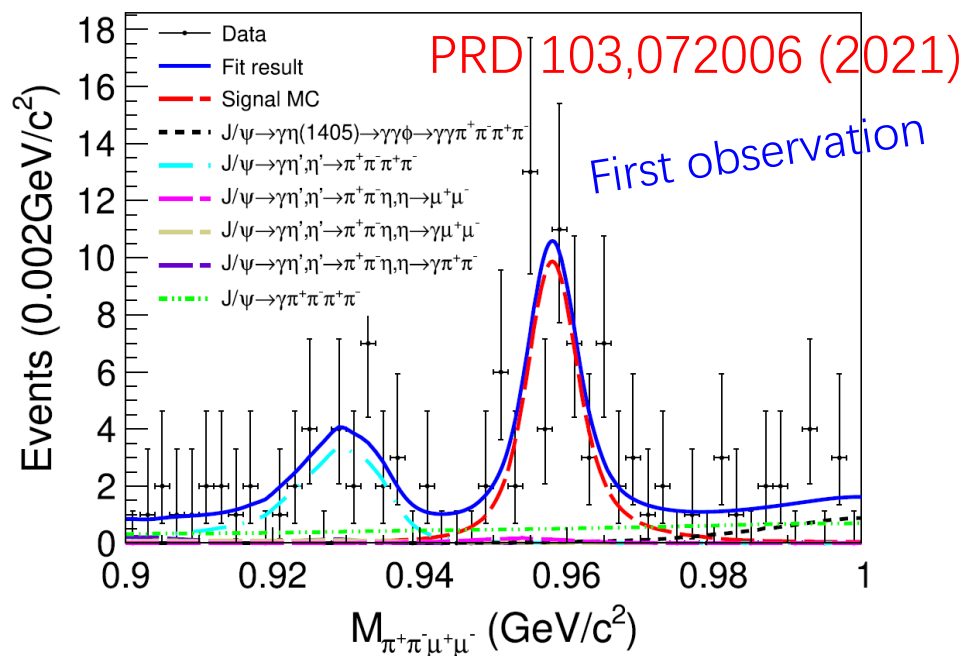
	hidden gauge Model	modified VMD	chiral unitary approach
$\text{Br}(\eta' \rightarrow \pi^+ \pi^- e^+ e^-)$	$(2.17 \pm 0.21) \times 10^{-3}$	$(2.27 \pm 0.13) \times 10^{-3}$	$(2.13^{+0.17}_{-0.31}) \times 10^{-3}$
$\text{Br}(\eta' \rightarrow \pi^+ \pi^- \mu^+ \mu^-)$	$(2.20 \pm 0.30) \times 10^{-5}$	$(2.41 \pm 0.25) \times 10^{-5}$	$(1.57^{+0.96}_{-0.75}) \times 10^{-5}$

Thimo Petri, arXiv: 1010.2378

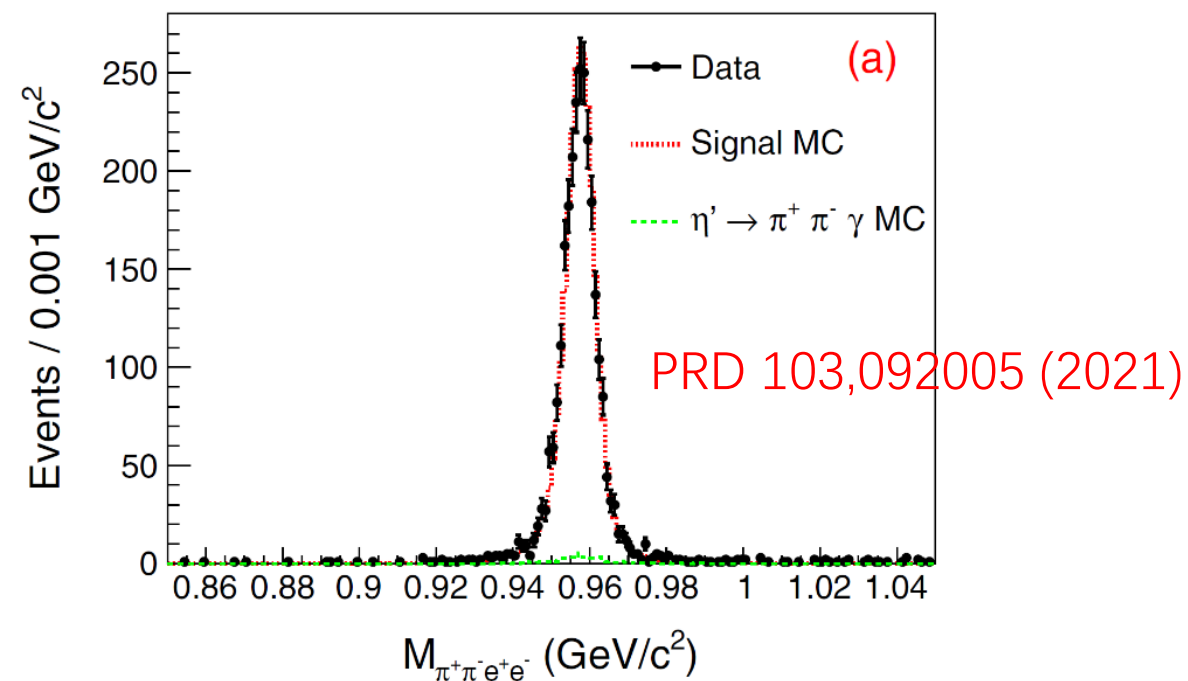
B. Borasoy, R. Nissler, EPJA 33(2007) 95

Study of $\eta' \rightarrow \pi^+ \pi^- \mu^+ \mu^-$ and $\eta' \rightarrow \pi^+ \pi^- e^+ e^-$

- 1.31×10^9 J/ψ are used to search for those decay via $J/\psi \rightarrow \gamma \eta'$



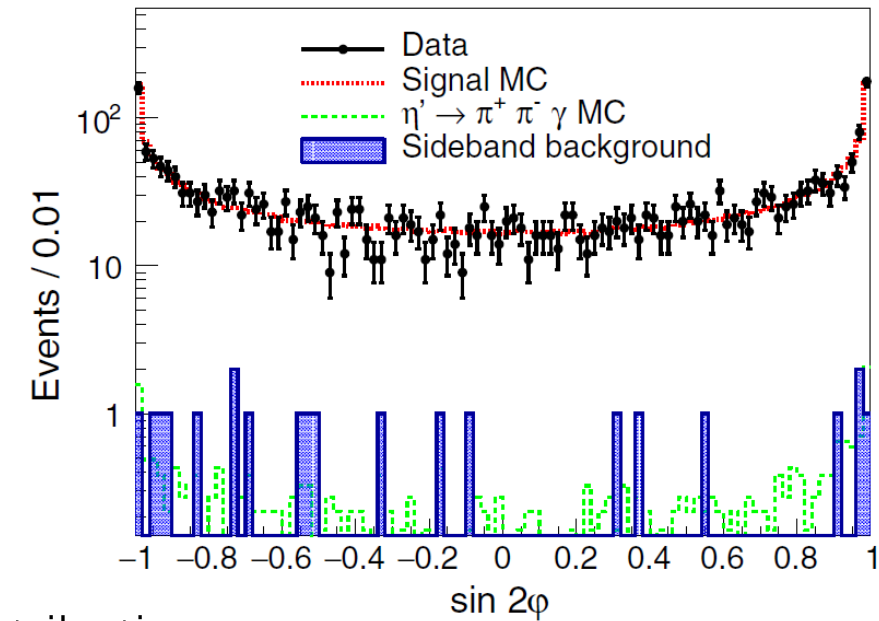
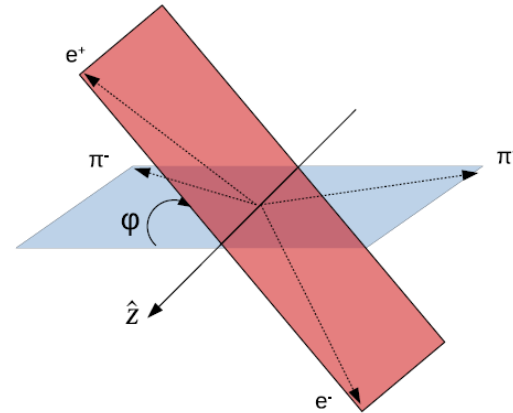
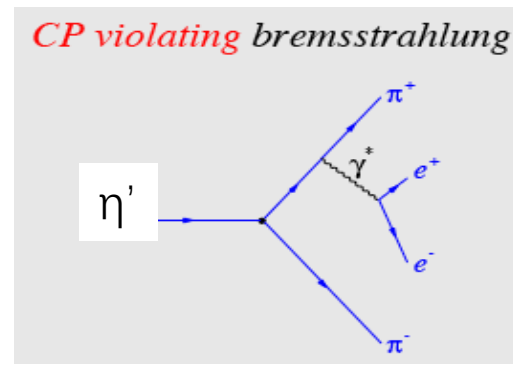
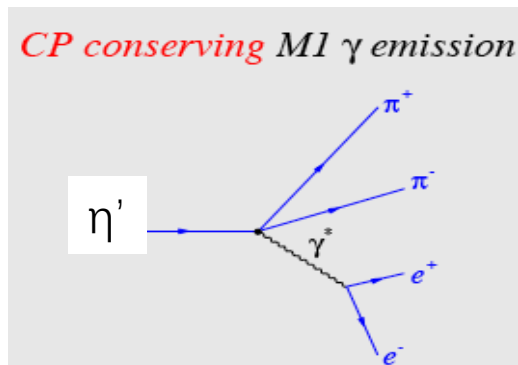
$$\mathcal{B}(\eta' \rightarrow \pi^+ \pi^- \mu^+ \mu^-) = (1.97 \pm 0.33(\text{stat}) \pm 0.19(\text{syst})) \times 10^{-5}$$



$$\mathcal{B}(\eta' \rightarrow \pi^+ \pi^- e^+ e^-) = (2.42 \pm 0.05(\text{stat}) \pm 0.08(\text{syst})) \times 10^{-3}$$

CP violation in $\eta' \rightarrow \pi^+ \pi^- e^+ e^-$

- A new sources of CP violation beyond the CKM phase and outside flavor-changing processes



[Dao-Neng Gao, Mod.Phys.Lett.A17 (2002) 1583]

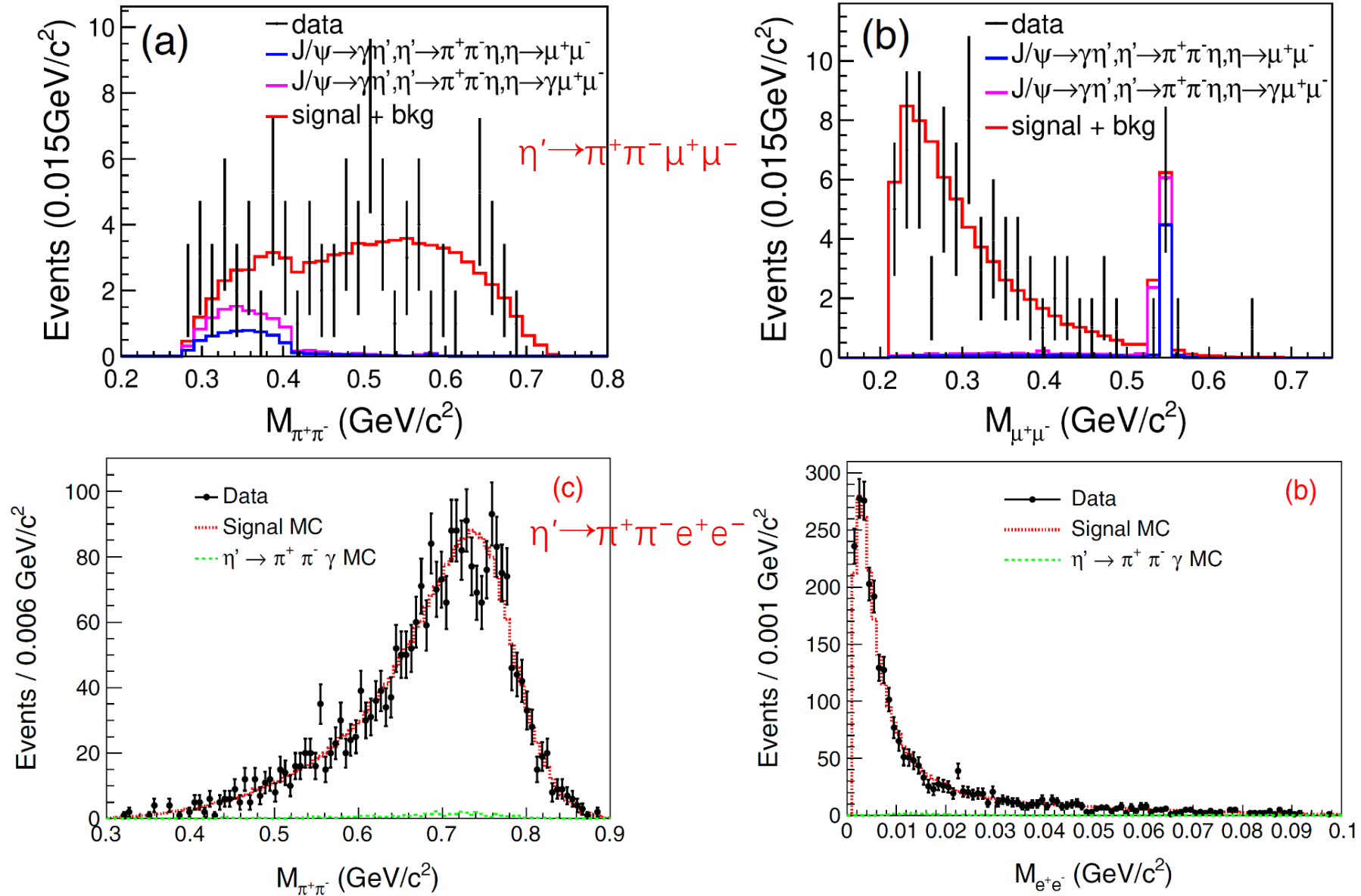
The interference term can be extracted by the asymmetry of $\sin 2\phi$ distribution

$$\mathcal{A}_\phi = \frac{N(\sin 2\phi > 0) - N(\sin 2\phi < 0)}{N(\sin 2\phi > 0) + N(\sin 2\phi < 0)} = (2.9 \pm 3.7_{\text{stat}} \pm 1.1_{\text{syst}})\%$$

PRD 103,092005 (2021)

Consistent with 0 within uncertainties, no CP-violation.

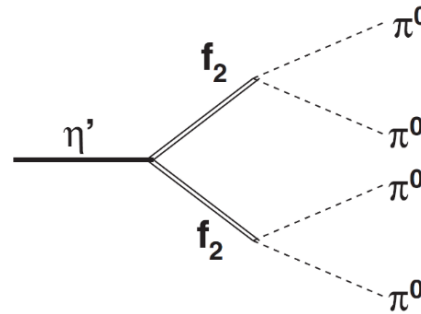
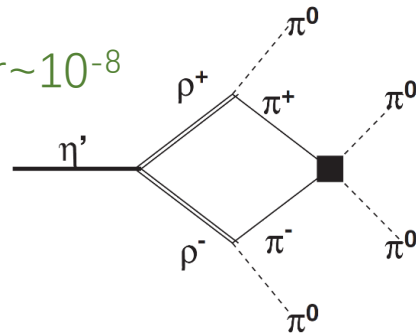
With future high statistics, possible to access the transition form factor



The rare decay of $\eta' \rightarrow \pi^0 \pi^0 \pi^0 \pi^0$

- CP-violation S-wave, induced by the QCD Lagrangian θ -term $\Rightarrow \text{Br} \sim 10^{-23}$
- CP-conserving higher order [F.K. Guo, B. Kubis, A. Wirzba, Phys. Rev. D 85,014014 \(2012\)](#)

D-wave pion loop $\Rightarrow \text{Br} \sim 10^{-8}$

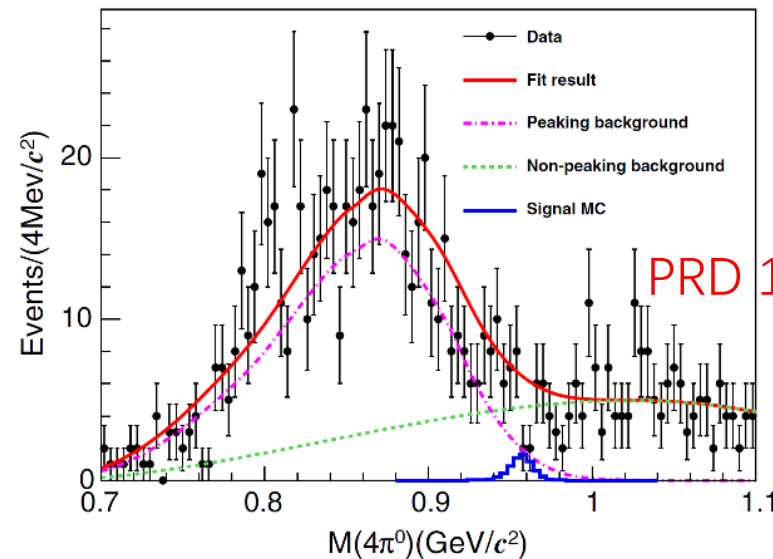


Small contribution from two f_2 tensor mesons

- 1.31×10^9 J/ ψ are used to search for this decay

the UL at 90% CL is set as:

$$\mathcal{B}(\eta' \rightarrow 4\pi^0) < 4.94 \times 10^{-5}$$



PRD 101,032001(2020)

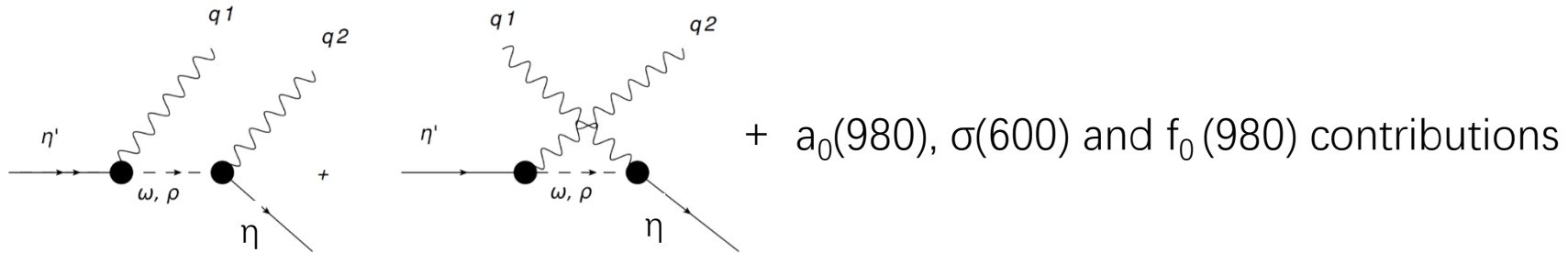
With 10 Billion J/ ψ , the UL is expected to reach 1.7×10^{-5} @ 90% C.L.

Doubly radiative decay $\eta' \rightarrow \gamma\gamma\eta$

- Within the frameworks of the linear σ model (L σ M) and VMD model

✓ $\text{BF}(\eta' \rightarrow \gamma\gamma\pi^0) = 2.91(21) \times 10^{-3}$ and $\text{BF}(\eta' \rightarrow \gamma\gamma\eta) = 1.17(8) \times 10^{-4}$

R. Escribano, and S. Gonzalez-Solis, R. Jora and E. Royo, PRD 102, 034026 (2020)



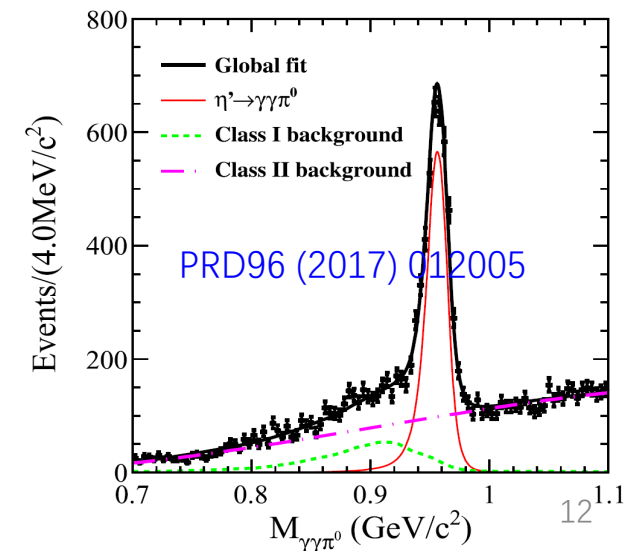
- ✓ With 1.31×10^9 J/ ψ , BESIII reported the first observation of $\eta' \rightarrow \gamma\gamma\pi^0$

$\text{BF}(\eta' \rightarrow \gamma\gamma\pi^0) = (32.0 \pm 0.7 \pm 2.3) \times 10^{-4}$

The branching fractions of the dominant process $\eta' \rightarrow \gamma\omega$

$\mathcal{B}(\eta' \rightarrow \gamma\omega) \times \mathcal{B}(\omega \rightarrow \gamma\pi^0) = (23.7 \pm 1.4(\text{stat}) \pm 1.8(\text{syst})) \times 10^{-4}$

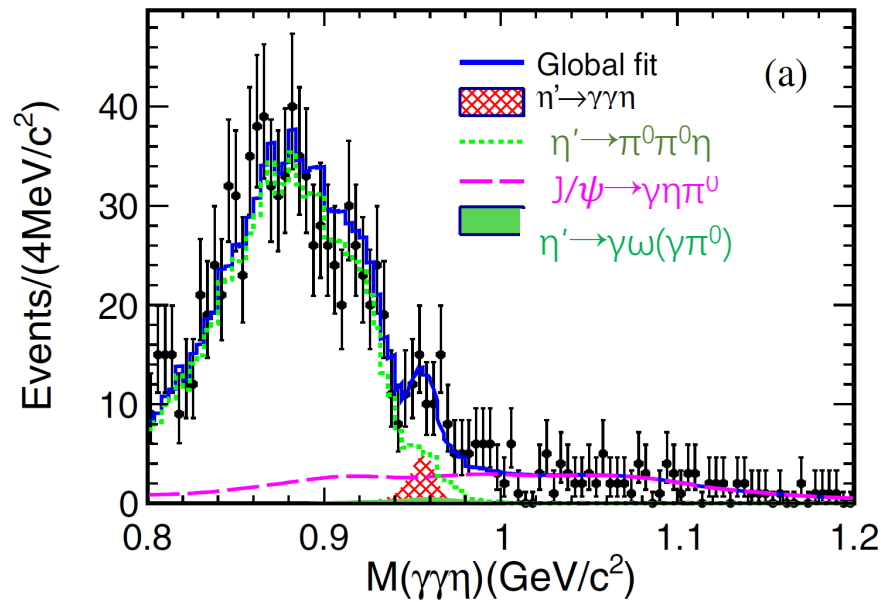
$\text{BF}(\eta' \rightarrow \gamma\gamma\pi^0)_{\text{NR}} = (6.16 \pm 0.64 \pm 0.67) \times 10^{-4}$



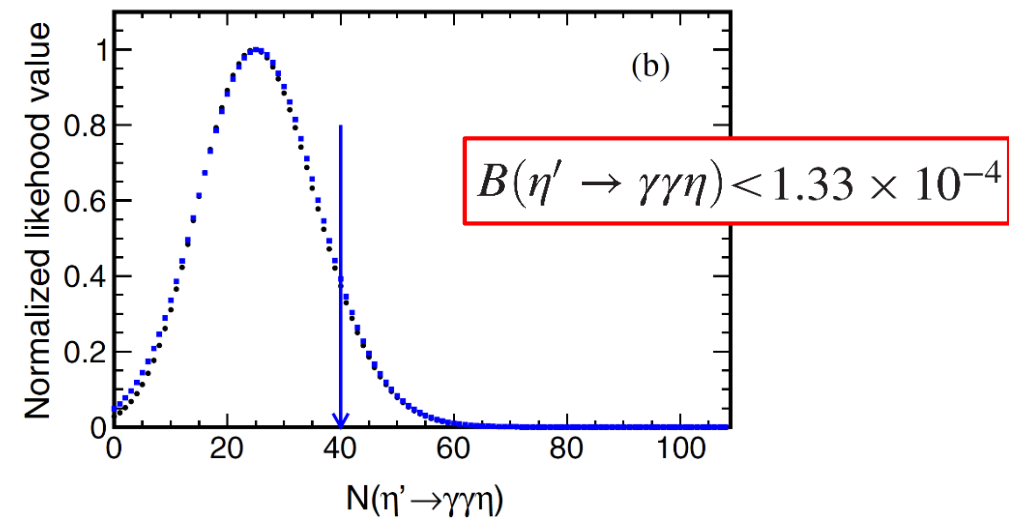
Doubly radiative decay $\eta' \rightarrow \gamma\gamma\eta$

PRD 100, 052015 (2019)

- 1.31×10^9 J/ψ sample used to search for this decay via $J/\psi \rightarrow \gamma\eta'$ and $\eta \rightarrow \gamma\gamma$
- A global fit yields 24.9 ± 10.3 $\eta' \rightarrow \gamma\gamma\eta$ signal events with a statistical significance of 2.6σ



An UL at 90% CL is also set by Bayesian approach:

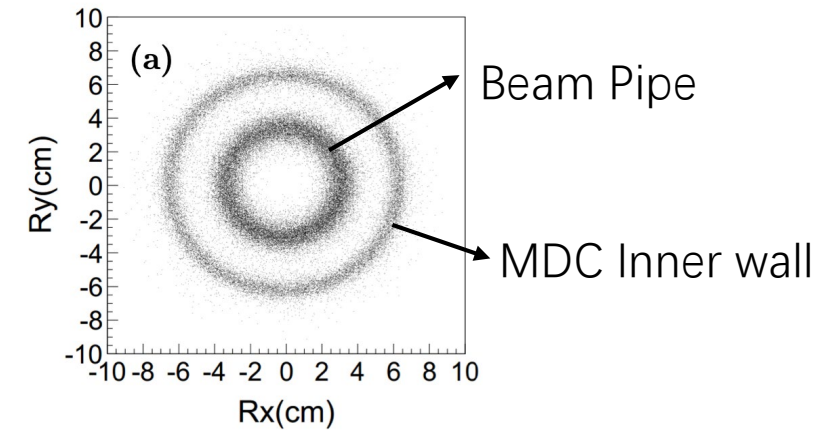
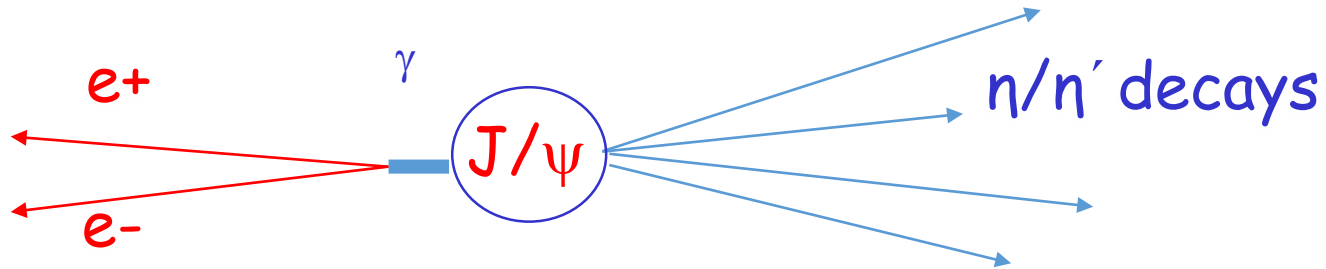


$$B(\eta' \rightarrow \gamma\gamma\eta) = (8.25 \pm 3.41 \pm 0.72) \times 10^{-5}$$

With 10 Billion J/ψ , the existence of this decay can be established

γ conversion: η/η' inclusive decays

- No absolute BF measurements of η/η' due to difficulty of tagging its inclusive decays



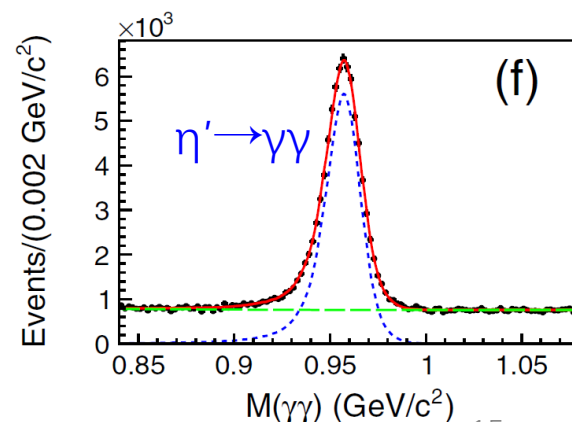
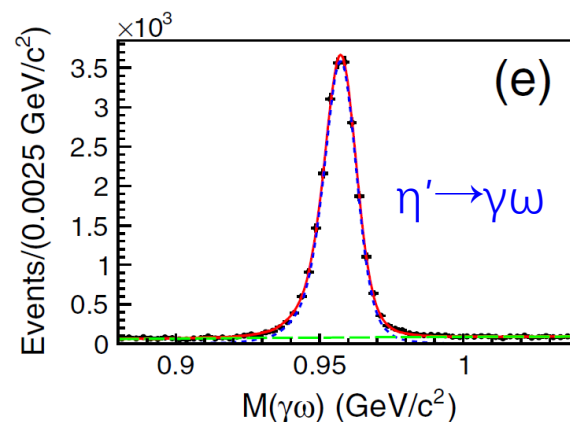
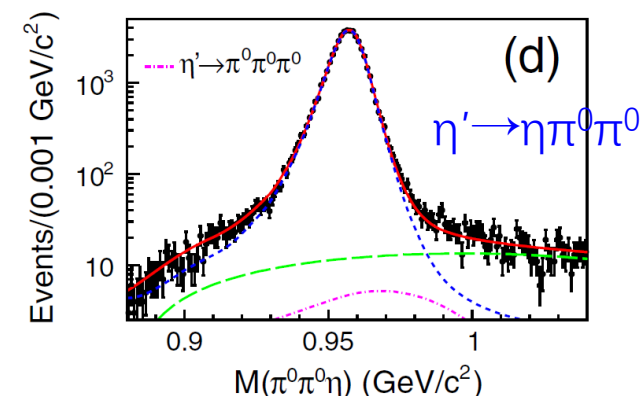
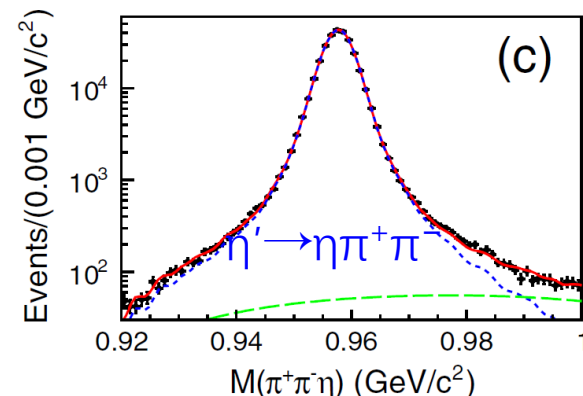
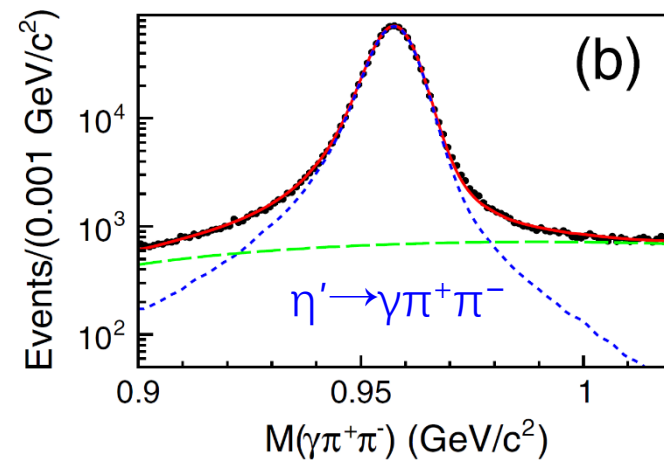
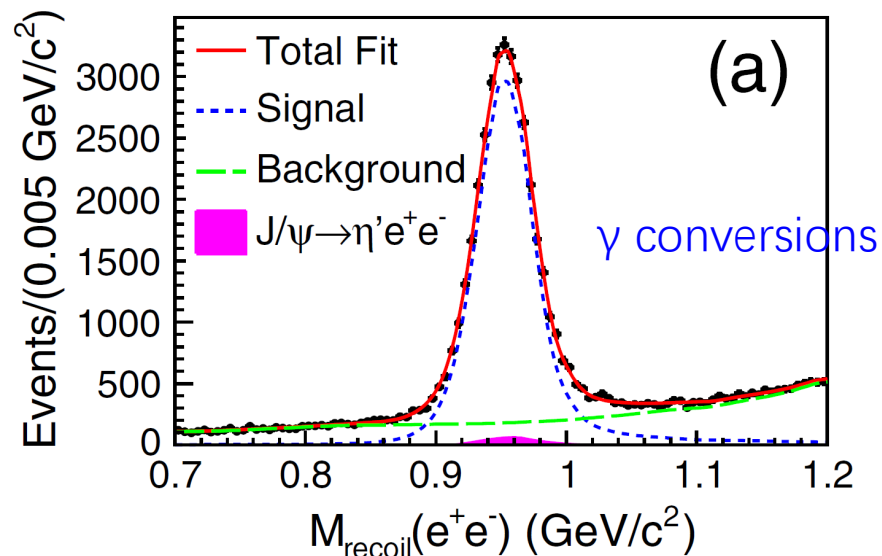
$$\mathcal{B}(\eta' \rightarrow X) = \frac{N_{\eta' \rightarrow X}^{\text{obs}}}{\epsilon_{\eta' \rightarrow X}} \frac{\epsilon}{N_{J/\psi \rightarrow \gamma \eta'}^{\text{obs}}}$$

Full reconstruction with the radiative γ directly detected by EMC

using γ conversions to tag η/η'

Absolute BFs of η' decays

PRL122, 142002 (2019)

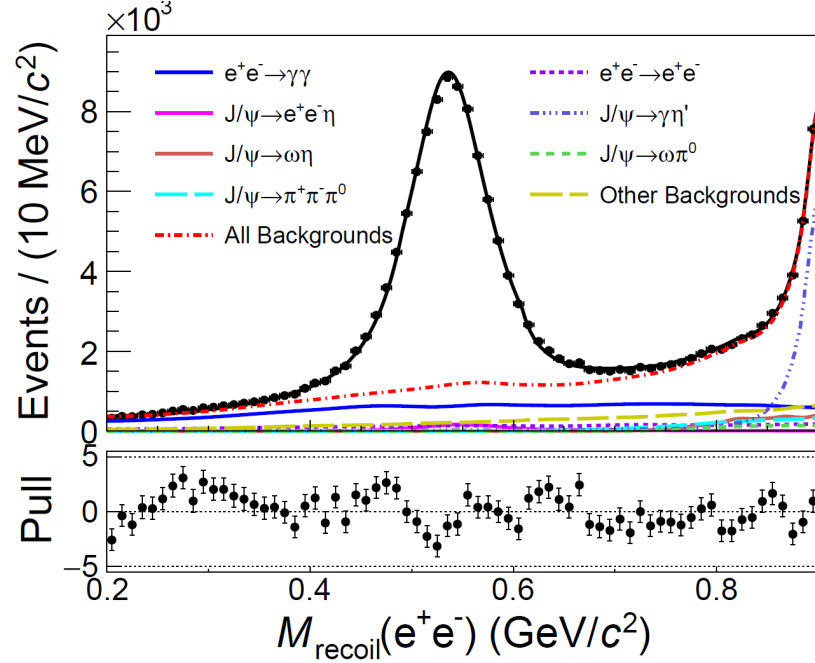


$\mathcal{B}(\eta' \rightarrow X)(\%)$		
Decay mode	This measurement	PDG [7]
$\eta' \rightarrow \gamma \pi^+ \pi^-$	$29.90 \pm 0.03 \pm 0.55$	28.9 ± 0.5
$\eta' \rightarrow \eta \pi^+ \pi^-$	$41.24 \pm 0.08 \pm 1.24$	42.6 ± 0.7
$\eta' \rightarrow \eta \pi^0 \pi^0$	$21.36 \pm 0.10 \pm 0.92$	22.8 ± 0.8
$\eta' \rightarrow \gamma \omega$	$2.489 \pm 0.018 \pm 0.074$	2.62 ± 0.13
$\eta' \rightarrow \gamma \gamma$	$2.331 \pm 0.012 \pm 0.035$	2.22 ± 0.08

$$\text{BF}(J/\psi \rightarrow \gamma \eta') = (5.27 \pm 0.03 \pm 0.05) \times 10^{-3}$$

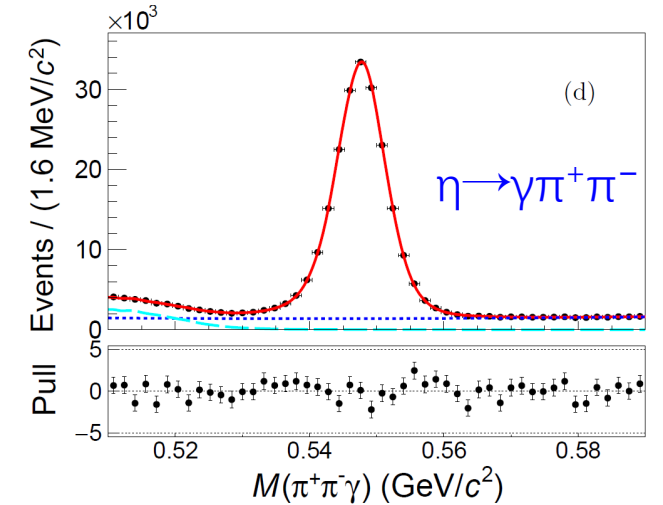
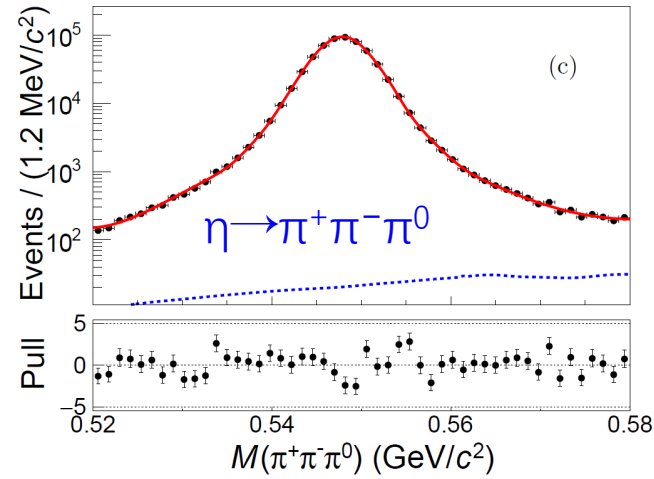
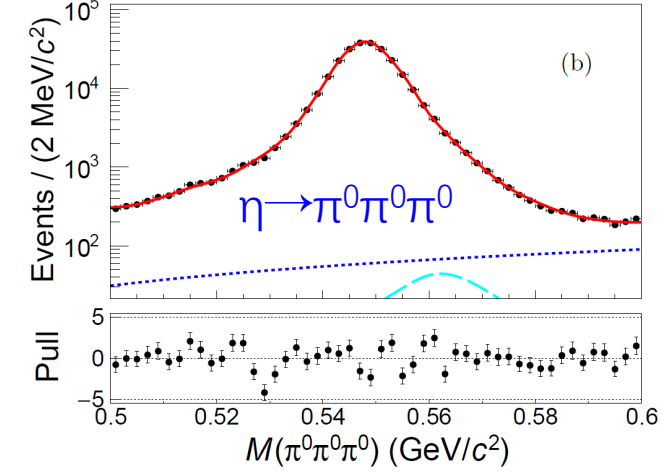
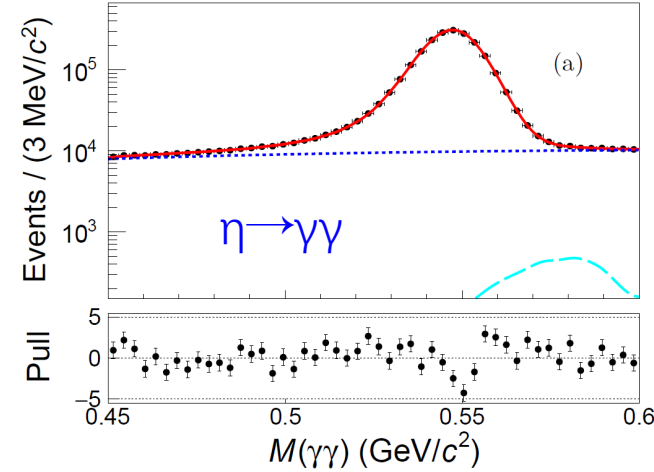
Absolute BFs of η decays

arXiv:2109.12812, Accepted by PRD



X	$\mathcal{B}(\eta \rightarrow X) (\%)$		
	This Work	CLEO	PDG
$\gamma\gamma$	$39.86 \pm 0.04 \pm 0.99$	$38.45 \pm 0.40 \pm 0.36$	39.41 ± 0.20
$\pi^0\pi^0\pi^0$	$31.96 \pm 0.07 \pm 0.84$	$34.03 \pm 0.56 \pm 0.49$	32.68 ± 0.23
$\pi^+\pi^-\pi^0$	$23.04 \pm 0.03 \pm 0.54$	$22.60 \pm 0.35 \pm 0.29$	22.92 ± 0.28
$\pi^+\pi^-\gamma$	$4.38 \pm 0.02 \pm 0.10$	$3.96 \pm 0.14 \pm 0.14$	4.22 ± 0.08

$$\text{BF}(J/\psi \rightarrow \gamma\eta) = (1.067 \pm 0.005 \pm 0.023) \times 10^{-3}$$



Conclusion

- J/ψ decay provides a unique laboratory to study light meson decays
- With 2009+2012 J/ψ data (1.3 Billion), BESIII Collaboration produced fruitful results related light meson decays
 - Study of $\eta' \rightarrow \pi^+ \pi^- \mu^+ \mu^-$ and $\eta' \rightarrow \pi^+ \pi^- e^+ e^-$
 - Rare decays $\eta' \rightarrow \pi^0 \pi^0 \pi^0 \pi^0$ and of $\eta' \rightarrow \gamma \gamma \eta$
 - Precision measurement of the BF's of η/η' decays
 - ... and many other interesting results not covered in this talk
- And now to 10 Billion J/ψ events collected at BESIII
 - A unique worldwide sample, allows to study light mesons with the unprecedented statistics
 - More interesting results are foreseen

Thanks for your attention!!!