Light Meson Decays at BESIII

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OUTLINE

- Light meson physics
- Recent results on η/η' decays
  - Observation of $\eta' \to \pi^+\pi^-\mu^+\mu^-$
  - Observation of $\eta' \to e^+e^-e^+e^-$
  - Evidence of the cusp effect in $\eta' \to \pi^0\pi^0\eta$
  - Search for $\eta' \to 4\pi^0$
  - BFs of η/η' decays via gamma conversion
- Summary

Light Meson Physics

- **Light mesons**
  - important roles in particle physics, e.g. strong interactions, Quark Model, CP violation …
- **Rich physics in the light meson decays**
  - test ChPT predictions
  - Form factors
  - Test fundamental symmetries
  - Probe new physics beyond the SM

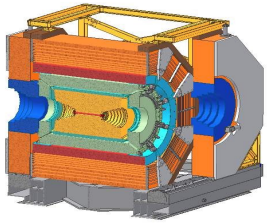
Source of η/η′ events

CLAS(12)

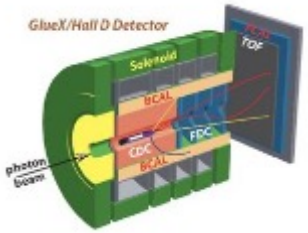
Crystal Ball

WASA-at-COSY

KLOE-2

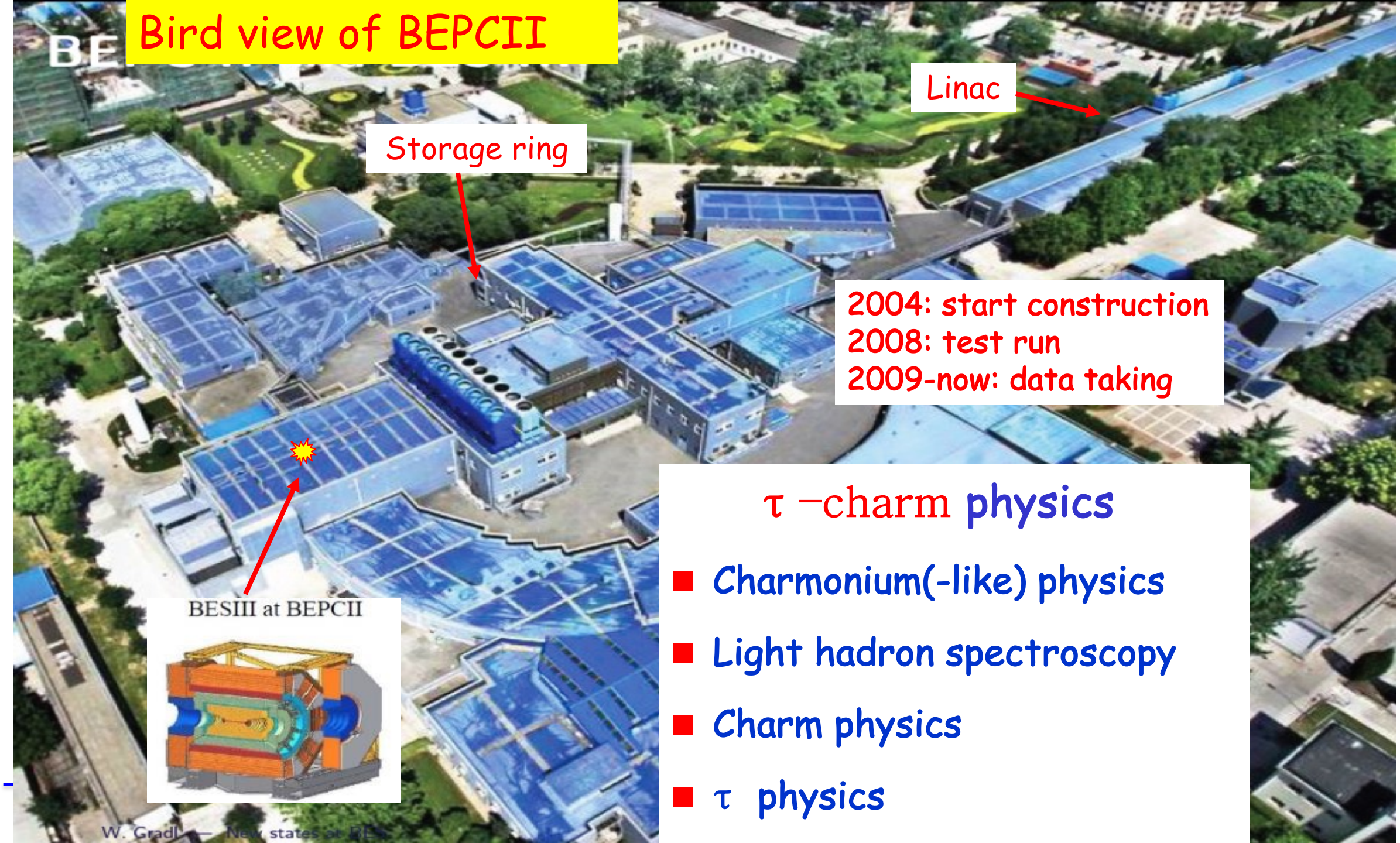


BESIII



GlueX

Bird view of BEPCII



2004: start construction
2008: test run
2009-now: data taking

τ –charm physics

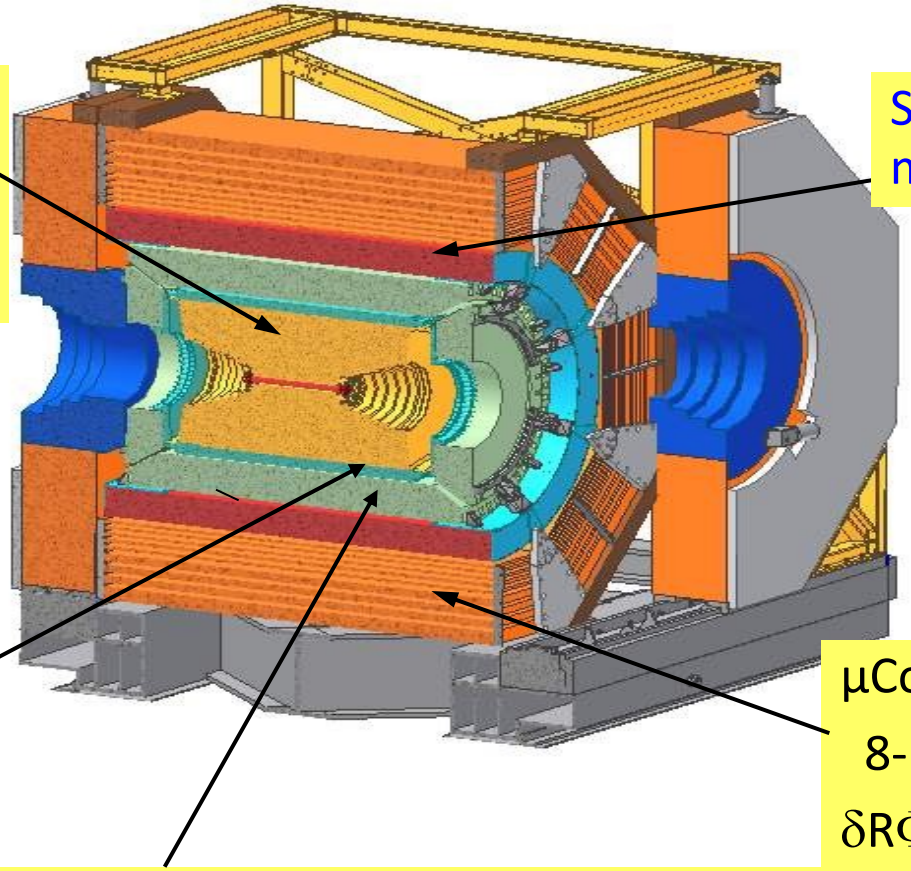
- Charmonium(-like) physics
- Light hadron spectroscopy
- Charm physics
- τ physics

The BESIII Detector

Drift Chamber (MDC)

$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)

$\sigma_{dE/dx}$ ($^0/_0$) = 6%



Super-conducting magnet (1.0 tesla)

Time Of Flight (TOF)

σ_T : 90 ps Barrel

110 ps endcap

μCounter

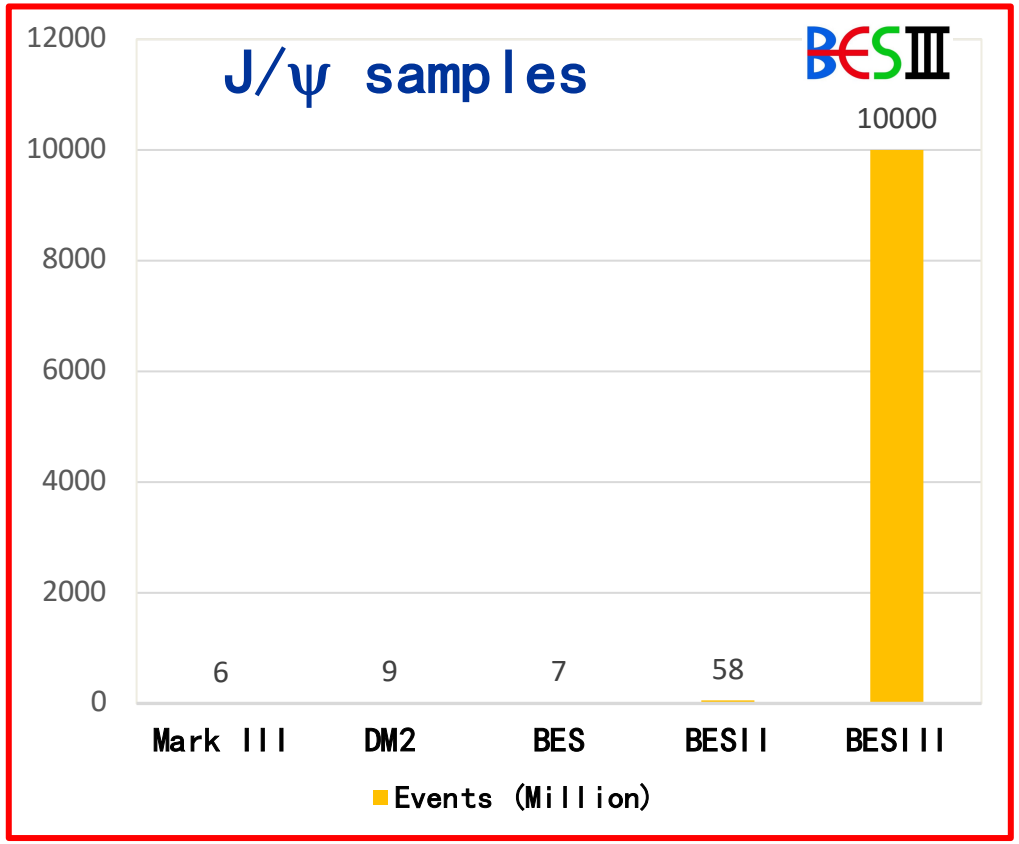
8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)

(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

η/η′ decays at BESIII



- 10 billion J/ψ events available
- BESIII: a light meson factory

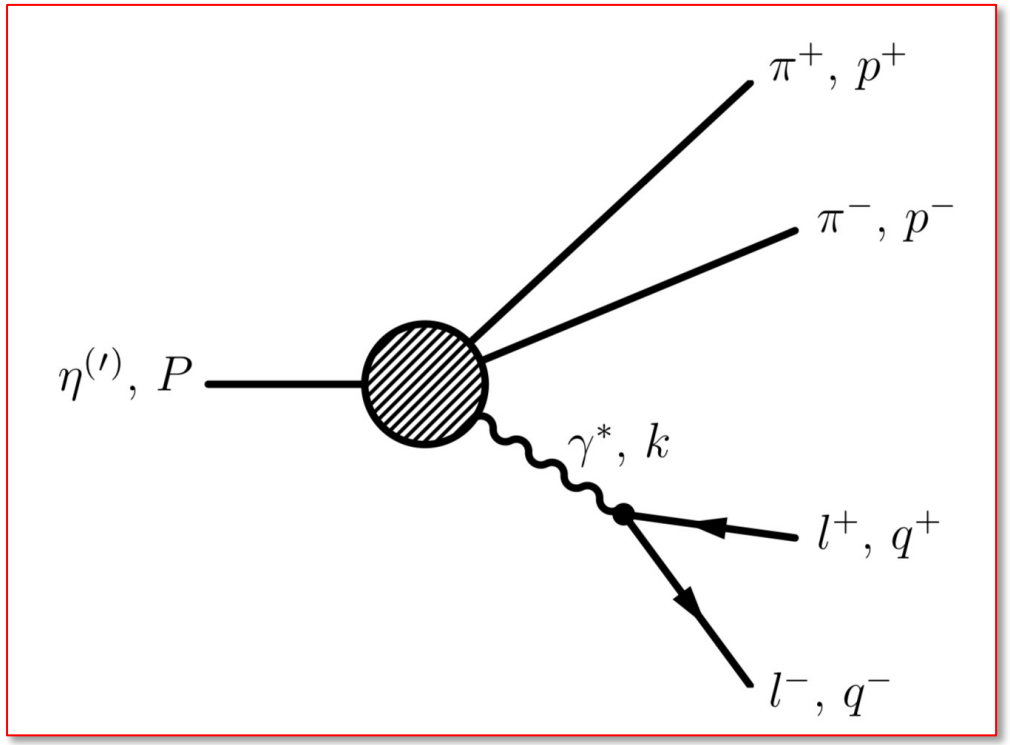
- $J/\psi \to \gamma\eta/\eta'$ → 1×10^7 η, 5.2×10^7 η′
- $J/\psi \to \phi\eta/\eta'$ → 4×10^6 η, 2.5×10^6 η′

η/η′ decays at BESIII

Hadronic decays
Radiative decays
Rare/forbidden decays

Decay channel	Physics	Publication
$\eta' \to 2(\pi^+\pi^-)$, $\pi^+\pi^-\pi^0\pi^0$	First observation, BR	PRL112, 251801(2014)
$\eta' \to \gamma e^+e^-$	First observation, BR, TFF	PRD92, 012001(2015)
$\eta \to \pi^+\pi^-\pi^0$, $\eta/\eta' \to \pi^0\pi^0\pi^0$	Matrix elements, m_u-m_d	PRD92, 012014(2015)
$\eta' \to \omega e^+e^-$	First observation, BR	PRD92, 051101(2015)
$\eta' \to K\pi$	Weak decay, UL	PRD93, 072008 (2016)
$\eta' \to \rho\pi$	First observation, BR	PRL118, 012001(2017)
$\eta' \to \gamma\gamma\pi^0$	BR, B boson	PRD96, 012005(2017)
$\eta' \to \gamma\pi^+\pi^-$	BR, box anomaly	PRL120, 242003(2018)
$\eta' \to \pi^+\pi^-\eta$, $\eta' \to \pi^0\pi^0\eta$	Matrix elements, cusp effect	PRD97, 012003(2018)
$\omega \to \pi^+\pi^-\pi^0$	Dalitz plot analysis	PRD98, 112007(2018)
$P \to \gamma\gamma$	BRs, chiral anomaly	PRD97, 072014(2018)
$\eta' \to \gamma\gamma\eta$	UL	PRD100, 052015(2019)
Absolute BF of η′ decays	BRs	PRL122, 142002(2019)
$\eta' \to \pi^0\pi^0\pi^0\pi^0$	CP-violation, UL	PRD101, 032001(2020)
$\eta' \to \pi^+\pi^-e^+e^-$	BR, CP-viol assymm	PRD103, 092005(2021)
$\eta' \to \pi^+\pi^-u^+u^-$	BR, decay dynamic	PRD103, 072006(2021)
Absolute BF of η decays	BRs	PRD104,092004(2021)
$\eta' \to \pi^0\pi^0\eta$	Cusp effect	arXiv:2207.01104

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

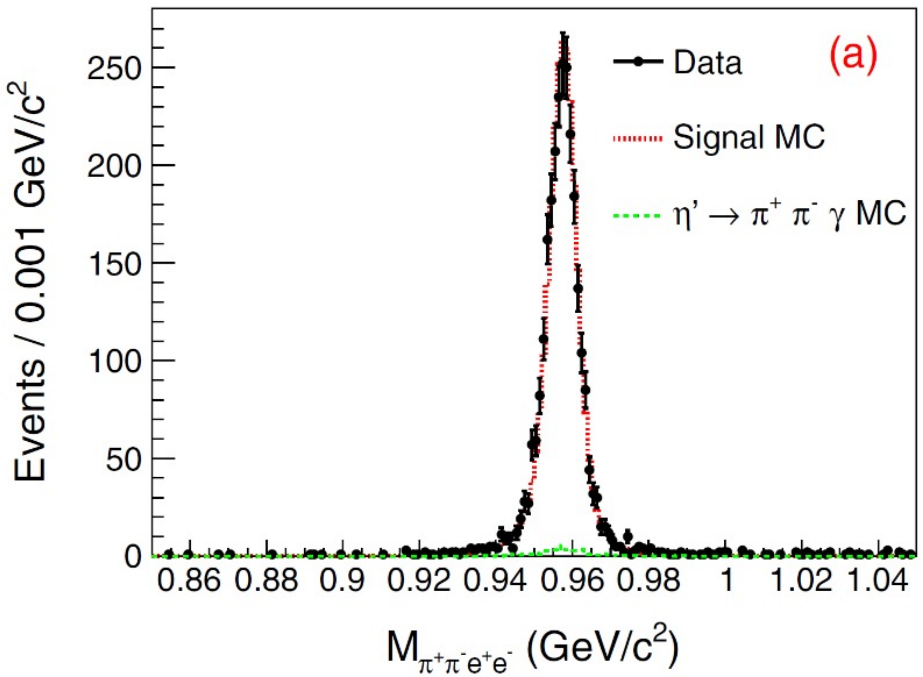


$\eta' \to \pi^+\pi^- l^+ l^-$ has similar structure of $\eta' \to \pi^+\pi^-\gamma$, replacing the γ with an off-shell one that decays into a lepton pair

- Box anomaly
- Form factor → $(g-2)_\mu$
- Test the CP symmetry

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

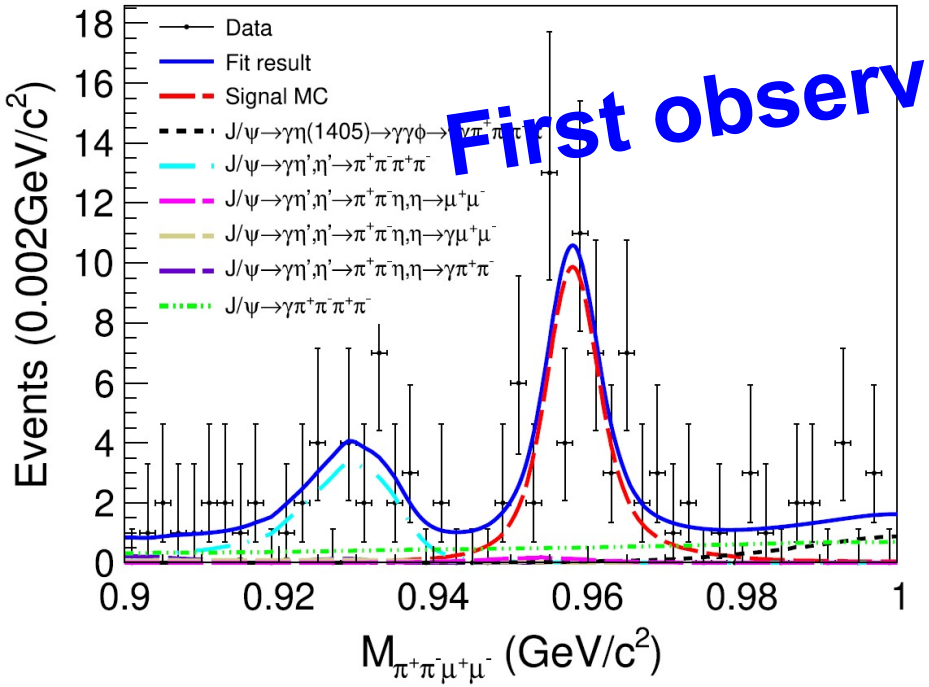
PRD103, 092005 (2021)



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

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

PRD103, 072006 (2021)



First observation

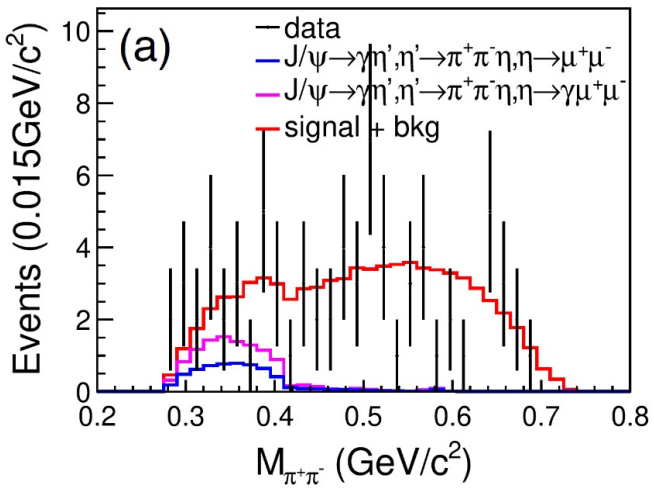
$$\mathcal{B}(\eta' \to \pi^+\pi^-\mu^+\mu^-) = (1.97 \pm 0.33(\text{stat}) \pm 0.19(\text{syst})) \times 10^{-5}$$

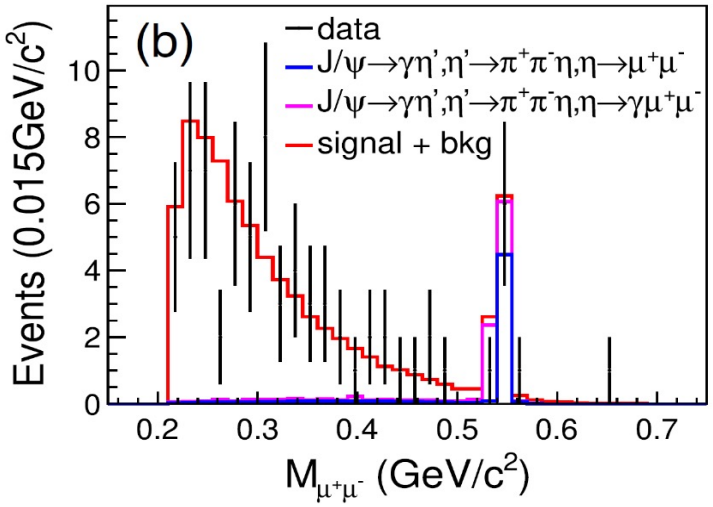
	hidden gauge Model	modified VMD	chiral unitary approach
Br ($\eta' \to \pi^+\pi^-e^+e^-$)	$(2.17 \pm 0.21) \times 10^{-3}$	$(2.27 \pm 0.13) \times 10^{-3}$	$(2.13^{+0.17}_{-0.31}) \times 10^{-3}$
Br($\eta' \to \pi^+\pi^-\mu^+\mu^-$)	$(2.20 \pm 0.30) \times 10^{-5}$	$(2.41 \pm 0.25) \times 10^{-5}$	$(1.57^{+0.96}_{-0.75})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

Thimo Petri, arXiv: 1010.2378

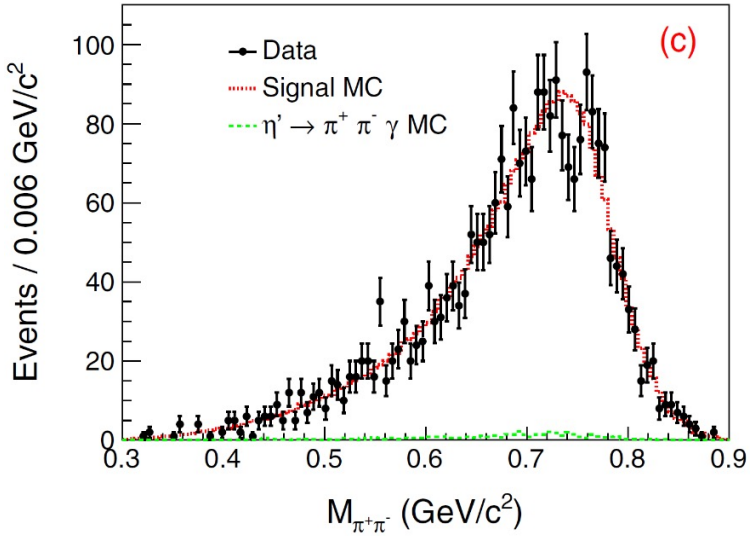
B. Borasoy, R. Nissler, EPJA 33(2007) 95

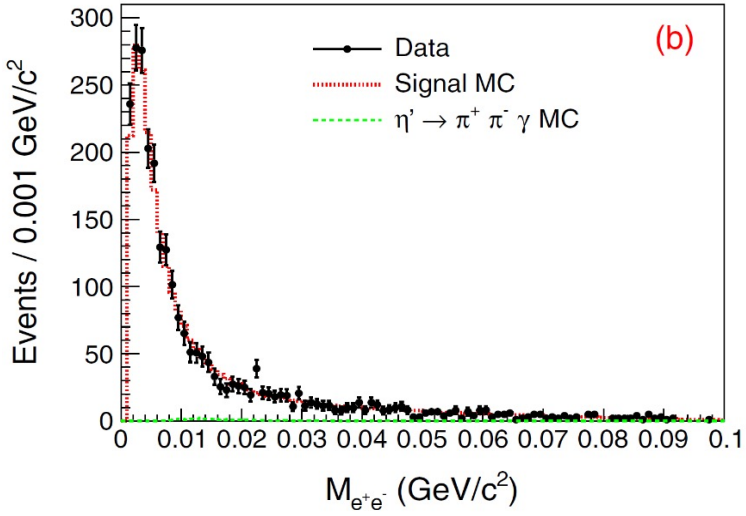
$\eta' \to \pi^+\pi^-\mu^+\mu^-$





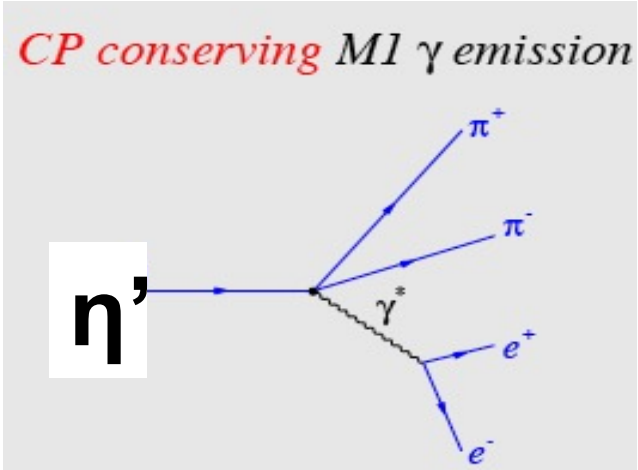
$\eta' \to \pi^+\pi^-e^+e^-$

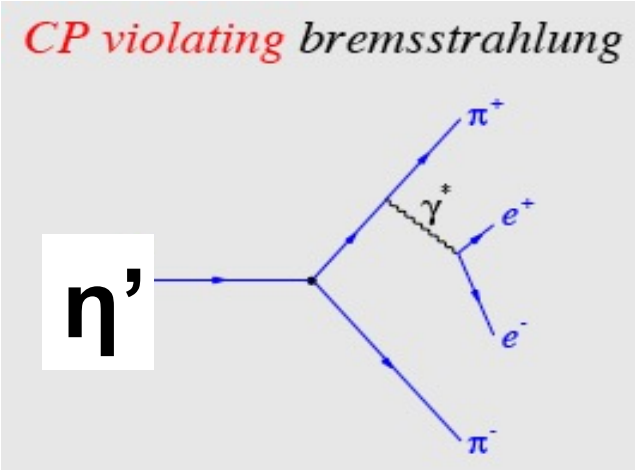


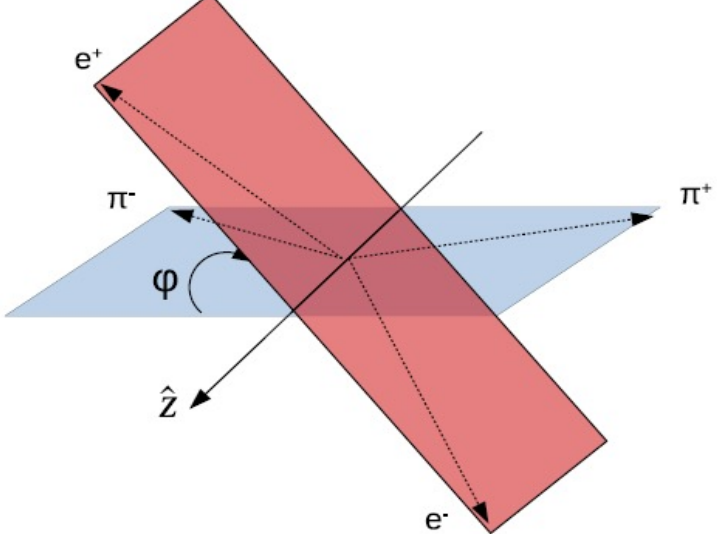


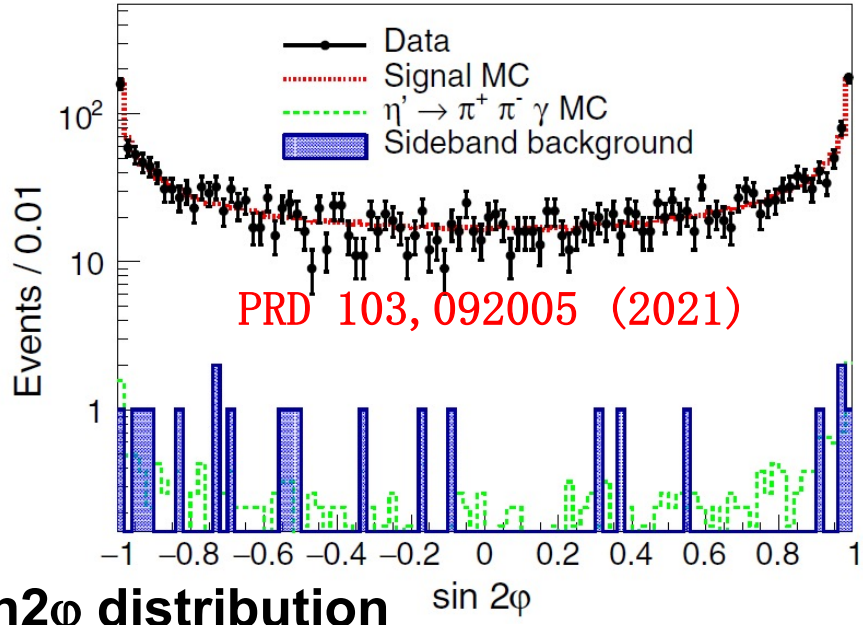
With high statistics of 10 bllion J/ψ events, possible to access the transition form factor

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









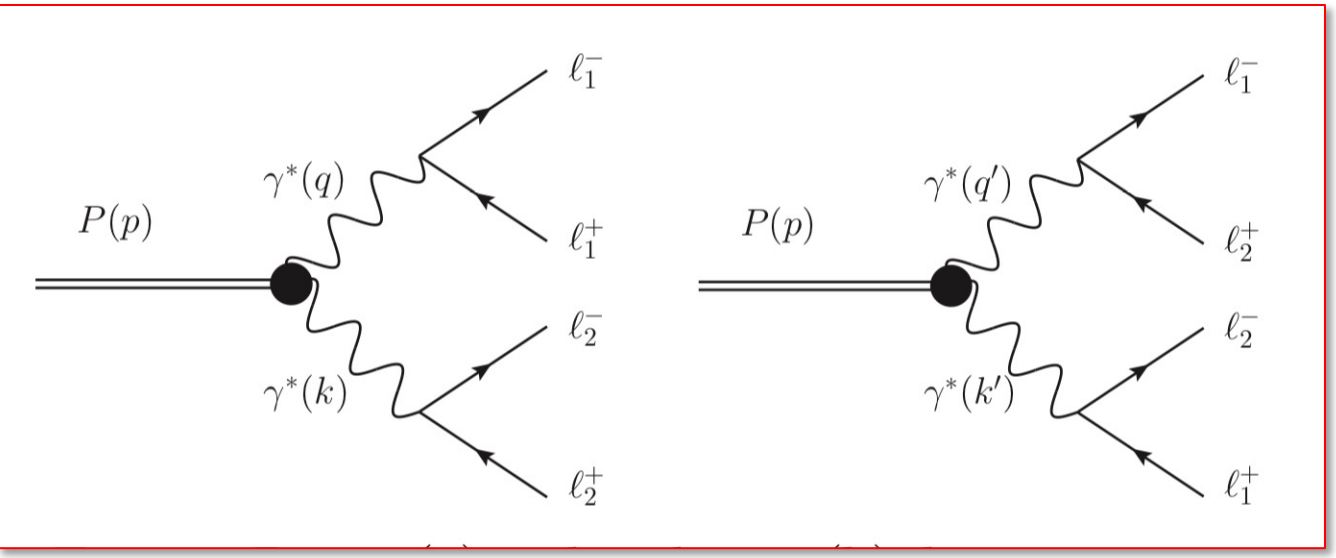
- **A new sources of CP violation outside flavor-changing processes**

The interference term can be extracted by the asymmetry of sin2φ distribution

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

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

$\eta' \to l^+ l^- l^+ l^-$



Thimo Petri, arXiv: 1010.2378

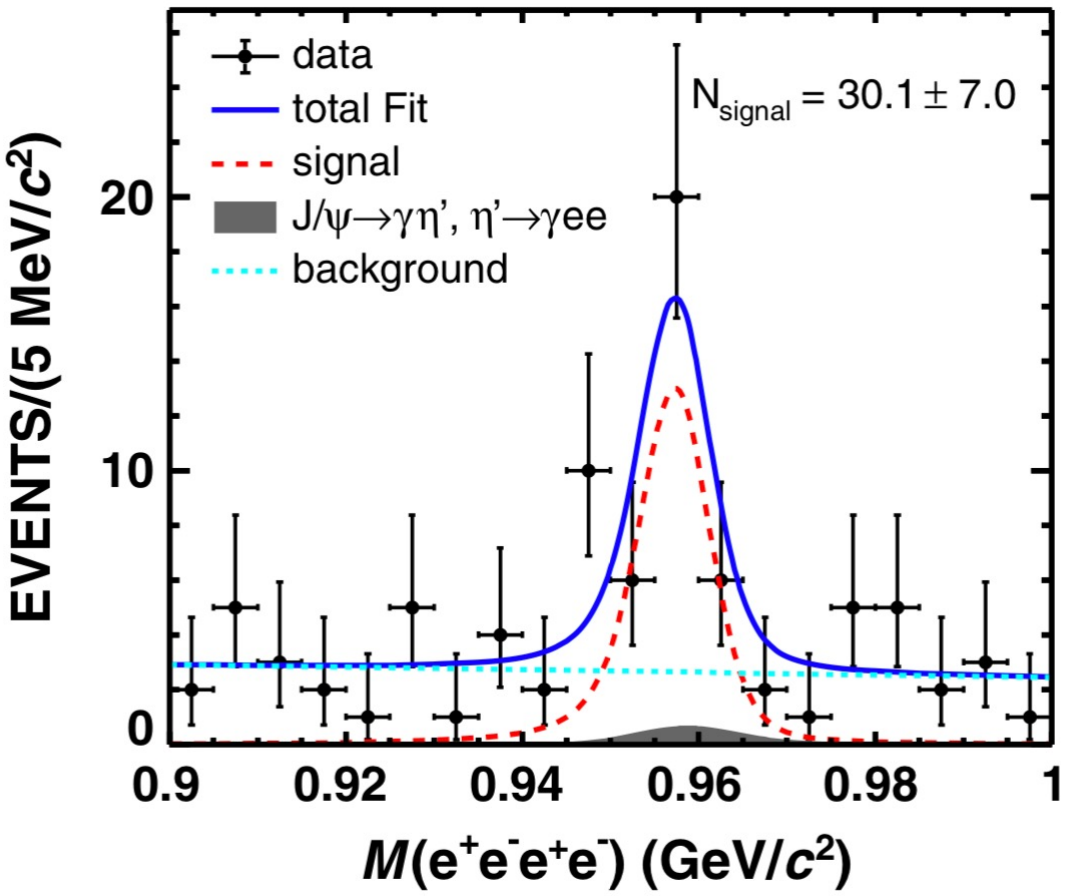
Chinese Physics C42 (2018) 023109

$\eta' \to e^+e^-e^+e^-$	$2.10(45)\times10^{-6}$
$\eta' \to \mu^+\mu^-\mu^+\mu^-$	$1.69(36)\times10^{-8}$
$\eta' \to e^+e^-\mu^+\mu^-$	$6.39(91)\times10^{-7}$

- Test the theoretical models
- Form factors→ $(g\text{-}2)_\mu$
- No experimental evidence yet!

Observation of $\eta' \to e^+e^-e^+e^-$

PRD 105, 112010(2022)



— Statistical significance 5.7σ

— BF in reasonable agreement with theoretical predictions

— insufficient for extraction of TFF

$$\mathcal{B}(\eta' \to e^+e^-e^+e^-) = (4.5 \pm 1.0(\text{stat}) \pm 0.5(\text{sys})) \times 10^{-6}$$

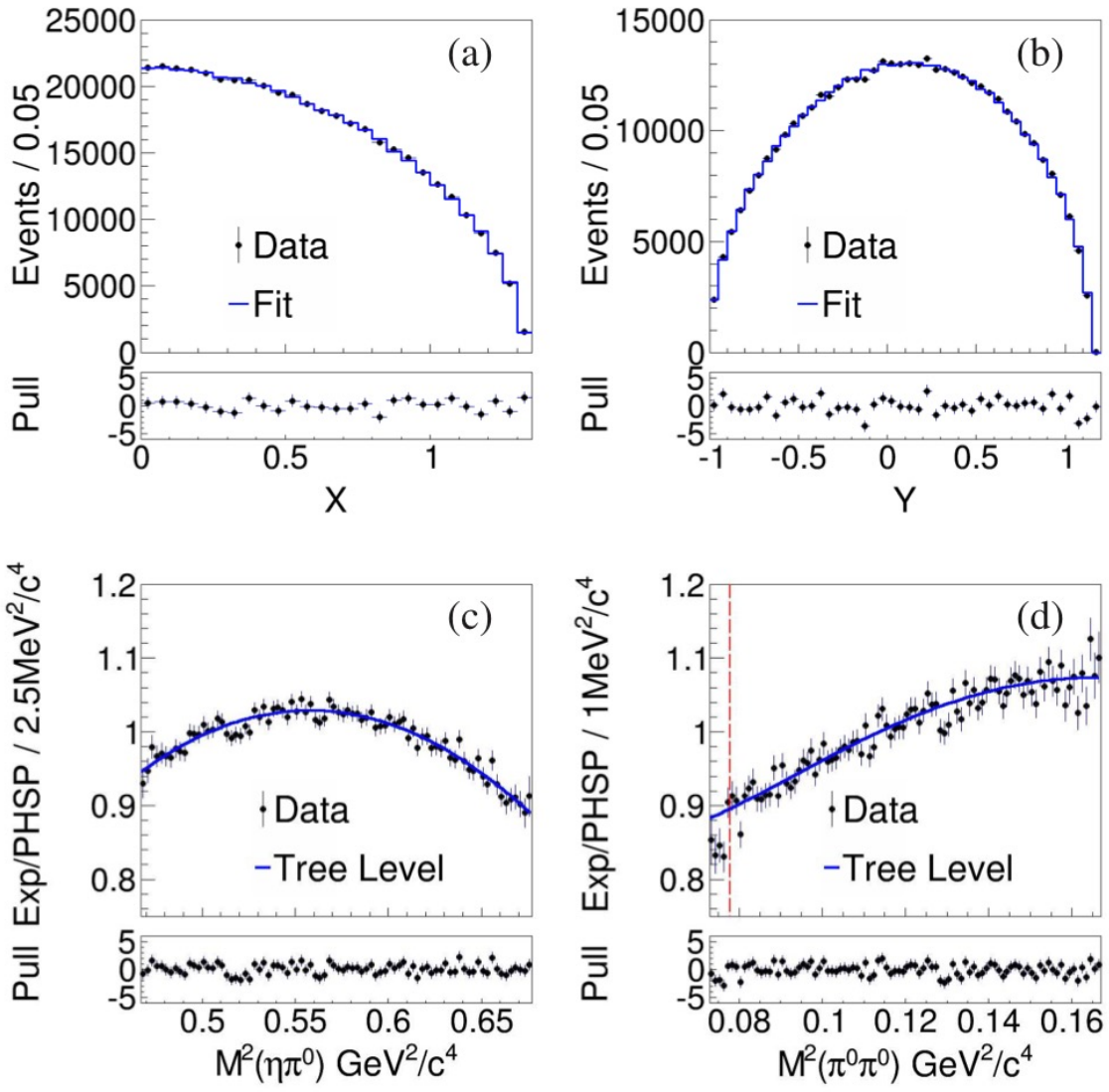
Evidence of the cusp effect in $\eta' \to \pi^0\pi^0\eta$

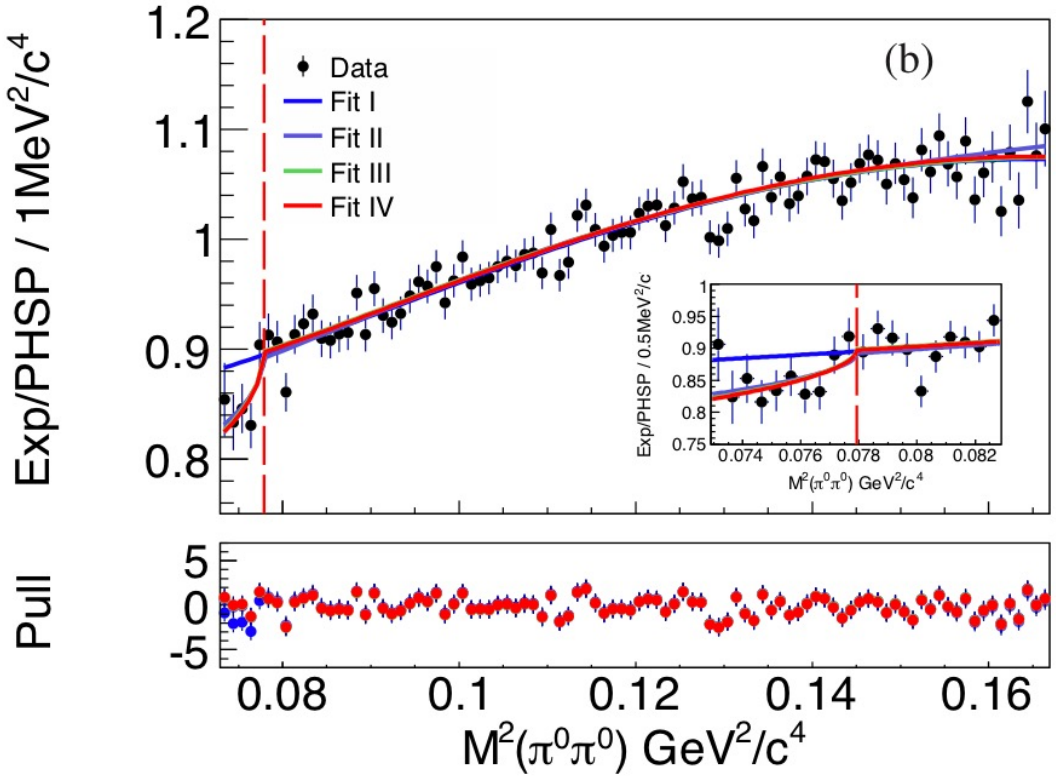
arXiv:2207.01104

- Test the effective ChPT
- Investigation on ππ and πη final interactions
- The cusp effect is sizeable in this decay

$$X = \frac{\sqrt{3}}{Q}(T_{\pi^+} - T_{\pi^-}), \qquad Y = \frac{m_\eta + 2m_\pi}{m_\pi}\frac{T_\eta}{Q} - 1$$

$$M^2 = A(1 + aY + bY^2 + cX + dX^2)$$





- Non-relativistic effective field theory

  B. Kubis and S. P. Schneider, EPJC 62, 511 (2009)

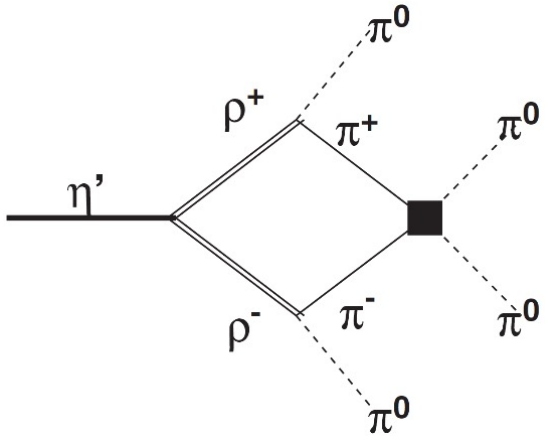
- Fits at different cases
  - Fit I: without the cusp effect
  - Fit II-IV: with the cusp effect
- Evidence of the cusp effect @ 3.5σ !

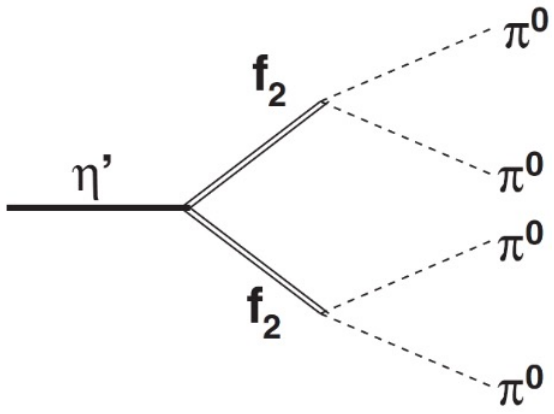
Parameters	Fit I	Fit II	Fit III	Fit IV
a	$-0.075 \pm 0.003 \pm 0.001$	-0.207 ± 0.013	-0.143 ± 0.010	$-0.077 \pm 0.003 \pm 0.001$
b	$-0.073 \pm 0.005 \pm 0.001$	-0.051 ± 0.014	-0.038 ± 0.006	$-0.066 \pm 0.006 \pm 0.001$
d	$-0.066 \pm 0.003 \pm 0.001$	-0.068 ± 0.004	-0.067 ± 0.003	$-0.068 \pm 0.004 \pm 0.001$
$a_0 - a_2$	-	0.174 ± 0.066	0.225 ± 0.062	$0.226 \pm 0.060 \pm 0.012$
a_0	-	0.497 ± 0.094	-	-
a_2	-	0.322 ± 0.129	-	-
Statistical Significance	-	3.4σ	3.7σ	3.6σ

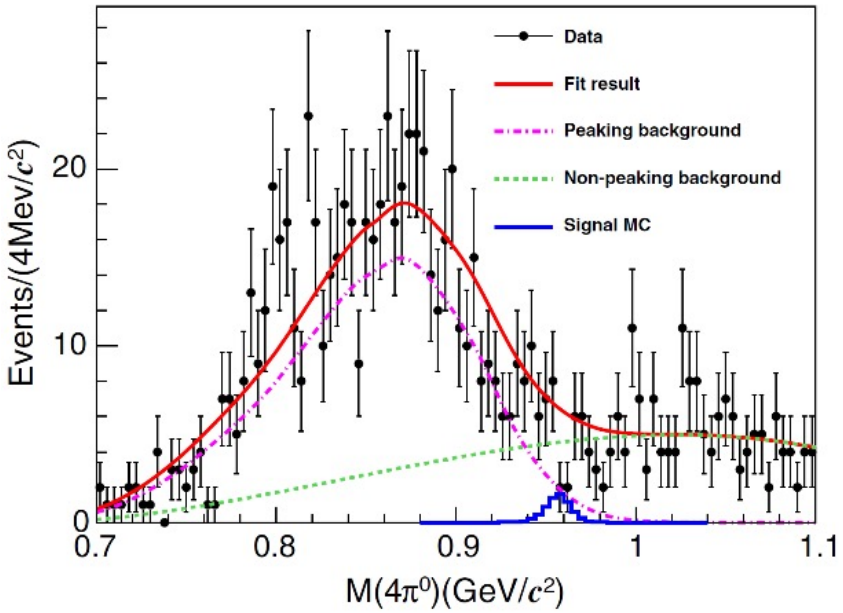
Search for the rare decay of $\eta' \to 4\pi^0$

- CP-violation S-wave, induced by the QCD Lagrangian θ-term ⇒ B~10^{-23}
- CP-conserving higher order F.K. Guo, B. Kubis, A. Wirzba, Phys. Rev. D 85,014014 (2012)

D-wave pion loop ⇒ B~10^{-8}





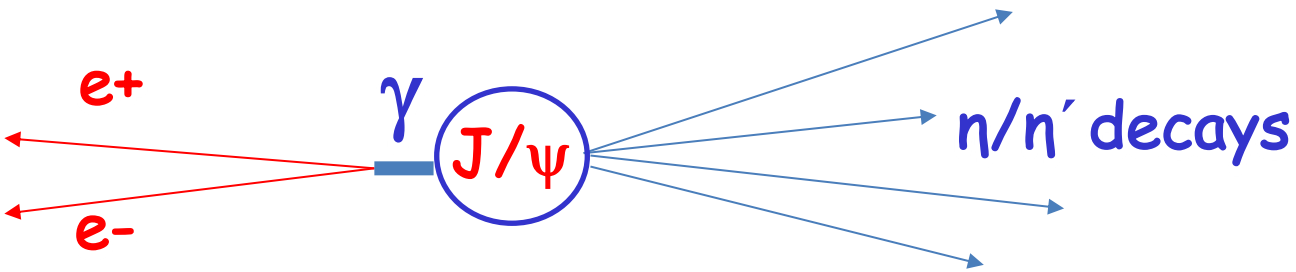


$$\mathcal{B}(\eta' \to 4\pi^0) < 4.94 \times 10^{-5}$$ **@ 90% CL**

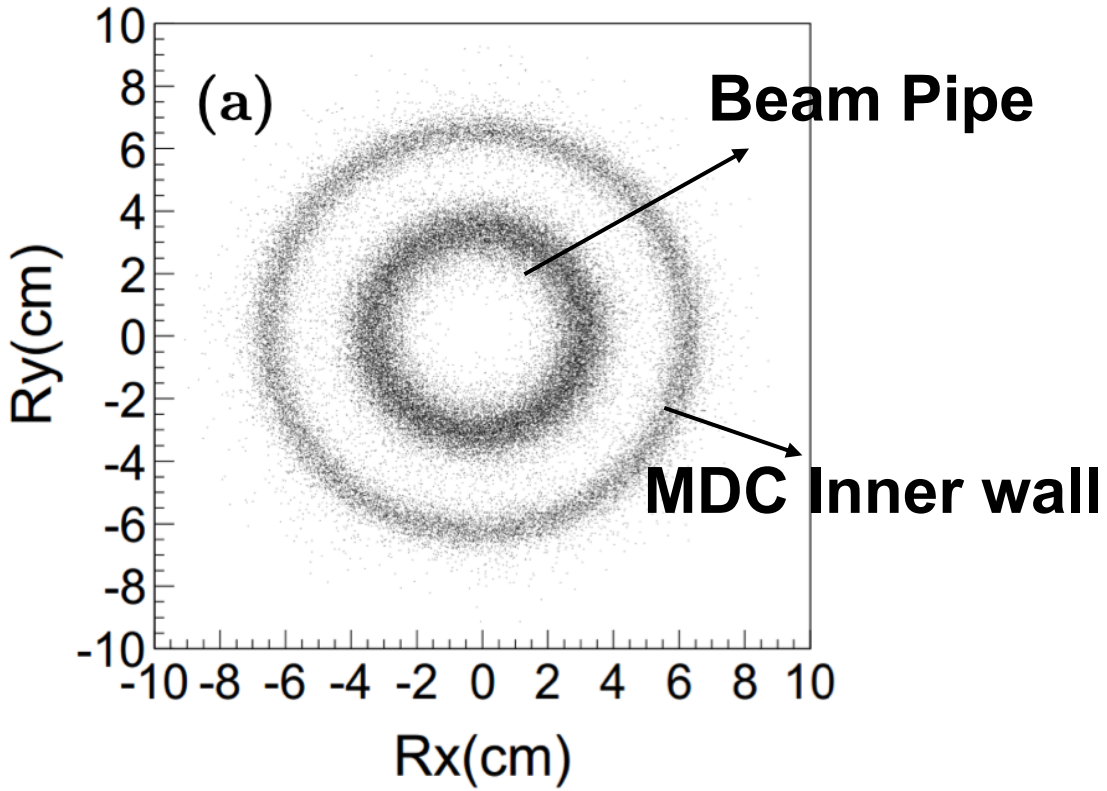
With 10 billion J/ψ events, the UL is expected to reach ~10^{-6} @ 90% C.L. PRD 101, 032001 (2020)

γ conversion: η/η′ inclusive decays

- A novel way to measure the absolute BFs of η/η′ decays



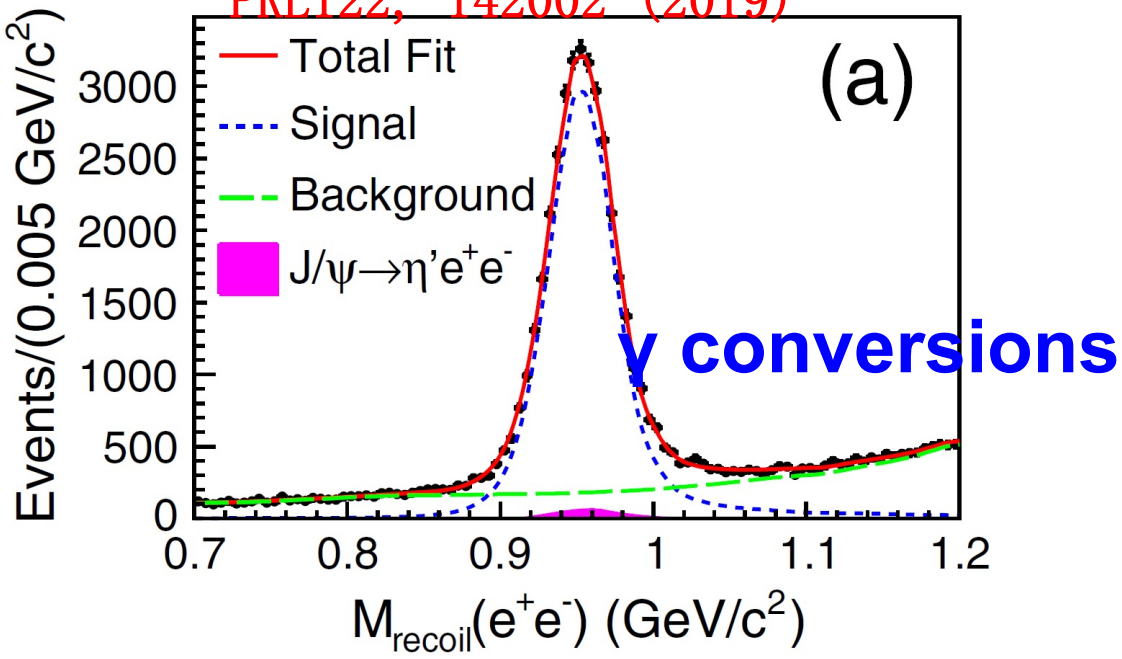
$$\mathcal{B}(\eta' \to X) = \frac{N^{\rm obs}_{\eta' \to X}}{\varepsilon_{\eta' \to X}} \frac{\varepsilon}{N^{\rm obs}_{J/\psi \to \gamma\eta'}}$$

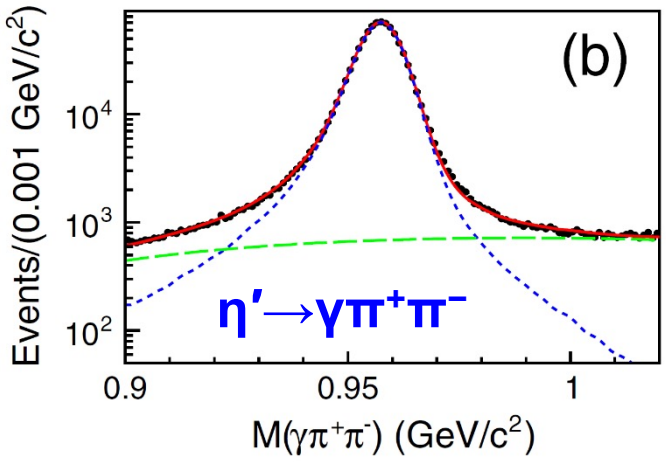


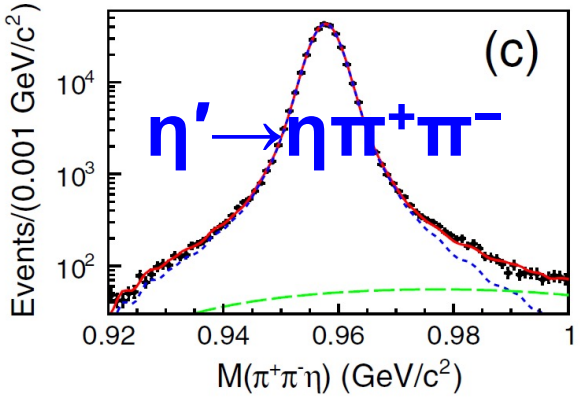
Excellent momentum resolution for electrons @MDC

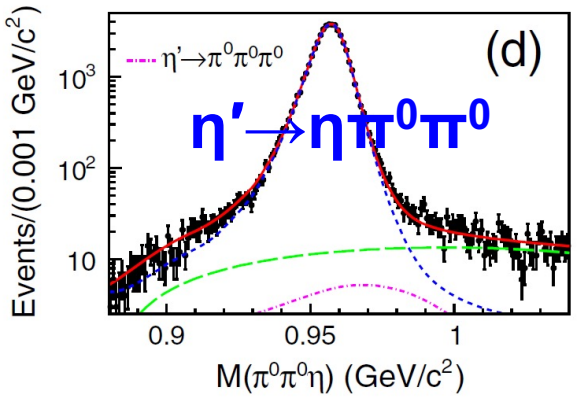
Absolute BFs of η′ decays

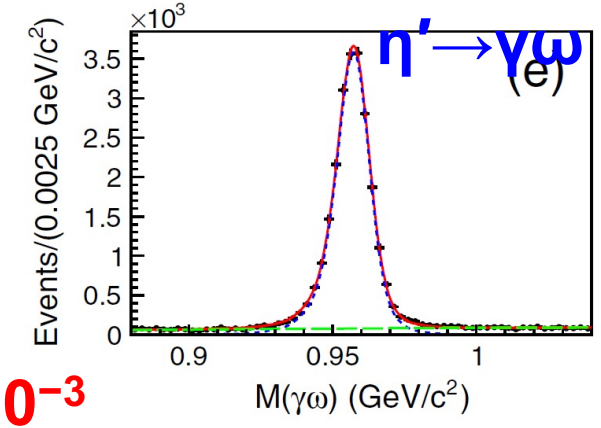
PRL122, 142002 (2019)

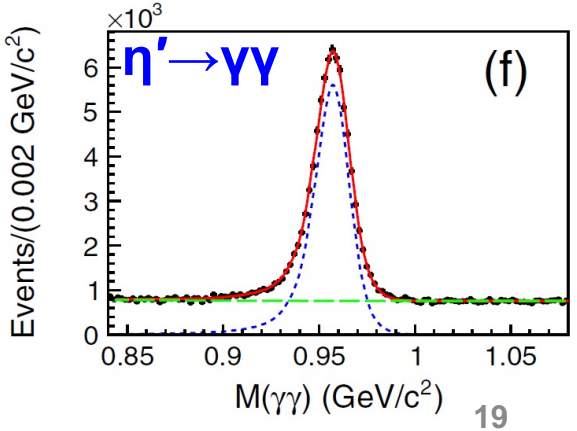










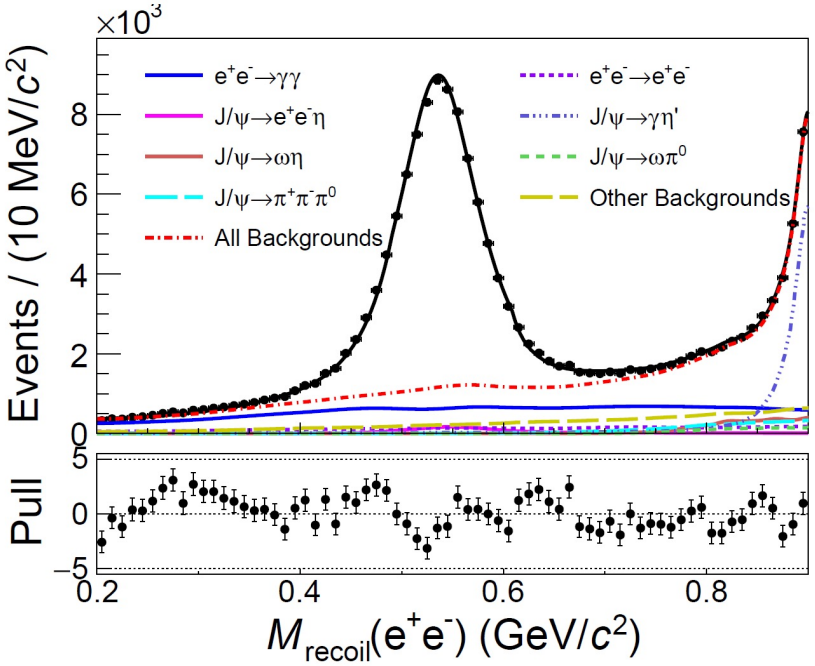


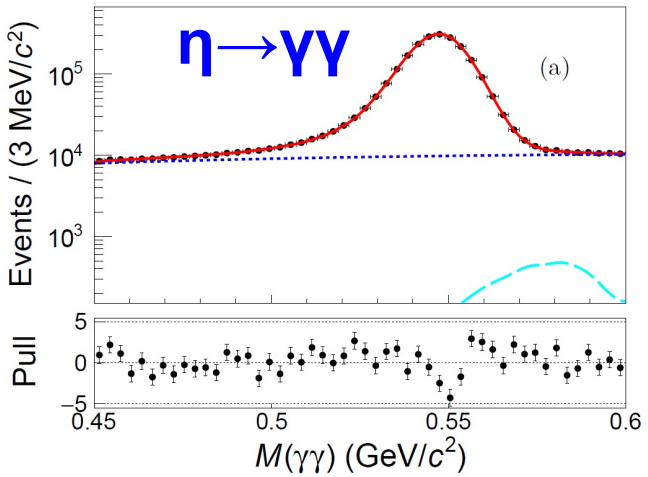
Decay mode	$\mathcal{B}(\eta' \to X)(\%)$ This measurement	PDG [7]
$\eta' \to \gamma\pi^+\pi^-$	$29.90 \pm 0.03 \pm 0.55$	28.9 ± 0.5
$\eta' \to \eta\pi^+\pi^-$	$41.24 \pm 0.08 \pm 1.24$	42.6 ± 0.7
$\eta' \to \eta\pi^0\pi^0$	$21.36 \pm 0.10 \pm 0.92$	22.8 ± 0.8
$\eta' \to \gamma\omega$	$2.489 \pm 0.018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

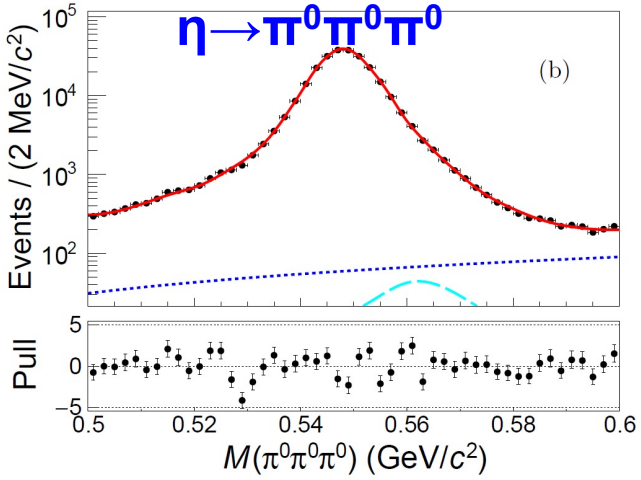
$B(J/\psi \to \gamma\eta') = (5.27 \pm 0.03 \pm 0.05) \times 10^{-3}$

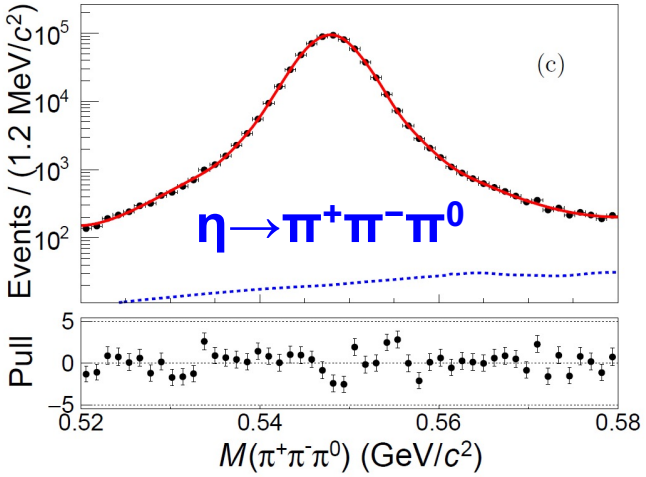
Absolute BFs of η decays

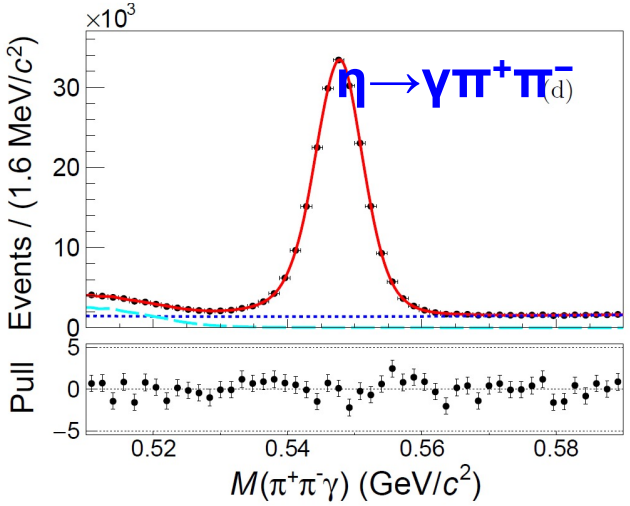
PRD104, 092004(2021)











X	$\mathcal{B}(\eta \to X)$ (%) 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

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

Summary

- Recent results on Light Meson decays are presented
  - η/η' : hadronic, radiative and rare decays
- BESIII: 10 billion J/ψ events
  - a unique place for light mesons
  - Allow to study light meson decays with high precision
- More results are expected to come soon
  - Dalitz plots of η /η' decays
  - Rare and forbidden decays
  - Form Factors
  - .....

Many thanks for your attention !