Light Meson Decays at BESIII

Shuangli Yang

(On behalf of BESIII collaboration)

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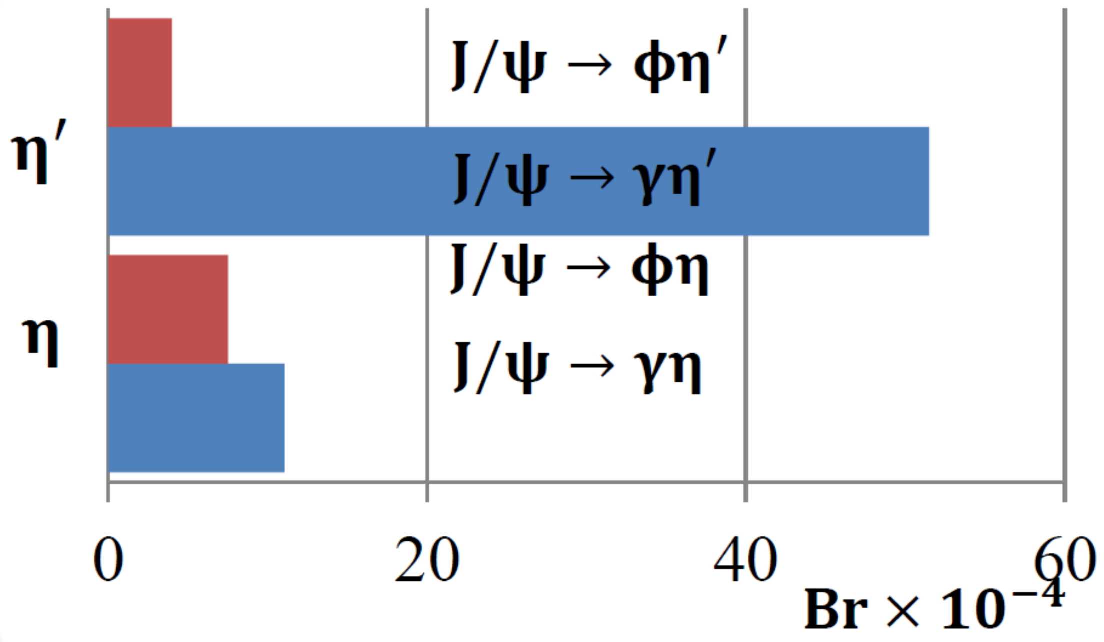
Outline

- Introduction
- Recent results on light meson decays
  - η/η' decays
  - $a_0 - f_0$ mixing
- Summary

η/η' from J/ψ decays



- BESIII: τ −charm factory
- High production rate of light mesons in J/ψ decays
- Also a factory for light mesons ($\eta/\eta'/\omega$ …)
- η/η' from J/ψ radiative decays

  $\rightarrow 7.2\times10^6\ \eta'$

  $\rightarrow 2.4\times10^6\ \eta$

η/η': a rich physics field

η		η'	
$M = 584$ MeV, $\Gamma = 1.3$keV		$M = 958$ MeV, $\Gamma = 197$keV	
Hadronic Decays			
$\eta \to \pi^0\pi^0\pi^0$	32.6%	$\eta' \to \pi^+\pi^-\eta$	42.9%
$\eta \to \pi^+\pi^-\pi^0$	22.9%	$\eta' \to \pi^0\pi^0\eta$	22.2%
Radiative Decays			
$\eta \to \gamma\gamma$	39.4%	$\eta' \to \rho^0\gamma$	29.1%
$\eta \to \pi^+\pi^-\gamma$	4.2%	$\eta' \to \omega\gamma$	2.7%
		$\eta' \to \gamma\gamma$	2.2%
99.1%		99.1%	

- text predictions by ChPT
- transition form factors
- text fundamental symmetries
- probe physics beyond the SM

Recent Results on η/η' Decays

- **Hadronic decays**
  - $\eta' \to \pi^+\pi^-\pi^0,\ \pi^0\pi^0\pi^0$
  - $\eta' \to \pi^+\pi^-\eta, \pi^0\pi^0\eta$
- **Radiative decays**
  - $\eta' \to \gamma\gamma\pi^0$
  - $\eta' \to \gamma\pi^+\pi^-$

Amplitude analysis of the decays $\eta' \to 3\pi$

- $\eta' \to 3\pi$ are isospin-violating processes due to the $d - u$ quark mass difference

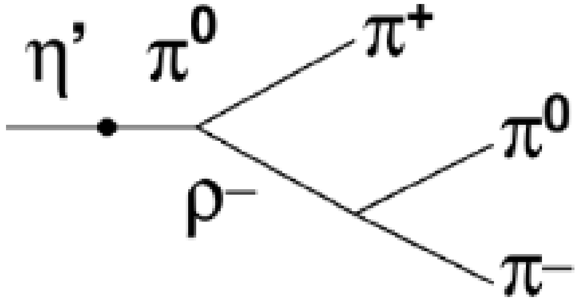
- light quark mass ratio $(m_d - m_u)/m_s$ can be extracted by the ratio of decay widths:

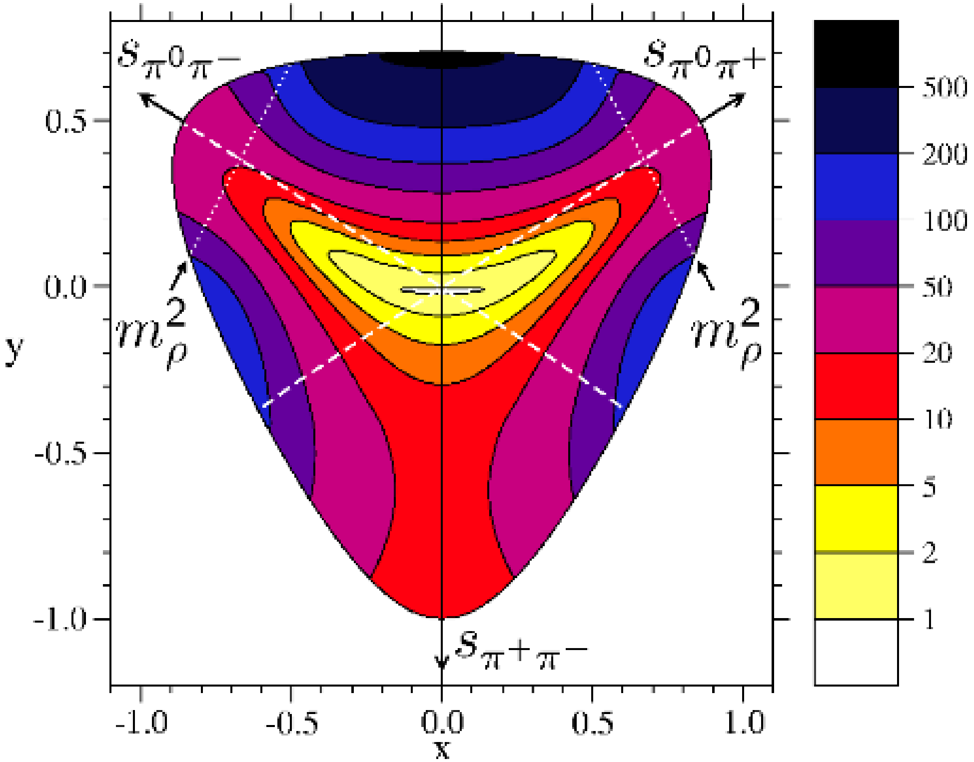
$$r = \frac{\Gamma_{\eta' \to \pi^+\pi^-\pi^0}}{\Gamma_{\eta' \to \eta\pi^+\pi^-}} \approx (16.8)\frac{3}{16}\left(\frac{m_d - m_u}{m_s}\right)^2$$

D. Gross et al., Phys. Rev. D. **19**, 2188 (1979)

- Using ChPT, large P-wave contribution of $\eta' \to \rho^\pm\pi^\mp$ is predicted in $\eta' \to \pi^+\pi^-\pi^0$ [Eur. Phys. J. A 26, 383(2005)]

- So far, no direct experimental evidence of $\eta' \to \rho^\pm\pi^\mp$ in $\eta' \to \pi^+\pi^-\pi^0$





Amplitude analysis of the decays $\eta' \to 3\pi$

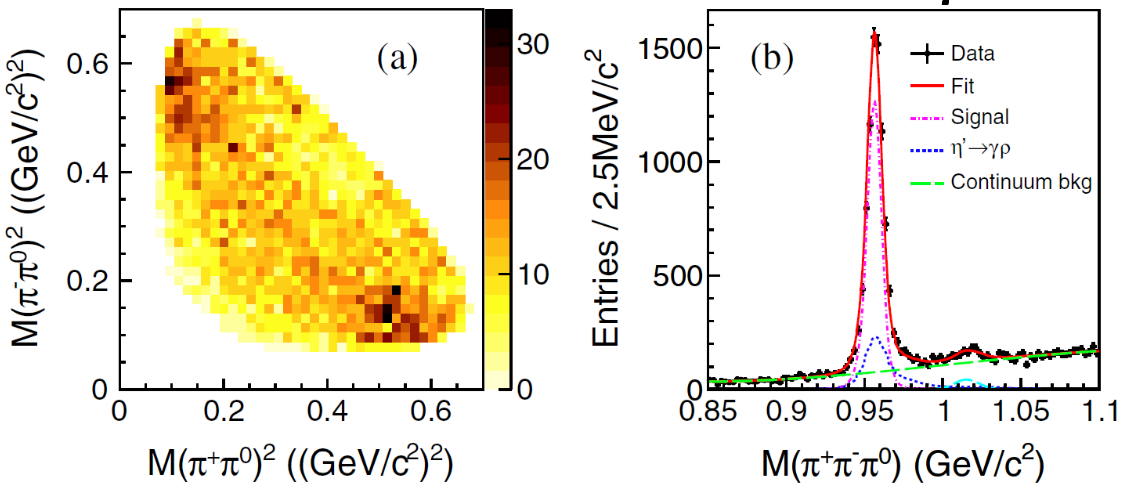
- Based on 1310M J/ψ data, η' from $J/\psi \to \gamma\eta'$
- Two clusters of events corresponding to $\eta' \to \rho^{\pm}\pi^{\mp}$ are observed
- The decay $\eta' \to \gamma\rho$ and $\eta' \to \pi^0\pi^0\eta$ result in the peaking background

$$\mathcal{B}(\eta' \to \pi^+\pi^-\pi^0) = (35.91 \pm 0.54 \pm 1.74)\times 10^{-4}$$

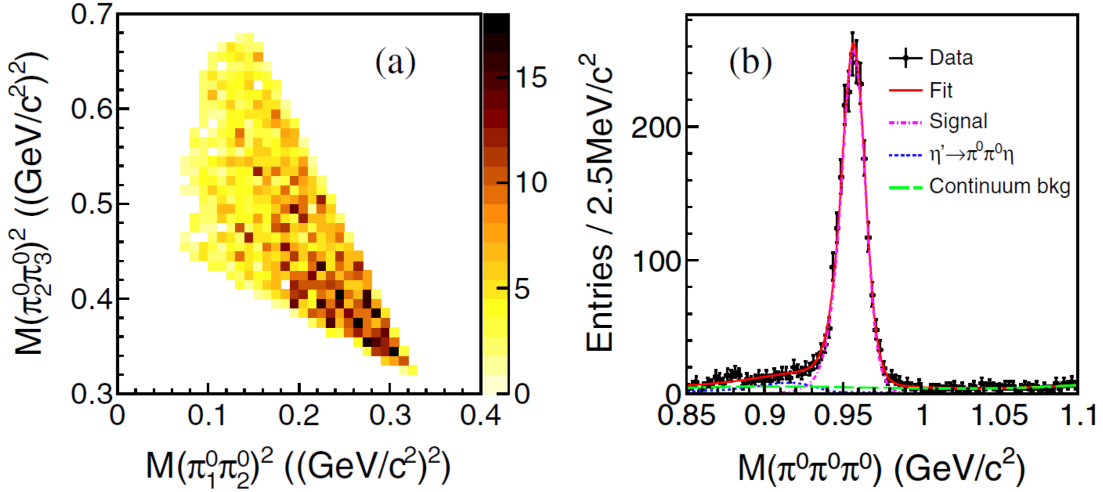
$$\mathcal{B}(\eta' \to \pi^0\pi^0\pi^0) = (35.22 \pm 0.82 \pm 2.54)\times 10^{-4}$$

- The branching fractions of $\eta' \to \pi^+\pi^-\pi^0$ and $\eta' \to \pi^0\pi^0\pi^0$ are in good agreement with previous BESIII results (Phys. Rev. Lett. 108, 182001 (2012))

$\eta' \to \pi^+\pi^-\pi^0$ **8267 η' events**

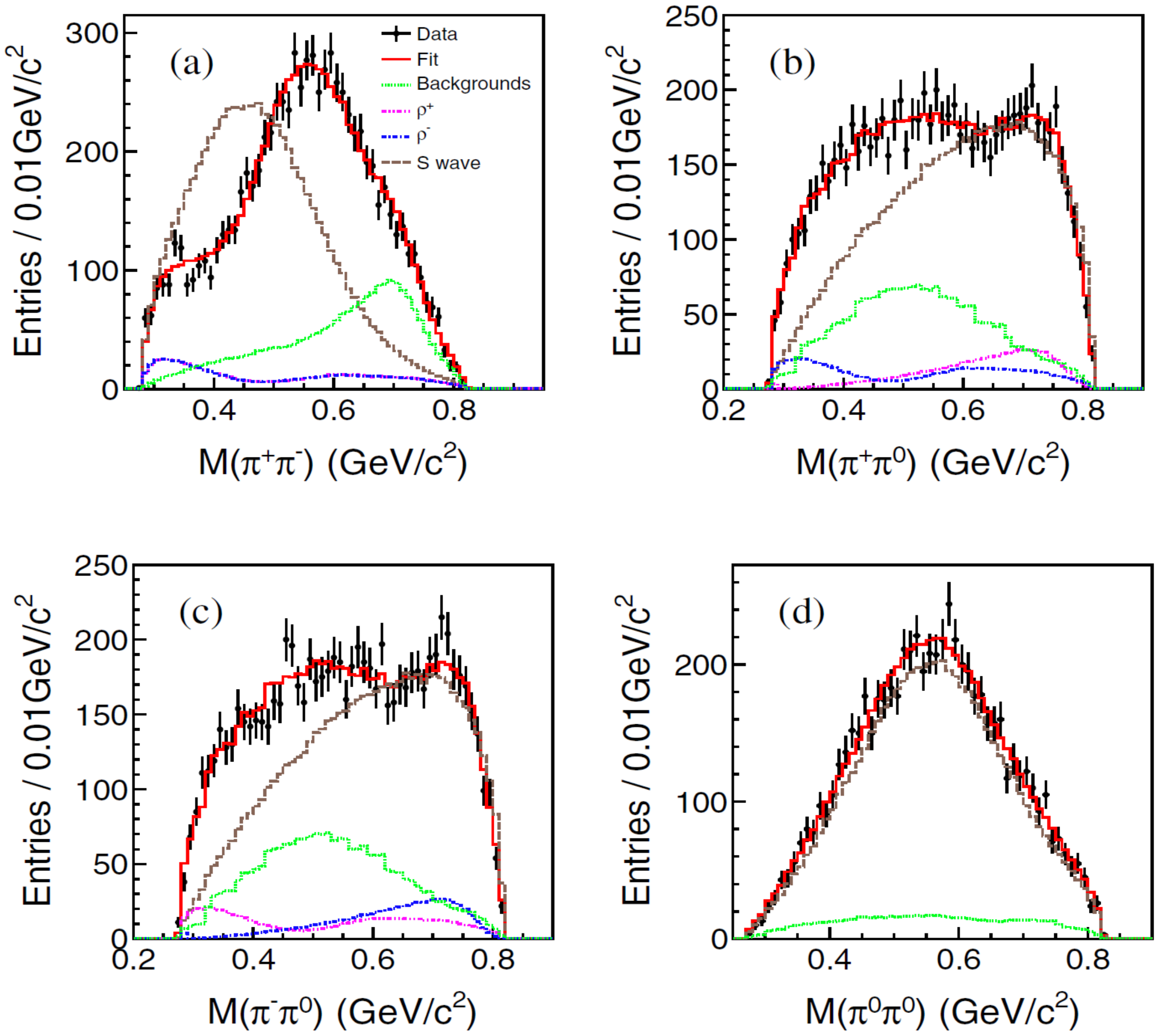


$\eta' \to \pi^0\pi^0\pi^0$ **2237 η' events**



Phys. Rev. Lett. **118**, 012001 (2017)

Amplitude analysis of the decays $\eta' \to 3\pi$



Phys. Rev. Lett. **118**, 012001 (2017)

Decay Mode	$B(10^{-4})$
$\pi^+\pi^-\pi^0$	$35.91 \pm 0.54 \pm 1.74$
$\pi^0\pi^0\pi^0$	$35.22 \pm 0.82 \pm 2.54$
$\rho^\pm\pi^\mp$	$7.44 \pm 0.60 \pm 1.26 \pm 1.84$
$(\pi^+\pi^-\pi^0)_S$	$37.63 \pm 0.77 \pm 2.22 \pm 4.48$

- Amplitude analysis combining $\eta' \to \pi^+\pi^-\pi^0$ and $\eta' \to \pi^0\pi^0\pi^0$.
- Described by three components: P wave $\rho^\pm\pi^\mp$), resonant S wave ($\sigma\pi^0$), phase-space S wave ($\pi\pi\pi$)
- The P-wave contribution from $\rho^\pm$ is observed for the first time with high statistical significance.
- Obtained decay width ratios:

$\boldsymbol{r_\pm} = (\mathbf{8.77 \pm 1.19})\times\mathbf{10^{-3}}$
$\boldsymbol{r_0} = (\mathbf{15.86 \pm 1.33})\times\mathbf{10^{-3}}$

Matrix elements for the decays $\eta' \to \pi^+\pi^-\eta, \pi^0\pi^0\eta$

BESIII

- Impact of gluon component on the dynamics of η' decays
- Comparison to the theoretical calculations with the effective ChPT
- Previous measurements on the dalitz plot of $\eta' \to \pi\pi\eta$ are from VES, GAMS and CLEO

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

$T_{\pi,\eta}$ denote the kinetic energies of a pion and η in the η' rest frame

$$Q = T_\eta + T_{\pi^+} + T_{\pi^-} = m_{\eta'} - m_\eta - 2m_\pi$$

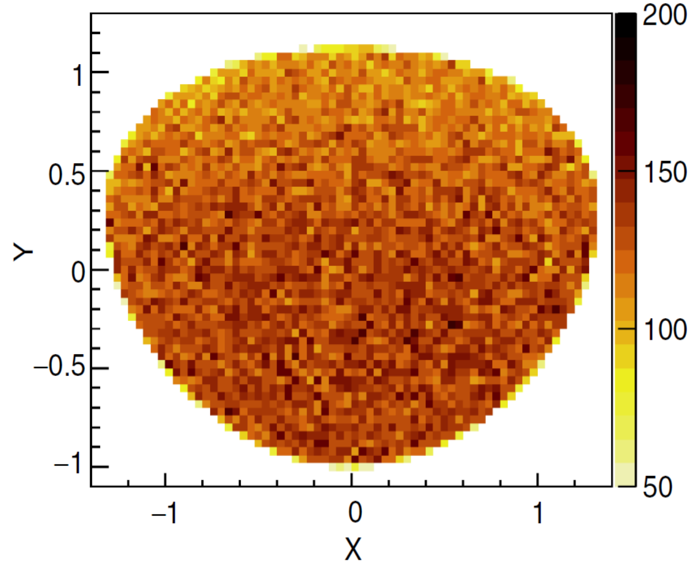
Two representations used

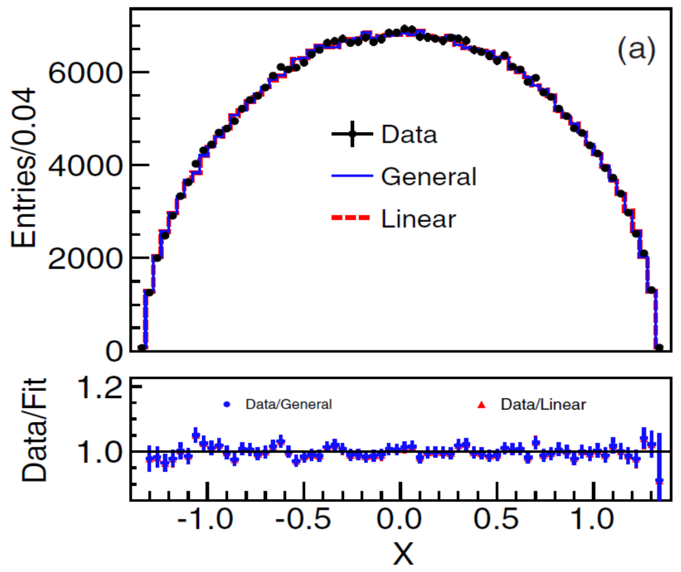
$$|M(X,Y)|^2 = N(1 + aY + bY^2 + cX + dX^2 + \cdots)$$ (general representation)

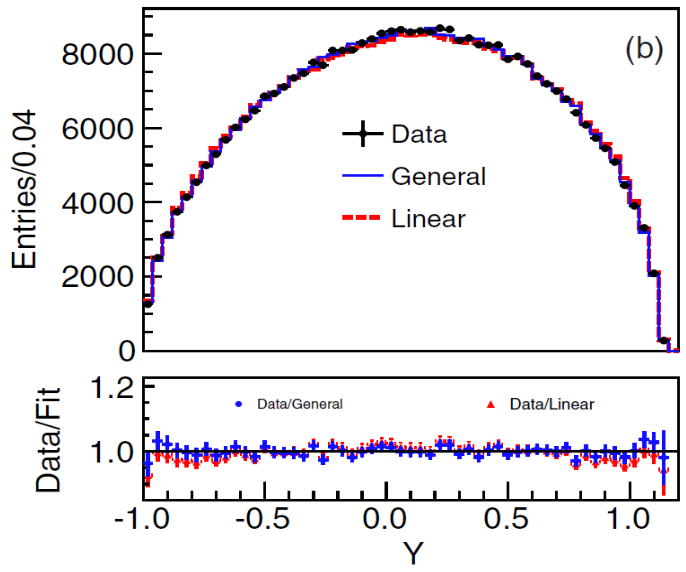
$$|M(X,Y)|^2 = N(|1 + \alpha Y|^2 + cX + dX^2 + \cdots)$$ (linear representation)

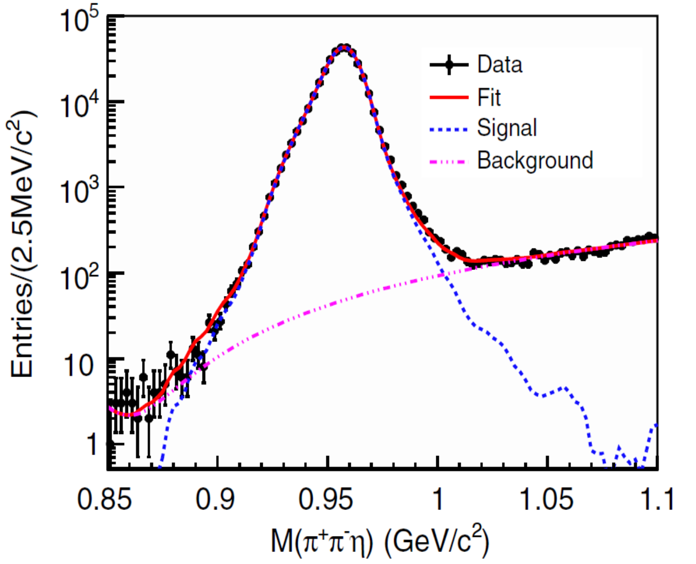
Phys. Rev. D. **97**, 012003(2018)

Matrix elements for the decays $\eta' \to \pi^+\pi^-\eta, \pi^0\pi^0\eta$





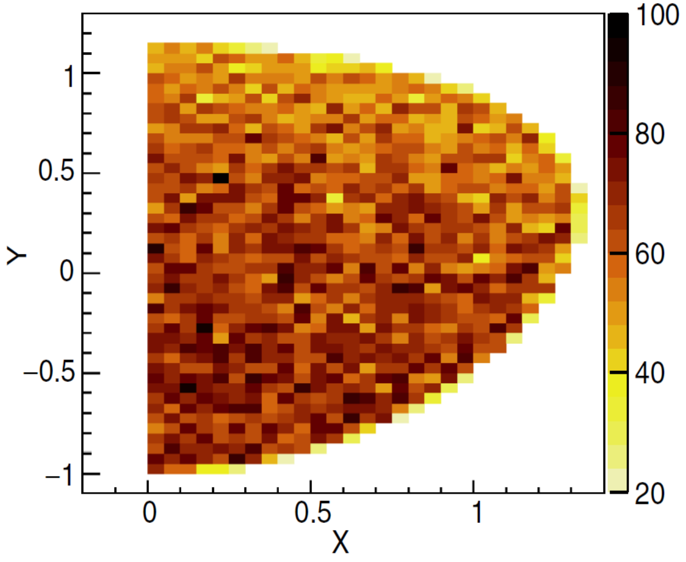


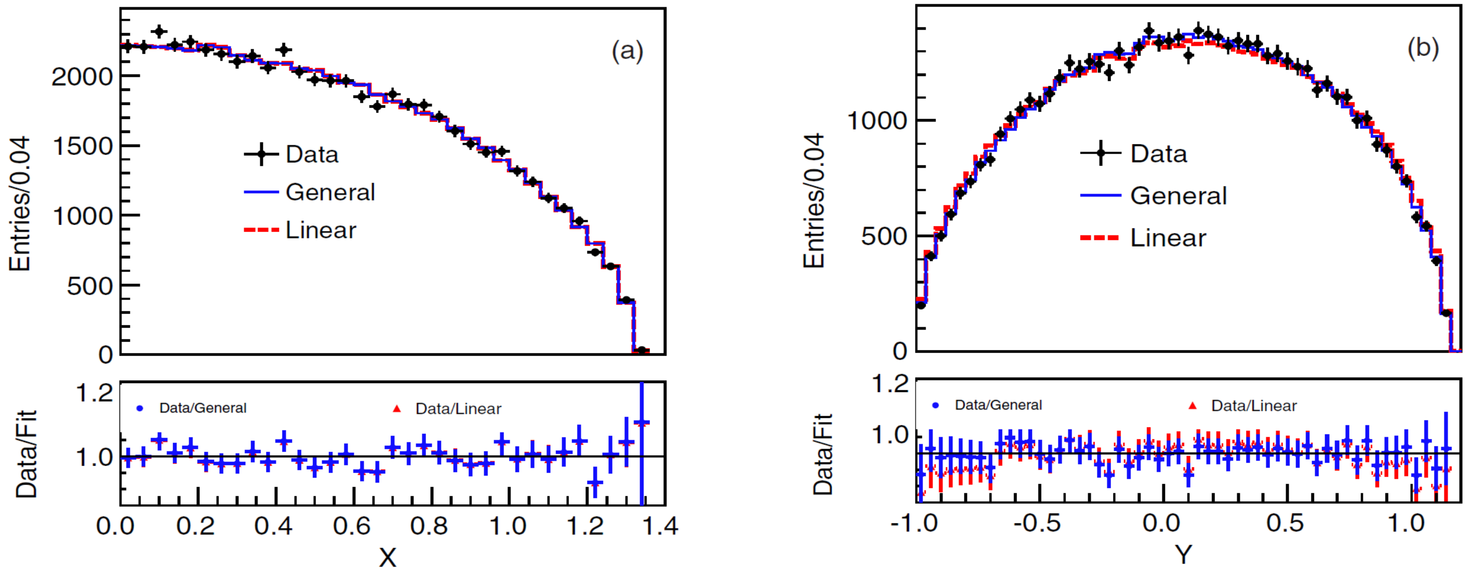


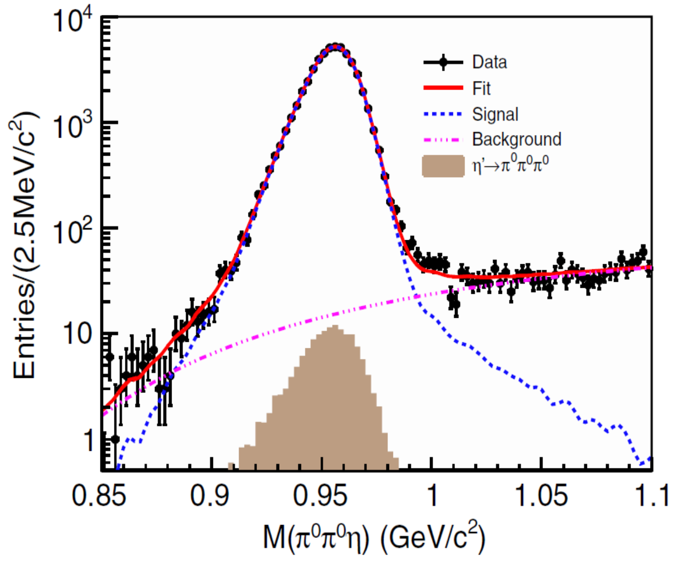
	$\eta' \to \eta\pi^+\pi^-$				
Parameter	EFT [5]	Large N_C [7]	RChT [7]	VES [10]	This work
a	−0.116(11)	−0.098(48)	(fixed)	−0.127(18)	−0.056(4)(2)
b	−0.042(34)	−0.050(1)	−0.033(1)	−0.106(32)	−0.049(6)(6)
c	...	...	...	+0.015(18)	0.0027(24)(18)
d	+0.010(19)	−0.092(8)	−0.072(1)	−0.082(19)	−0.063(4)(3)
$\Re(\alpha)$	...	...	...	−0.072(14)	−0.034(2)(2)
$\Im(\alpha)$	...	...	...	0.000(100)	0.000(19)(1)
c	...	...	...	+0.020(19)	0.0027(24)(15)
d	...	...	...	−0.066(34)	−0.053(4)(4)

Phys. Rev. D. **97**, 012003(2018)

Matrix elements for the decays $\eta' \to \pi^+\pi^-\eta, \pi^0\pi^0\eta$



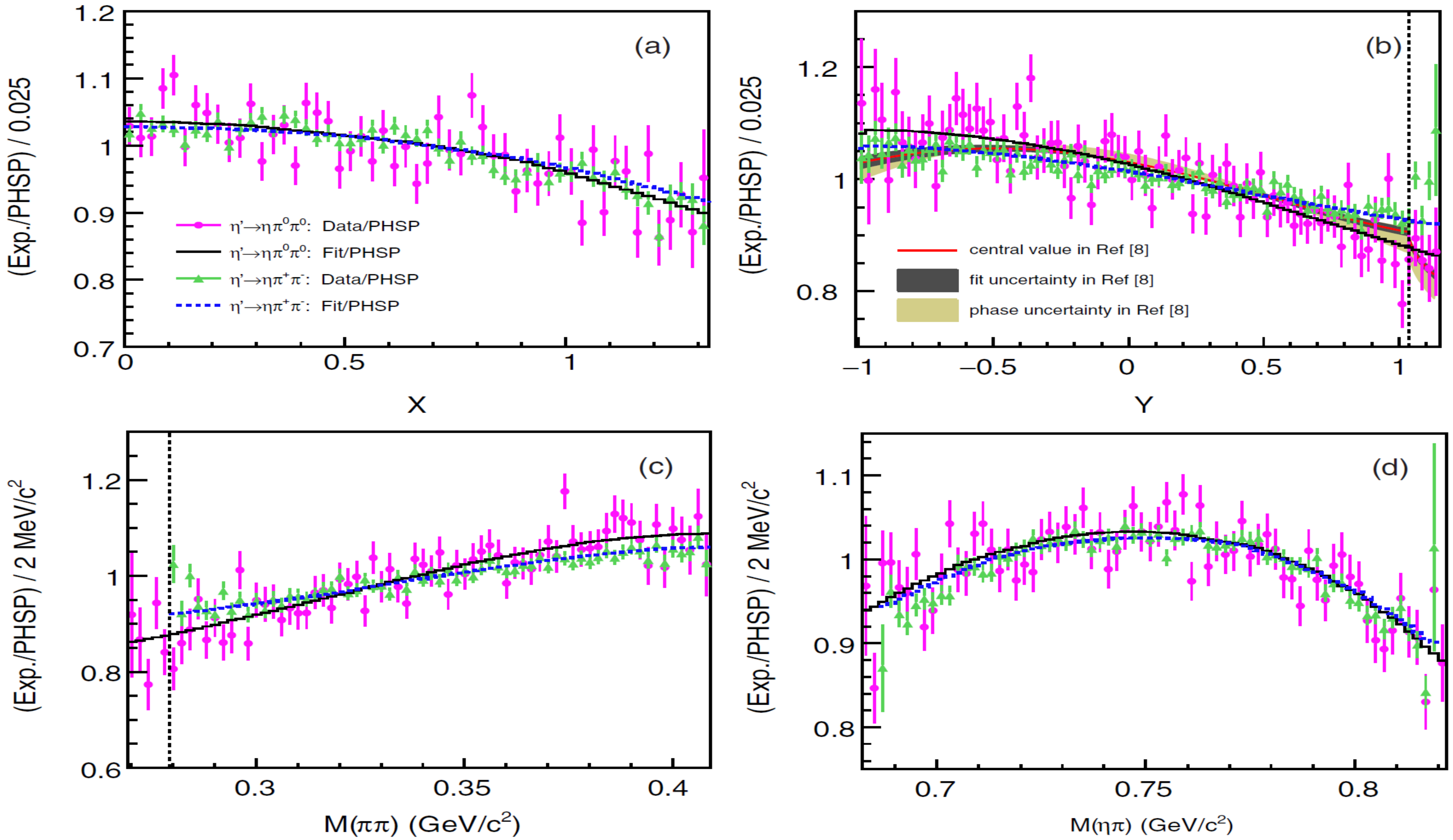




	$\eta' \to \eta\pi^0\pi^0$		
Parameter	EFT [5]	GAMS-4π [12]	This work
a	−0.127(9)	−0.067(16)	−0.087(9)(6)
b	−0.049(36)	−0.064(29)	−0.073(14)(5)
c	...	...	...
d	+0.011(21)	−0.067(20)	−0.074(9)(4)
$\Re(\alpha)$	...	−0.042(8)	−0.054(4)(1)
$\Im(\alpha)$	...	0.000(70)	0.000(38)(2)
c	...	...	...
d	...	−0.054(19)	−0.061(9)(5)

Phys. Rev. D. **97**, 012003(2018)

Search for cusp effect in $\eta' \to \pi^0\pi^0\eta$



- With current statistics , it is difficult to establish cusp effect near the $\pi\pi$ mass threshold.

Phys. Rev. D **97**, 012003(2018)

Observation of the doubly radiative decay $\eta' \to \gamma\gamma\pi^0$

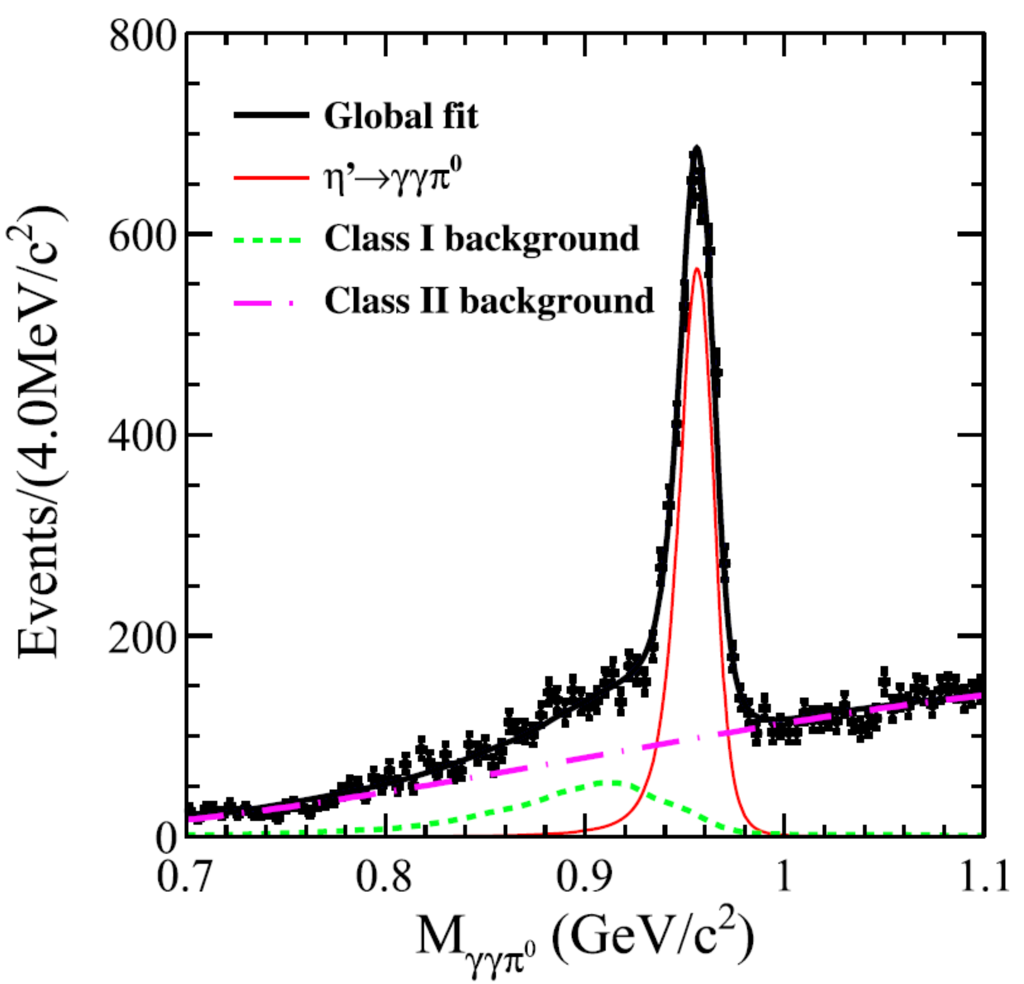
Phys. Rev. D **96**, 012005(2017)

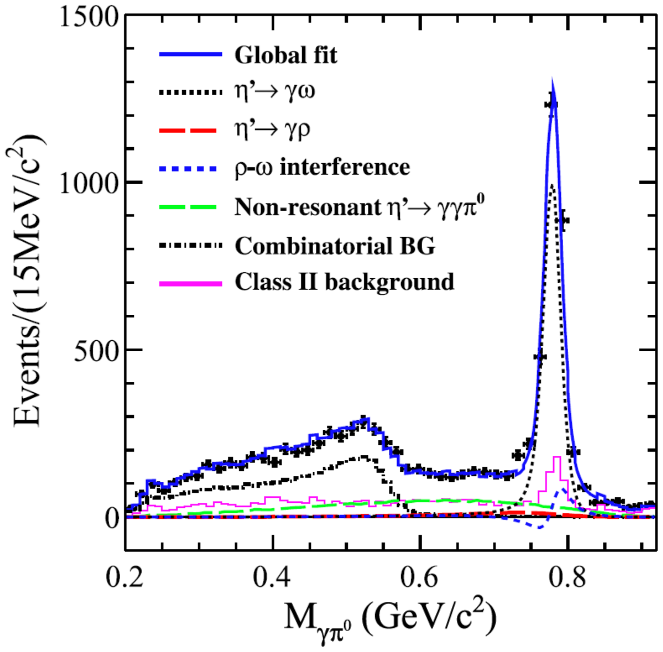
- Test QCD calculations on the transition form factor
- Check the high order of ChPT
- In experiment, only an upper limit of $\mathcal{B}(\eta' \to \gamma\gamma\pi^0) < 8\times10^{-4}$ at 90% C.L.

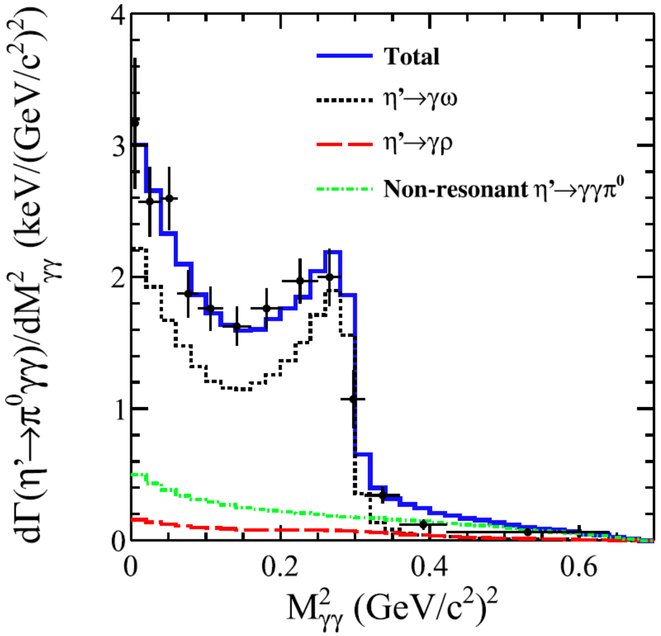
† $\eta' \to \gamma\gamma\pi^0$: Signal shape from MC, incoherent mixture of ρ, ω and non-resonant components.

† Class-I background: $J/\psi \to \gamma\eta'$ with η' decaying into other final states other than the signal final state.

† Class-II background: J/ψ decays without η' ($J/\psi \to \gamma\pi^0\pi^0$ and $J/\psi \to \omega\eta$ with $\omega \to \gamma\pi^0$ and $\eta \to \gamma\gamma$)







Phys. Rev. D **96**, 012005(2017)

	$\eta' \to \gamma\gamma\pi^0$ (Inclusive)	$\eta' \to \gamma\omega, \omega \to \gamma\pi^0$	$\eta' \to \gamma\gamma\pi^0$ (Non-resonant)
$N^{\eta'}$	$3435 \pm 76 \pm 244$	$2340 \pm 141 \pm 180$	$655 \pm 68 \pm 71$
ϵ	16.1%	14.8%	15.9%
$\mathcal{B}\ (10^{-4})$	$32.0 \pm 0.7 \pm 2.3$	$23.7 \pm 1.4 \pm 1.8^{a}$	$6.16 \pm 0.64 \pm 0.67$
$\mathcal{B}_{PDG}\ (10^{-4})$	–	21.7 ± 1.3^{b}	< 8 [9]
Predictions (10^{-4})	57 [7], 65 [8]	–	–

Linear σ model & VMD

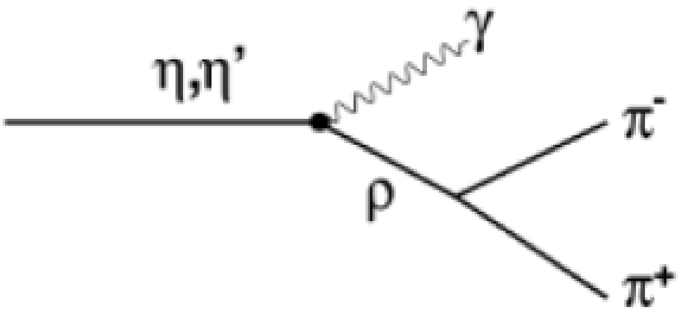
[7] R. Jora, Nucl. Phys. Proc. Suppl. 207-208, 224(2010);

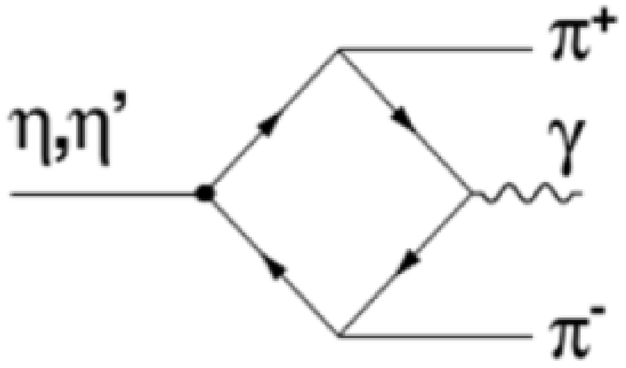
[8] R. Escribano, *Proc. Sci.,* QNP2012 (2012) 079;

[9]D. Alde et al. (GAMS-2000), Z. Phys. C 36, 603 (1987).

Precision Study of $\eta' \to \gamma\pi^+\pi^-$ Decay Dynamics

- $\eta' \to \gamma\pi^+\pi^-$ is the second most decay mode , with $(29.1 \pm 0.5)\%$
- In Vector Meson Dominance (VMD) model, this process is dominated by $\eta' \to \gamma\rho(770)$
- Studied by several experiments, a lone ρ^0 contribution did not describe the exp. data
- This discrepancy could be attributed to the Wess-Zumino-Witten anomaly in the ChPT, known as the box anomaly.
- Recently a model-independent approach based on ChPT are proposed



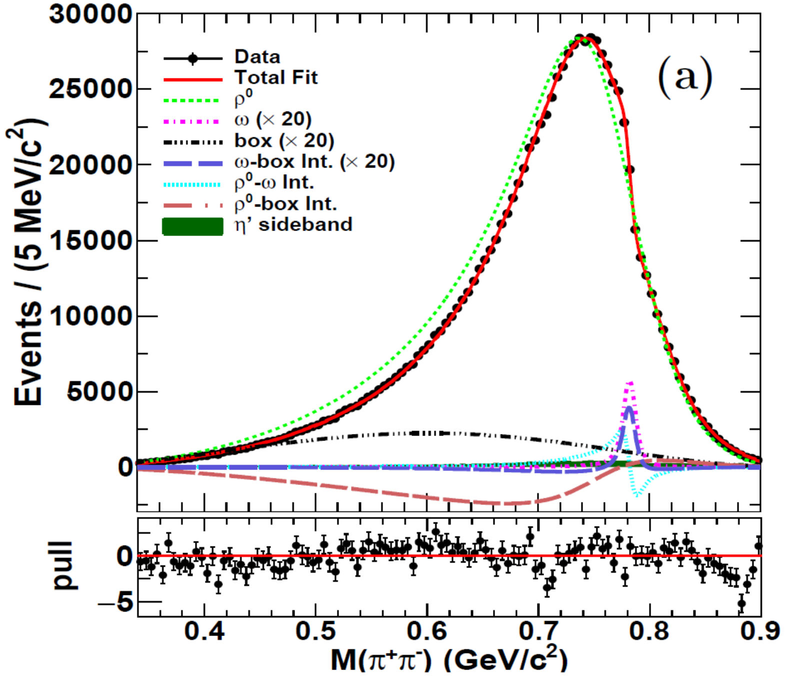


The dipion mass differential rate :

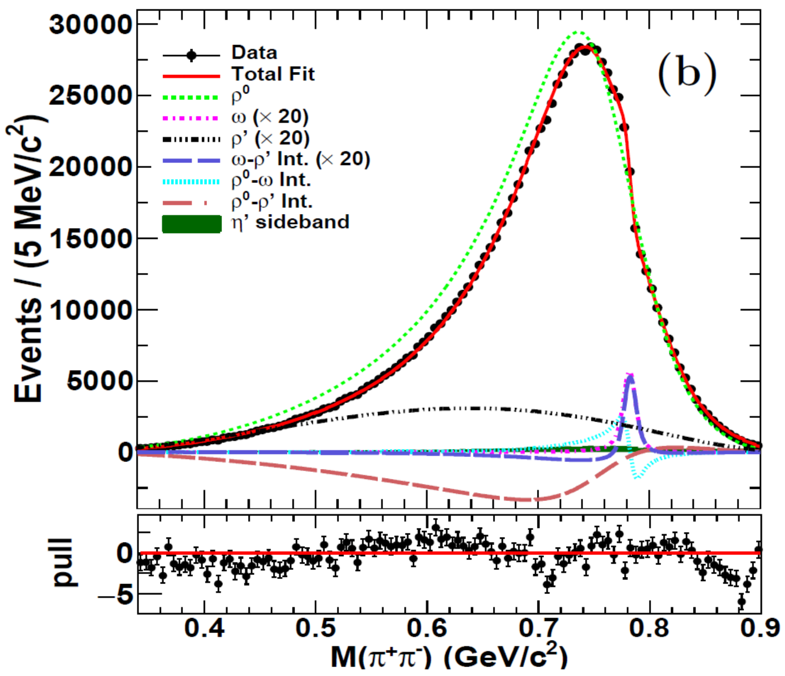
$$\frac{d\Gamma}{dM(\pi^+\pi^-)} = \frac{k_\gamma^3 q_\pi^3(s)}{48\pi^3}|A|^2$$

Precision Study of $\eta' \to \gamma\pi^+\pi^-$ Decay Dynamics

1). fit with $\rho(770)-\omega-$box anomaly



2). fit with $\rho(770)-\omega-\rho(1450)$

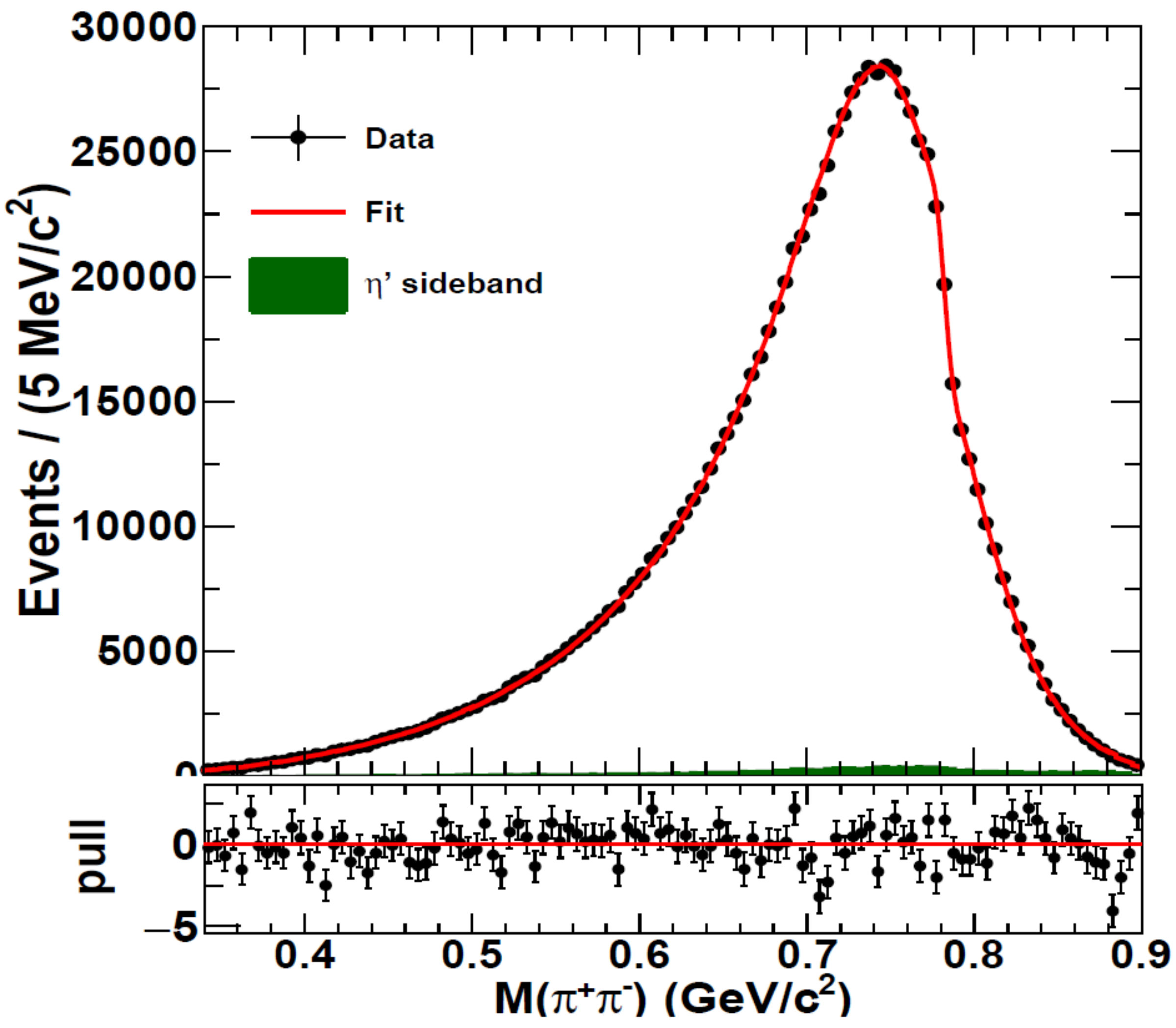


Model-dependent fit

- Besides $\rho(770)$, the ω is needed
- $\rho(770)-\omega$ cannot describe data well
- Extra contribution (maybe $\rho(1450)$ or box-anomaly, maybe both of them) is also necessary to provide a good description of data

Phys. Rev. Lett. **120**, 242003(2018),

Precision Study of $\eta' \to \gamma\pi^+\pi^-$ Decay Dynamics



Model independent fit

- $A = N \cdot P(s) \cdot F_V(s)$
- $P(s) = 1 + \kappa \cdot s + \lambda \cdot s^2 + \xi \cdot BW_\omega + \mathcal{O}(s^4)$
- $F_V(s)$ is the pion vector form factor

Fit results:

- $\kappa = (0.992 \pm 0.039 \pm 0.067 \pm 0.163)\mathrm{GeV}^{-2}$
- $\lambda = (-0.523 \pm 0.039 \pm 0.066 \pm 0.181)\mathrm{GeV}^{-4}$
- $\xi = 0.199 \pm 0.006 \pm 0.011 \pm 0.007$

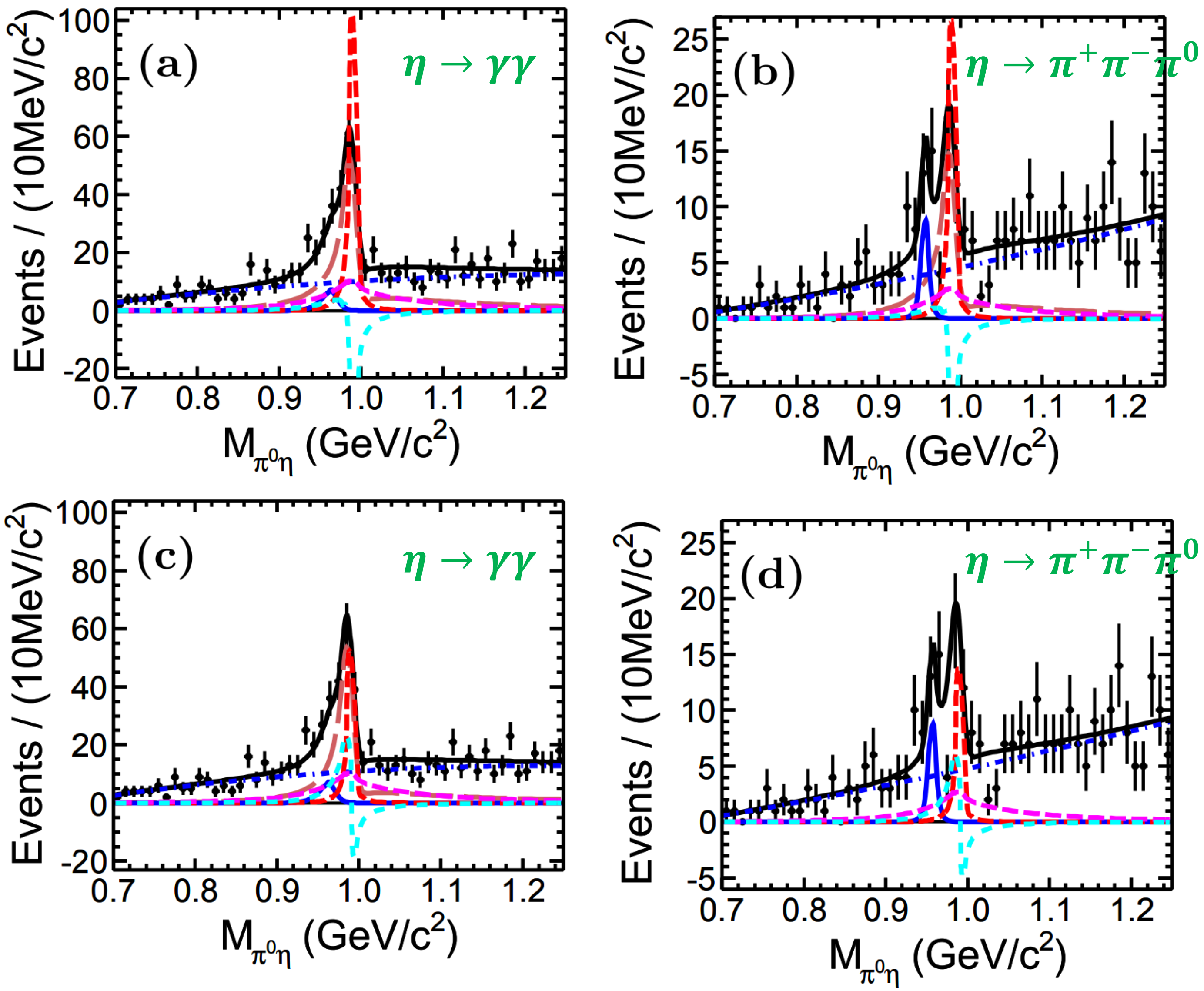
- The ω is necessary
- Quadratic term and the ω contribution are significant, linear polynomial is insufficient

Phys. Rev. Lett. **120**, 242003(2018),

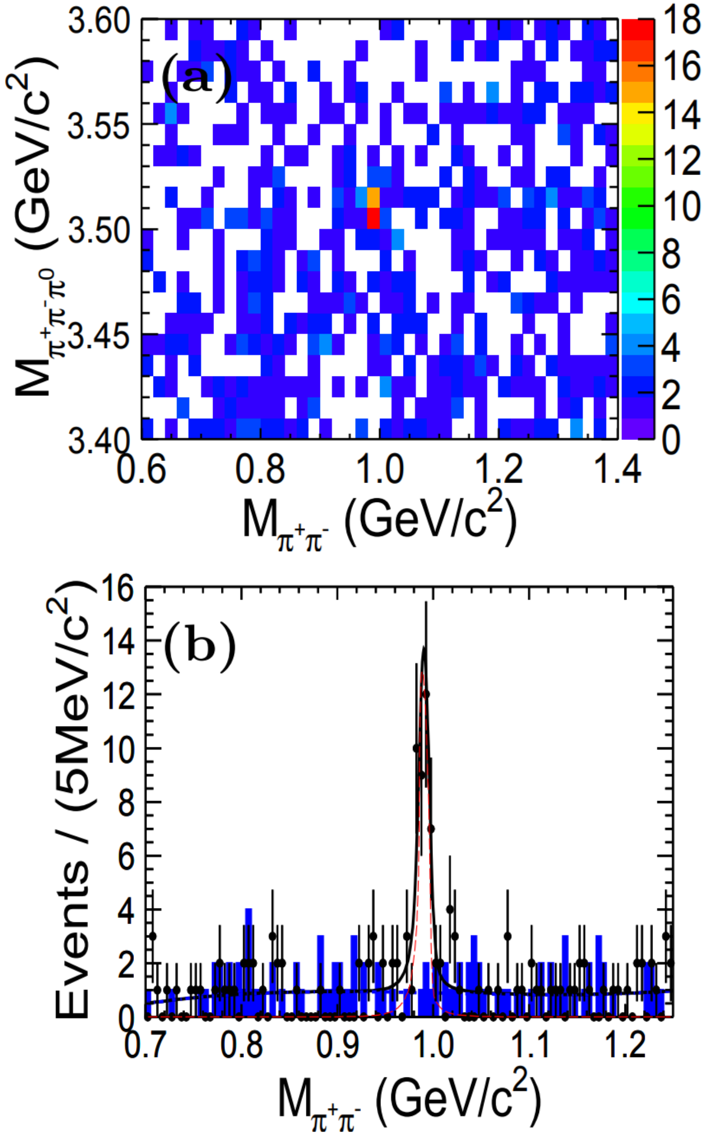
Observation of $a_0(980) - f_0(980)$ Mixing

$J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0$

$\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0 f_0(980) \to \pi^0\pi^+\pi^-$



arXiv:1802.00583 **Accepted by PRL**



Observation of $a_0(980) - f_0(980)$ Mixing

- Mixing intensity is crucial to understand the nature of $a_0^0(980)$ and $f_0(980)$
  - $\xi_{fa} = \frac{\mathcal{B}(J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi \eta \pi^0)}{\mathcal{B}(J/\psi \to \phi f_0(980) \to \phi \pi\pi)}$
  - $\xi_{af} = \frac{\mathcal{B}(\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0 f_0(980) \to \pi^0 \pi^+ \pi^-)}{\mathcal{B}(\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0 \pi^0 \eta)}$

- Final results of the branching fractions and the intensities of the $a_0^0(980) - f_0(980)$ mixing

Channel	$f_0(980) \to a_0^0(980)$ Solution I	$f_0(980) \to a_0^0(980)$ Solution II	$a_0^0(980) \to f_0(980)$
$\mathcal{B}$(mixing) (10^{-6})	$3.18 \pm 0.51 \pm 0.38 \pm 0.28$	$1.31 \pm 0.41 \pm 0.39 \pm 0.43$	$0.35 \pm 0.06 \pm 0.03 \pm 0.06$
$\mathcal{B}$(EM) (10^{-6})	$3.25 \pm 1.08 \pm 1.08 \pm 1.12$	$2.62 \pm 1.02 \pm 1.13 \pm 0.48$	—
$\mathcal{B}$(total) (10^{-6})	$4.93 \pm 1.01 \pm 0.96 \pm 1.09$	$4.37 \pm 0.97 \pm 0.94 \pm 0.06$	—
ξ (%)	$0.99 \pm 0.16 \pm 0.30 \pm 0.09$	$0.41 \pm 0.13 \pm 0.17 \pm 0.13$	$0.40 \pm 0.07 \pm 0.14 \pm 0.07$

Summary

- A unique place to study light meson decays
  - Observation of $\eta' \to \rho^{\pm}\pi^{\mp}$ in $\eta' \to \pi\pi\pi$
  - Dalitz plot of $\eta' \to \pi^+\pi^-\eta$, $\pi^0\pi^0\eta$
  - Study of $\eta' \to \gamma\pi^+\pi^-$ decay dynamics
  - Observation of $\eta' \to \gamma\gamma\pi^0$
  - First observation of $a_0^0(980) - f_0(980)$ mixing
- BESIII is an ideal laboratory to study light meson decays
- 1.3 billion + 3.7 billion (2017-2018) J/ψ events
- More interesting light meson decays are expected

Thanks for your attention!

BESIII publications on η/η' decays

- $\eta' \to \pi^+\pi^-\eta$ — Phys. Rev. D **83**, 012003 (2011)
- $\eta/\eta' \to \pi^+\pi^-, \pi^0\pi^0$ — Phys. Rev. D **84**, 032006 (2011)
- $\eta' \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$ — Phys. Rev. Lett. **108**, 182001 (2012)
- $\eta/\eta' \to$invisible — Phys. Rev. D **87**, 012009 (2013)
- weak decay — Phys. Rev. D **87**, 032006 (2013)
- $\eta' \to \pi^+\pi^- l^+ l^-$ — Phys. Rev. D **87**, 092011 (2013)
- $\eta' \to 3(\pi^+\pi^-)$ — Phys. Rev. D **88**, 091502 (2013)
- $\eta' \to 2(\pi^+\pi^-), \pi^+\pi^-\pi^0\pi^0$ — Phys. Rev. Lett **112**, 251801 (2014)
- $\eta' \to \gamma e^+ e^-$ — Phys. Rev. D **92**, 012001 (2015)
- $\eta \to \pi^+\pi^-\pi^0, \eta/\eta' \to \pi^0\pi^0\pi^0$ — Phys. Rev. D **92**, 012014 (2015)
- $\eta' \to \omega e^+ e^-$ — Phys. Rev. D **92**, 051101 (2015)
- $\eta' \to K\pi$ — Phys. Rev. D **93**, 072008 (2016)
- $\eta' \to \rho\pi$ — Phys. Rev. Lett. **118**, 012001 (2017)
- $\eta' \to \gamma\gamma\pi^0$ — Phys. Rev. D **96**, 012005 (2017)
- $\eta' \to \pi^+\pi^-\eta, \eta' \to \pi^0\pi^0\eta$ — Phys. Rev. D **97**, 012003 (2018)
- $\eta' \to \gamma\pi^+\pi^-$ — arXiv:1712.01525 Accepted by PRL