

Light meson decay at BESIII

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On behalf of BESIII collaboration

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Outline:

- BECP II and BES III detector:
- Introduction:
- Radiative decay:
 - $\eta' \rightarrow \gamma\gamma\pi^0$
 - $\eta' \rightarrow \gamma e^+ e^-$
- Hadronic decay:
 - $\eta' \rightarrow \pi^+ \pi^- \pi^0 / \pi^0 \pi^0 \pi^0$
- Rare decay:
 - $\eta' \rightarrow K^\pm \pi^\mp$
- Summary:

BEPCII and BESIII detector

Bird view of BEPCII:



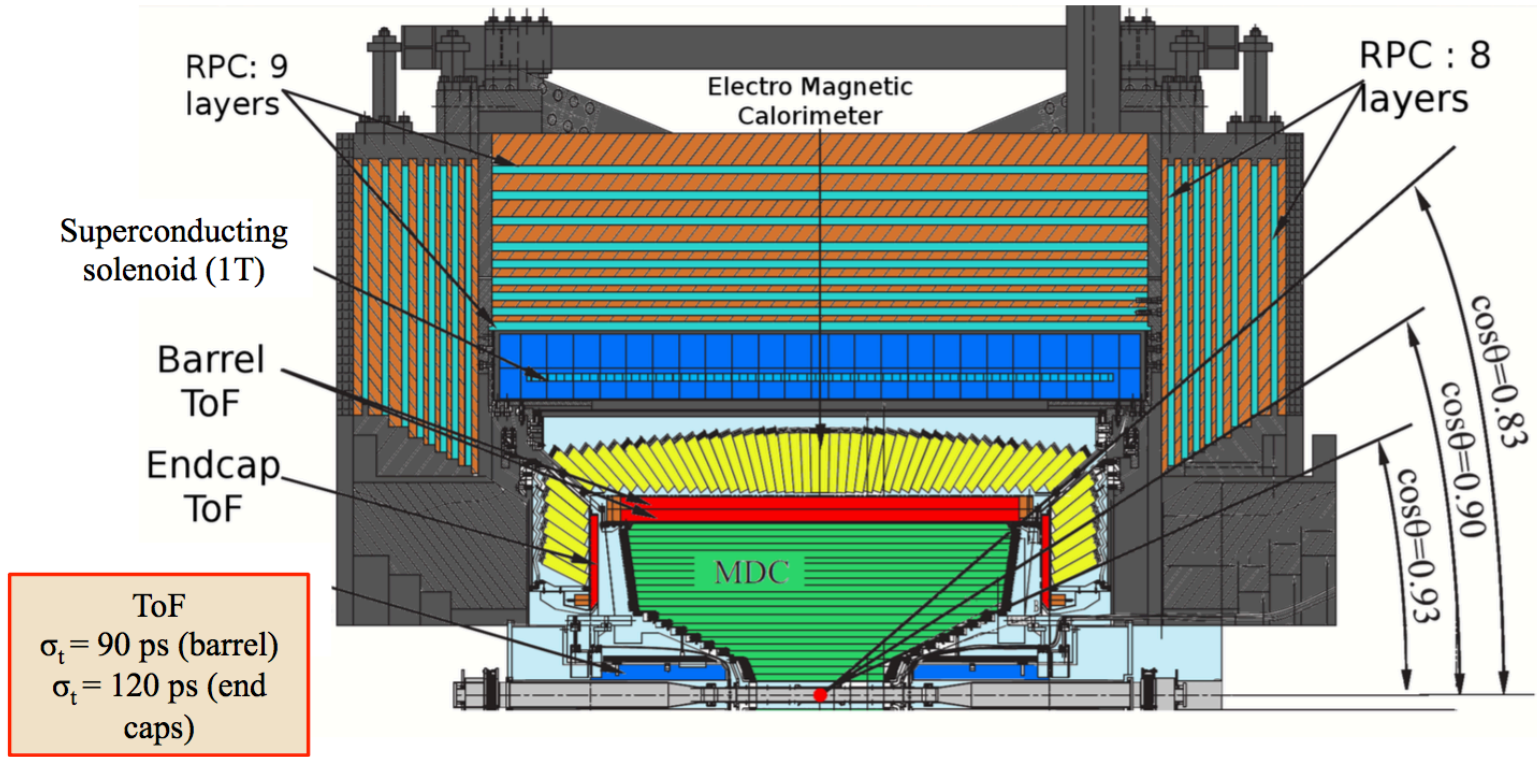
2016/04/05 22:29:41

Luminosity	10.00	E32/cm ² /s
	e+	e-
Energy [GeV]	1.8833	1.8830
Current [mA]	849.97	852.83
Lifetime [hr]	1.52	2.27
Inj.Rate [mA/min]	0.00	0.00

- 2004: started BEPCII/BESIII construction**
- ✓ **Double rings**
- ✓ **Beam energy: 1-2.3 GeV**
- ✓ **Designed luminosity: $1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$**
- 2008: test run**
- 2009 – today: BESIII physics runs**

BESIII detector:

Nucl. Instr. Meth. A614, 345 (2010)



Drift Chamber

$\sigma_{r\phi} = 130$ μm (single wire)

$\sigma_{pt}/p_t = 0.5$ % @ 1 GeV

Electromagnetic CsI(Tl) Calorimeter

$\sigma_E/E < 2.5$ % @ 1 GeV (barrel)

$\sigma_E/E < 5$ % @ 1 GeV (end caps)

$\sigma_{xy} = (6 \text{ mm})/E^{1/2}$ @ 1 GeV

Introduction:

η/η' physics:

□ η/η' : a rich physics field.

- Exploring the effective theory of QCD at low energy.
- Unique stage for understanding the distinct symmetry-breaking mechanisms present in low-energy QCD.
- Probe for physics beyond the Standard Model (SM).

□ Touched physics:

- $\eta' \rightarrow \gamma\gamma\pi^0$: Light meson decay mechanism,
- $\eta' \rightarrow \gamma e^+ e^-$: Transition Form Factor,
- $\eta' \rightarrow \pi\pi\pi$: Quark masses,
- $\eta \rightarrow \pi^+ \pi^- \pi^0$: Fundamental symmetries,
- $\eta/\eta' \rightarrow \pi\pi$: CP or P violation,
- $\eta' \rightarrow \mu e$: Lepton flavor violation,
- and more.

η/η' events at BESIII:

- 1.3×10^9 J/ψ events (2009+2012).
- η/η' from J/ψ radiative decay:
 - 1.4×10^6 η
 - 6.8×10^6 η'
- η/η' from J/ψ hadronic decay (e.g. $J/\psi \rightarrow \phi\eta'$):
 - 5×10^5 η
 - 3×10^5 η'
- World's largest data sample of J/ψ .
- Large data samples and an unique opportunity to investigate the decay of η/η' .

Radiative decay:

$J/\psi \rightarrow \gamma\eta', \eta' \rightarrow \gamma\gamma\pi^0$: motivation and inclusive decay

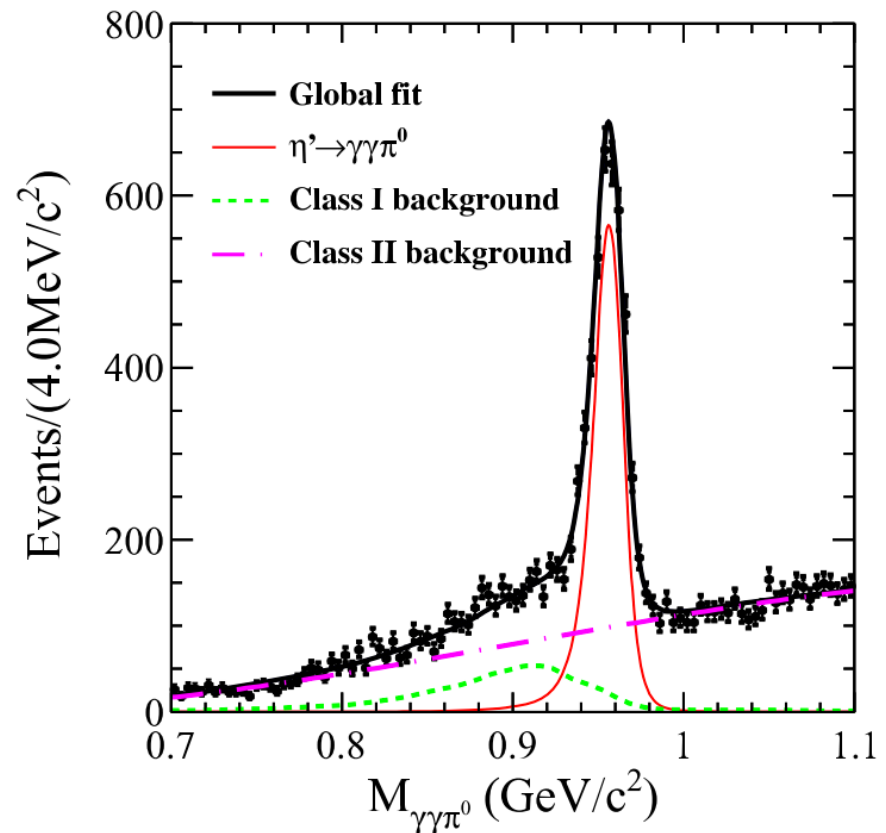
PRD 96, 012005 (2017)

□ Motivation:

- Test QCD calculations on the Transition Form Factor.
- Provide valuable inputs to the theoretical understanding of the light meson decay mechanisms.

□ Components:

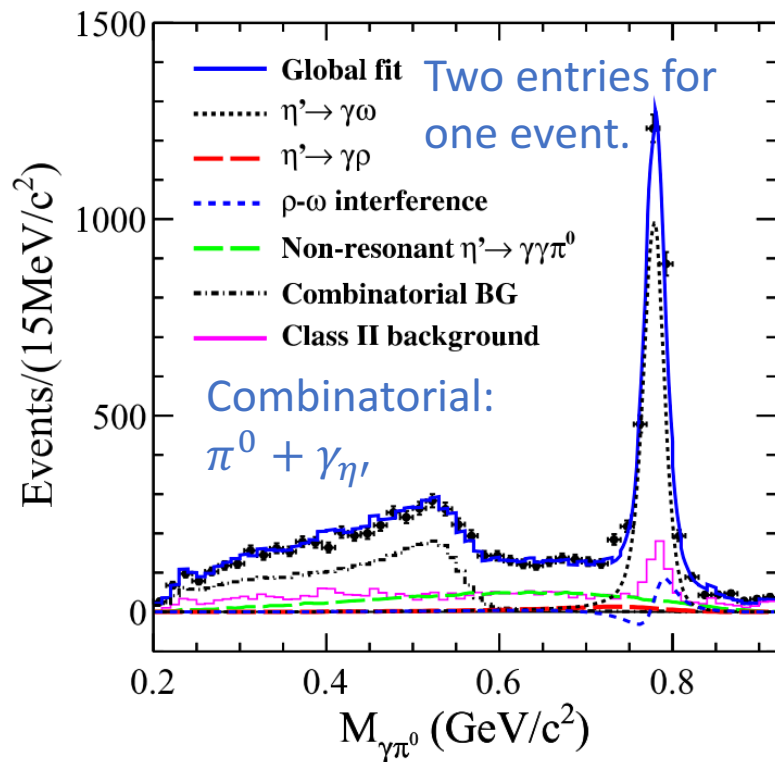
- **Signal:** inclusive decay (incoherent sum of ρ , ω and non-resonant component).
- **Class I:** $J/\psi \rightarrow \gamma\eta'$ with η' decaying into other final states ($\eta' \rightarrow \pi^0\pi^0\eta$, $\eta' \rightarrow 3\pi^0$).
- **Class II:** J/ψ to final states without η' ($J/\psi \rightarrow \gamma\pi^0\pi^0$, $J/\psi \rightarrow \omega\eta$).



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

$J/\psi \rightarrow \gamma\eta', \eta' \rightarrow \gamma\gamma\pi^0$: N-R decay and summary

PRD **96**, 012005 (2017)



- $BR(\eta' \rightarrow \gamma\gamma\pi^0)_{\text{Incl}}$ is measured for the first time.
- $(\eta' \rightarrow \gamma\gamma\pi^0)_{\text{NR}}$ is observed for the first time and BR agrees with the upper limit by GAMS-2000.
 Z. Phys. C 36, 603 (1987)
- Measured BRs could provide valuable inputs to theoretical understanding of light meson decay mechanisms.

	$\eta' \rightarrow \gamma\gamma\pi^0$ (Inclusive)	$\eta' \rightarrow \gamma\omega, \omega \rightarrow \gamma\pi^0$	$\eta' \rightarrow \gamma\gamma\pi^0$ (Nonresonant)
$N^{\eta'}$	$3435 \pm 76 \pm 244$	$2340 \pm 141 \pm 180$	$655 \pm 68 \pm 71$
ϵ	16.1%	14.8%	15.9%
$\mathcal{B}(10^{-4})$	$32.0 \pm 0.7 \pm 2.3$	$23.7 \pm 1.4 \pm 1.8^a$	$6.16 \pm 0.64 \pm 0.67$
$\mathcal{B}_{\text{PDG}}(10^{-4})$		Validation 21.7 ± 1.3^b	GAMS-2000 < 8
Predictions (10^{-4})			

$J/\psi \rightarrow \gamma\eta', \eta' \rightarrow \gamma e^+ e^-$: motivation

PRD **92**, 012001 (2015)

□ Decay rate:

$$\frac{d\Gamma(\eta' \rightarrow \gamma l^+ l^-)}{dq^2 \Gamma(\eta' \rightarrow \gamma\gamma)}$$

Phys. Rep. 128, 301 (1985)

$$= \frac{2\alpha}{3\pi} \frac{1}{q^2} \sqrt{1 - \frac{4m_l^2}{q^2}} \left(1 + \frac{2m_l^2}{q^2}\right) \left(1 - \frac{q^2}{m_{\eta'}^2}\right)^3 |F(q^2)|^2$$

$$= [\text{QED}(q^2)] \times |F(q^2)|^2$$

Transition Form Factor:

Inner structure of mesons.

Vector Meson Dominance model.

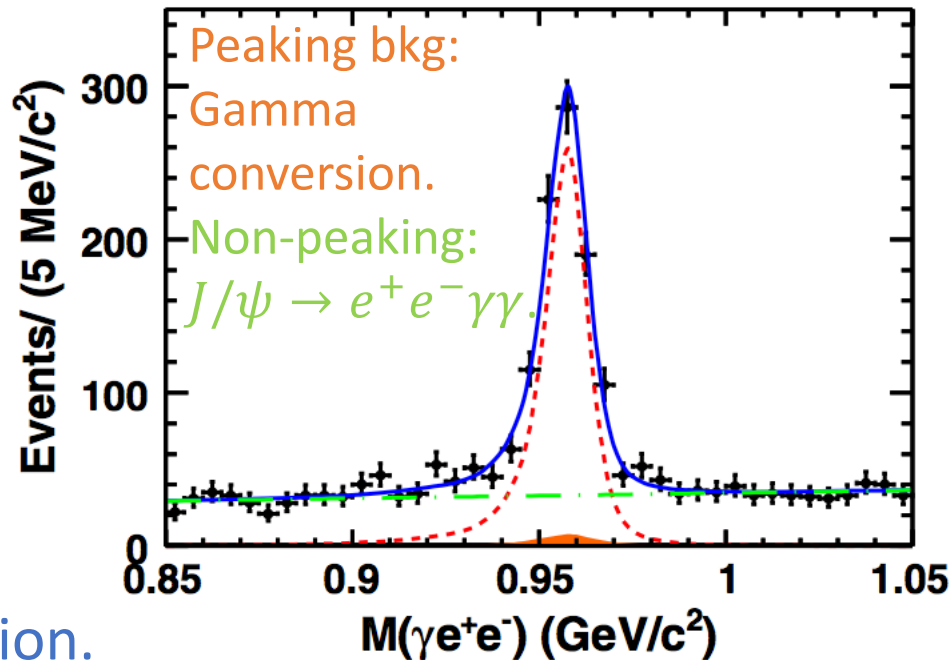
Point-like particles.

□ TFF: important in $a_\mu = \frac{g_{\mu-2}}{2}$, for theoretical calculation of a_μ can be related to form factors in $P \rightarrow \gamma\gamma^* \rightarrow \gamma e^+ e^-$.

□ EM Dalitz decay of $\eta' \rightarrow \gamma e^+ e^-$ had not been observed.

$J/\psi \rightarrow \gamma\eta', \eta' \rightarrow \gamma e^+ e^-$: observation

PRD **92**, 012001 (2015)



$\eta' \rightarrow \gamma\gamma$:

For normalization.

Purpose: partially cancel syst. errs.

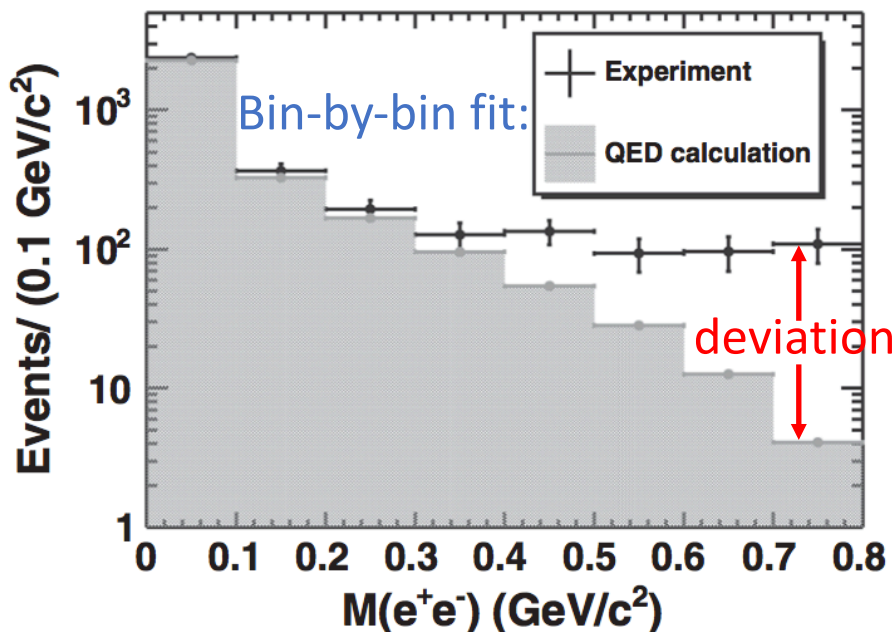
Consistent with
VMD's prediction:
$$\frac{\Gamma(\eta' \rightarrow \gamma e^+ e^-)}{\Gamma(\eta' \rightarrow \gamma\gamma)} = (2.06 \pm 0.02) \times 10^{-2}$$

arXiv:1010.2378

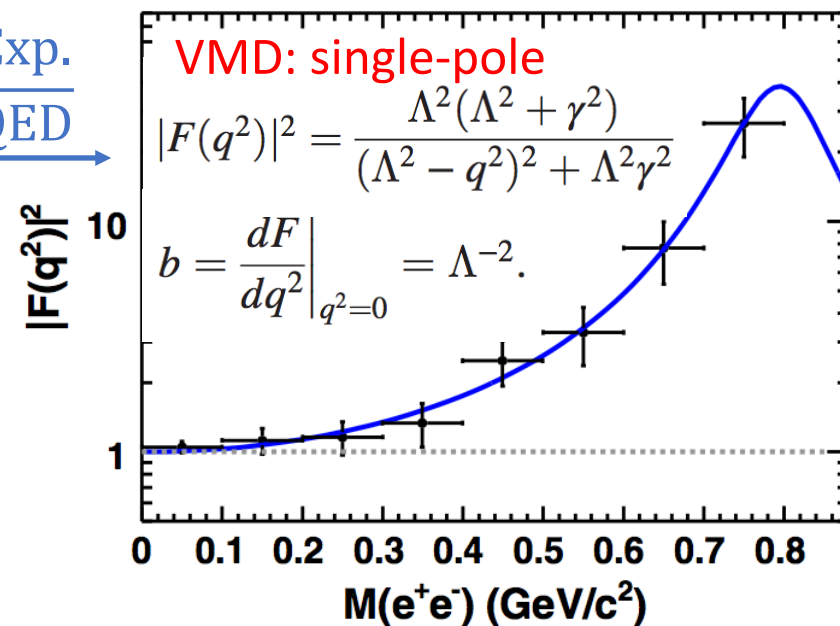
$$\frac{\Gamma(\eta' \rightarrow \gamma e^+ e^-)}{\Gamma(\eta' \rightarrow \gamma\gamma)} = (2.13 \pm 0.09(\text{stat}) \pm 0.07(\text{sys})) \times 10^{-2}$$
$$\mathcal{B}(\eta' \rightarrow \gamma e^+ e^-) = (4.69 \pm 0.20(\text{stat}) \pm 0.23(\text{sys})) \times 10^{-4}$$

$J/\psi \rightarrow \gamma\eta', \eta' \rightarrow \gamma e^+ e^-$: Transition Form Factor

PRD 92, 012001 (2015)



Exp.
/
QED



Theoretical predictions:

$b = 1.45 \text{ GeV}^{-2}$ VMD^a a. Phys. Lett. 104B, 311 (1981)

$b = 1.60 \text{ GeV}^{-2}$ ChPT^b b. Phys. Rev. D 45, 986 (1992)

$b = 1.53_{-0.08}^{+0.15} \text{ GeV}^{-2}$ Dispersion^c c. Eur. Phys. J. C 73, 2668 (2013)

$b = 1.53_{-0.08}^{+0.15} \text{ GeV}^{-2}$ Dispersion^c

Results from fit:

$\Lambda_{\eta'} = (0.79 \pm 0.04 \pm 0.02) \text{ GeV}$

$\gamma_{\eta'} = (0.13 \pm 0.06 \pm 0.03) \text{ GeV}$

$b = 1.60 \pm 0.17 \pm 0.08 \text{ GeV}^{-2}$

Slope of TFF is in agreement with theoretical predictions.

Measured TFF helps to improve theoretical precision of α_μ .

Hadronic decay:

$J/\psi \rightarrow \gamma\eta', \eta' \rightarrow \pi^+\pi^-\pi^0 / \pi^0\pi^0\pi^0$:

motivation

PRL 118, 012001 (2017)

- The decay is induced dominantly by the strong interaction via the explicit breaking of chiral symmetry by **d-u quark mass difference**.

- Measure the branching ratios to help to determine quark masses.

- $r_{\pm} = \frac{BR(\eta' \rightarrow \pi^+\pi^-\pi^0)}{BR(\eta' \rightarrow \pi^+\pi^-\eta)} \approx (16.8) \frac{3}{16} \left(\frac{m_d - m_u}{m_s} \right)^2$. Phys. Rev. D 19, 2188 (1979)

- $r_0 = \frac{BR(\eta' \rightarrow \pi^0\pi^0\pi^0)}{BR(\eta' \rightarrow \pi^0\pi^0\eta)}$.

- P-wave contribution: $\eta' \rightarrow \rho\pi$.

- Large for $\eta' \rightarrow \pi^+\pi^-\pi^0$ by chiral effective field theory, had not been observed.

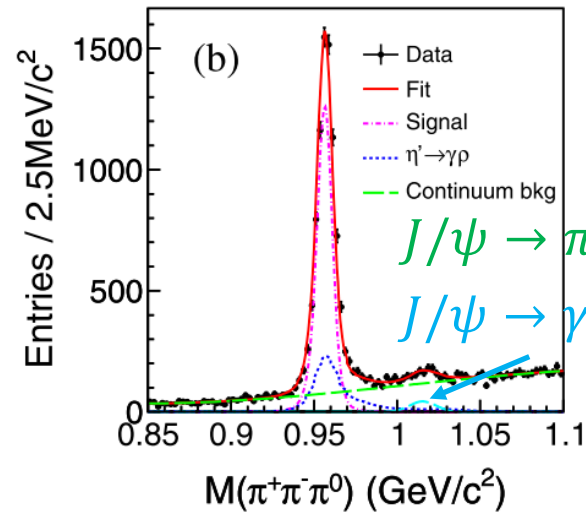
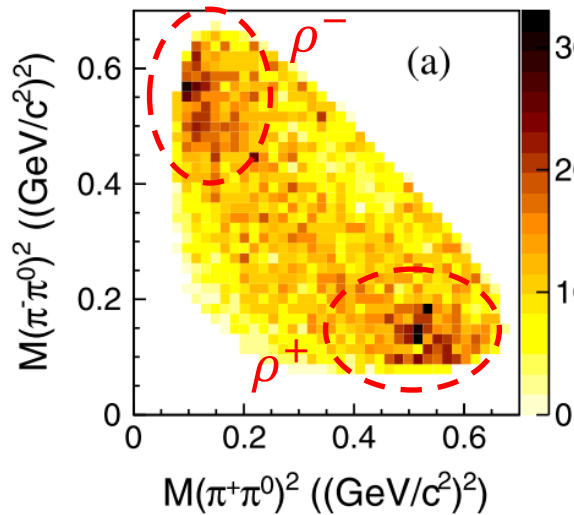
Eur. Phys. J. A 26, 383 (2005)

- Forbidden for $\eta' \rightarrow \pi^0\pi^0\pi^0$ by Bose symmetry.

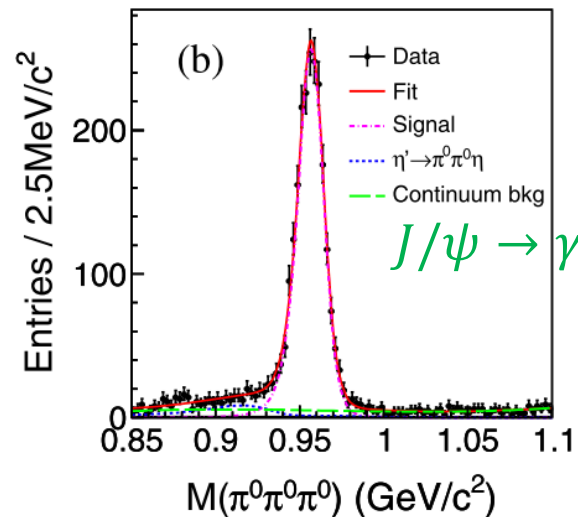
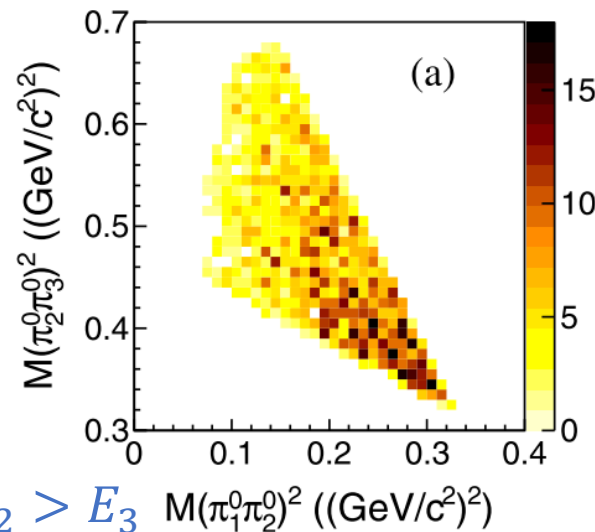
$J/\psi \rightarrow \gamma\eta', \eta' \rightarrow \pi^+\pi^-\pi^0 / \pi^0\pi^0\pi^0$: preparation

PRL 118, 012001 (2017)

$\eta' \rightarrow \pi^+\pi^-\pi^0$:
8267 events



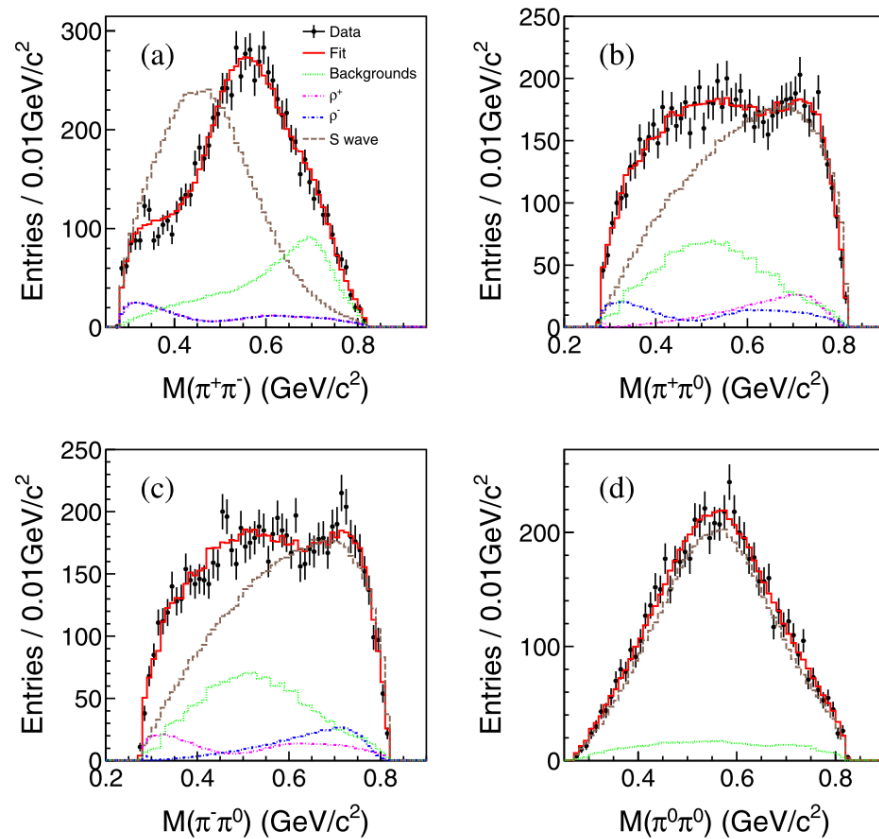
$\eta' \rightarrow \pi^0\pi^0\pi^0$:
2237 events



Purpose:
Obtain the
number of
continuum bkg.

$J/\psi \rightarrow \gamma\eta', \eta' \rightarrow \pi^+\pi^-\pi^0 / \pi^0\pi^0\pi^0$: result of amplitude analysis

PRL **118**, 012001 (2017)



- ▣ P-wave (ρ^\pm) is observed for the first time.
- ▣ In addition to non-resonant S-wave, resonant S-wave (σ) is observed (strong interference \rightarrow sum of S-wave).
- ▣ $BR(\eta' \rightarrow \pi^0\pi^0\pi^0)$: consistent to previous **BESIII** $[(35.6 \pm 4.0) \times 10^{-4}]^a$, two times larger than **GAMS** $[(16.0 \pm 3.2) \times 10^{-4}]^b$.
a. Phys. Rev. Lett. 108, 182001 (2012)
 b. Z. Phys. C 36, 603 (1987)

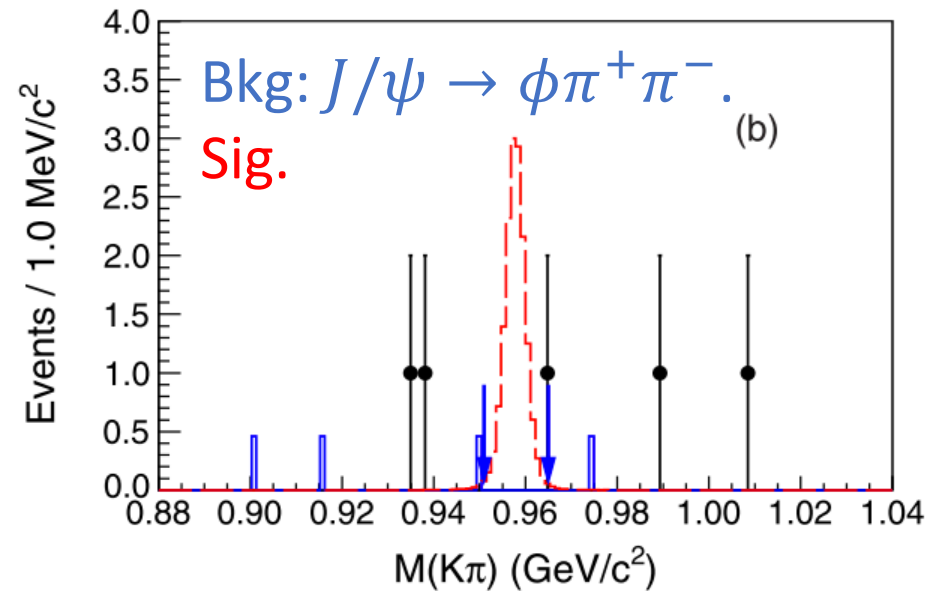
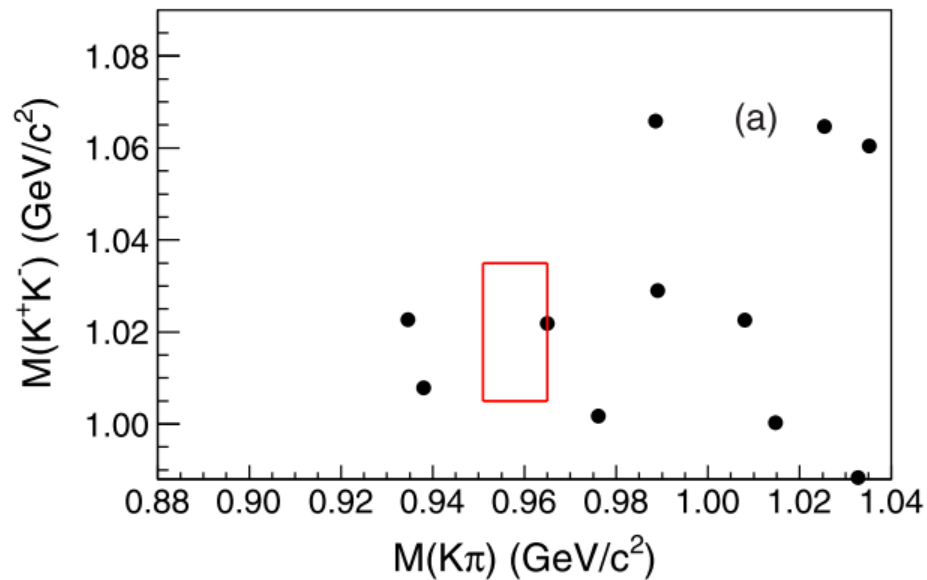
Decay mode	BR (10^{-4})	Comments
$\rho^\pm\pi^\mp$	$7.44 \pm 0.60 \pm 1.26 \pm 1.84$	P-wave
$\pi^+\pi^-\pi^0$	$37.63 \pm 0.77 \pm 2.22 \pm 4.48$	Sum of S-wave
$\pi^0\pi^0\pi^0$	$35.22 \pm 0.82 \pm 2.54$	

Observed substantial P- and S-wave resonant contributions have to be properly considered by theory before attempting to determine light quark masses from r .

Rare decay:

Searching for $J/\psi \rightarrow \phi\eta', \eta' \rightarrow K^\pm\pi^\mp$:

PRD **93**, 072008 (2016)



$$\frac{BR(\eta' \rightarrow K^\pm\pi^\mp)}{BR(\eta' \rightarrow \gamma\pi^+\pi^-)} < 1.3 \times 10^{-4} \text{ @90\% C.L.}$$
$$BR(\eta' \rightarrow K^\pm\pi^\mp) < 3.8 \times 10^{-5} \text{ @90\% C.L.}$$

Summary:

- η/η' decay: a rich physics field.
- Mentioned results in this report:

Decay processes:	Measurements:	Reference:
$\eta' \rightarrow \gamma\gamma\pi^0$	BR, N-R decay	PRD 96 , 012005 (2017)
$\eta' \rightarrow \gamma e^+ e^-$	BR, TFF	PRD 92 , 012001 (2015)
$\eta' \rightarrow \pi^+ \pi^- \pi^0 / \pi^0 \pi^0 \pi^0$	ρ, σ , BR	PRL 118 , 012001 (2017)
$\eta' \rightarrow K^\pm \pi^\mp$	UL on BR	PRD 93 , 072008 (2016)

- More results are expected to come soon.

Thank you.

Back up