



Highlights on Light Meson Physics

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Mini-Workshop on BESIII Physics-- 500 Publications

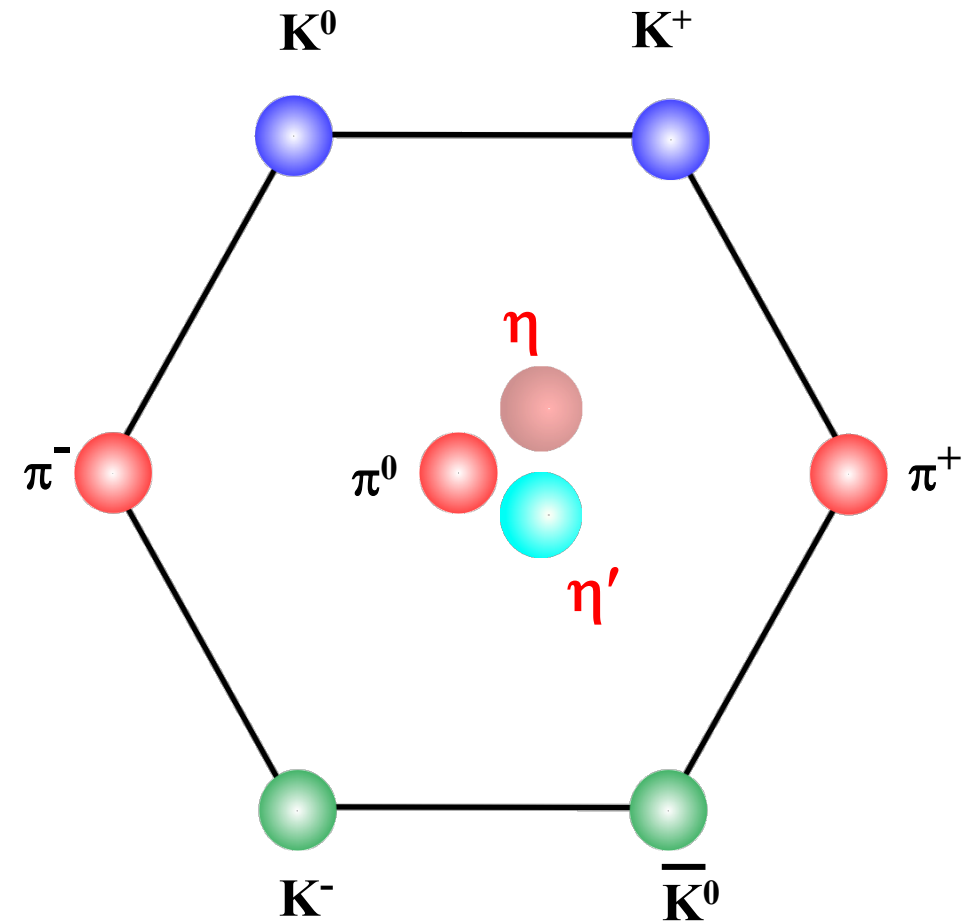
May 31st , 2023

OUTLINE

- Light meson physics
- BESIII: a light meson factory
- What is "NEW" at BESIII ?
- Summary

Light Meson Physics

- Light mesons
 - Important roles in particle physics, e.g. strong interactions, Quark Model, CP violation ...
- Rich physics
 - Test ChPT predictions
 - EM Form factors
 - Test fundamental symmetries
 - Probe new physics beyond the SM



Source of η/η' events



CLAS(12)



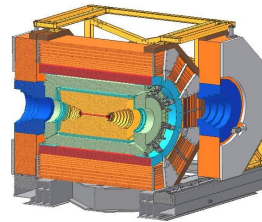
Crystal Ball



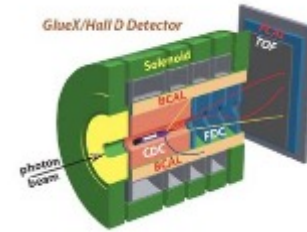
WASA-at-COSY



KLOE-2

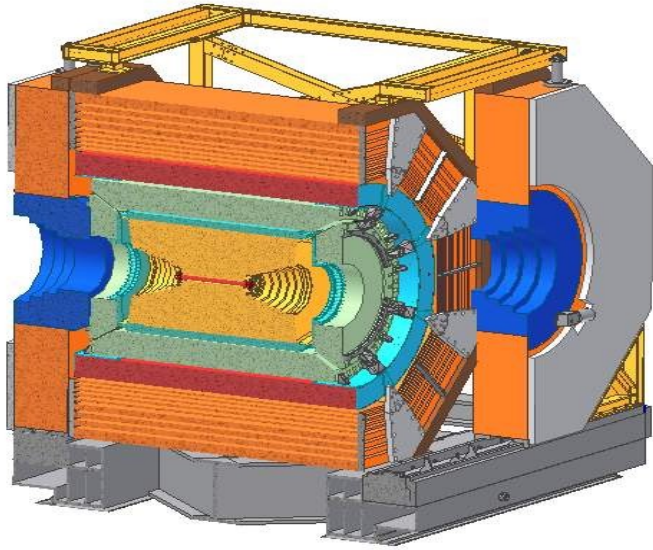


BESIII

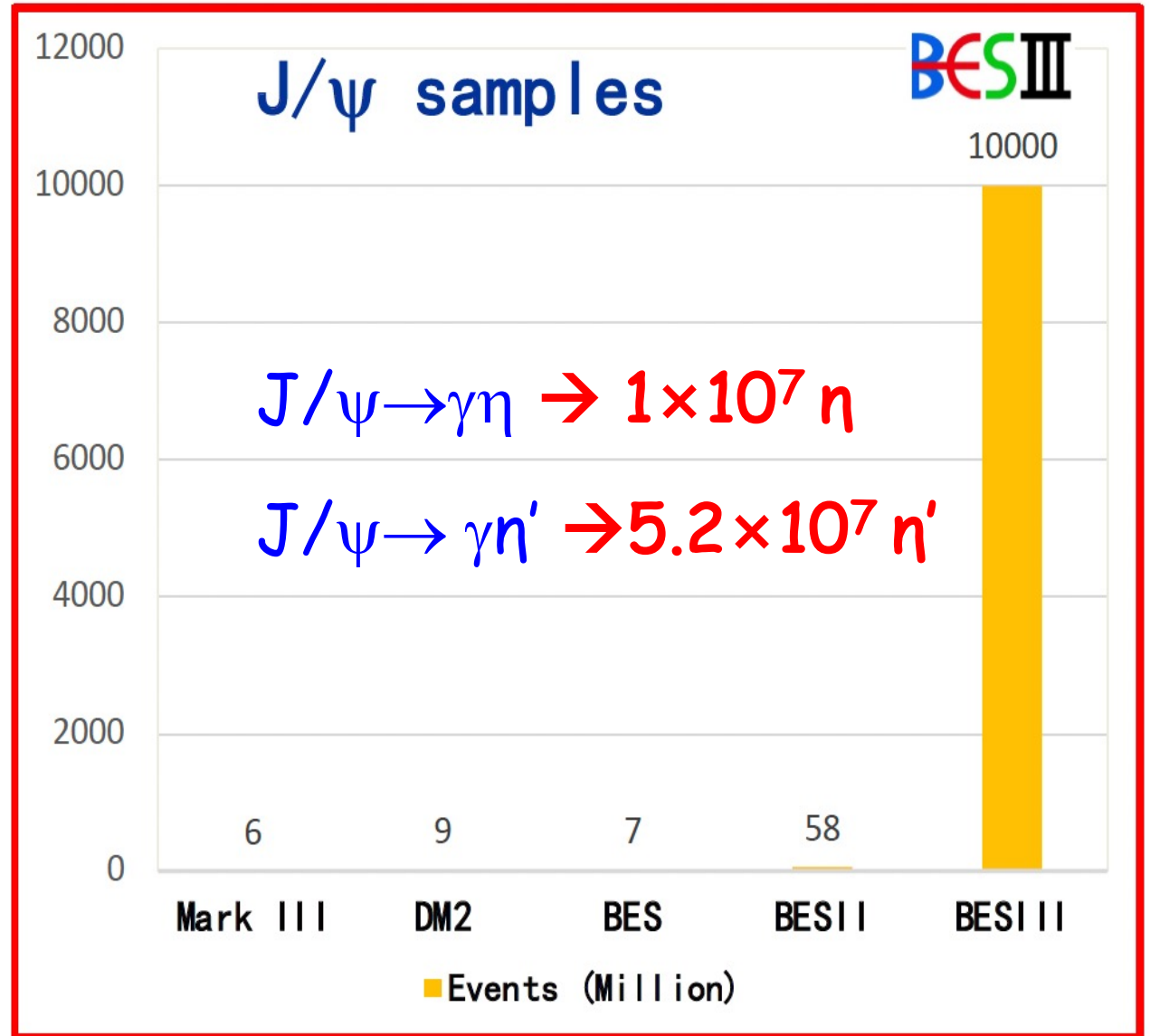


GlueX

η/η' events at BESIII



A light meson factory !



BESIII: an important role in η/η' decays

(25 publications since 2011)

What is "NEW" at BESIII ?

- New decays
- New decay mechanisms
- New approaches
- New tests for fundamental symmetries

$\eta'(958)$ REFERENCES

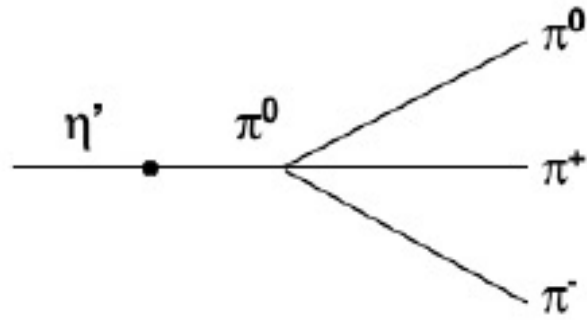
ABLIKIM	21I	PR D103 072006	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	21J	PR D103 092005	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	20E	PR D101 032001	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	19AW	PR D100 052015	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	19T	PRL 122 142002	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	18	PR D97 012003	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	18C	PRL 120 242003	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ADLARSON	18A	PR D98 012001	P. Adlarson <i>et al.</i>	(A2 Collab. at MAMI)
GONZALEZ-S...	18A	EPJ C78 758	S. Gonzalez-Solis, E. Passemar	(BEIJ, IND+)
AAIJ	17D	PL B764 233	R. Aaij <i>et al.</i>	(LHCb Collab.)
ABLIKIM	17	PRL 118 012001	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	17T	PR D96 012005	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	16M	PR D93 072008	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	15AD	PR D92 051101	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	15O	PR D92 012001	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	15P	PR D92 012007	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ACHASOV	15	PR D91 092010	M.N. Achasov <i>et al.</i>	(SND Collab.)
AKHMETSHIN	15	PL B740 273	R.R. Akhmetshin <i>et al.</i>	(CMD-3 Collab.)
PDG	15	RPP 2015 at pdg.lbl.gov		(PDG Collab.)
ABLIKIM	14M	PRL 112 251801	M. Ablikim <i>et al.</i>	(BESIII Collab.)
DONSKOV	14	MPL A29 1450213	S. Donskov <i>et al.</i>	(GAMS-4π Collab.)
PDG	14	CP C38 070001	K. Olive <i>et al.</i>	(PDG Collab.)
ABLIKIM	13	PR D87 012009	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	13O	PR D87 092011	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	13U	PR D88 091502	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	12F	PRL 108 182001	M. Ablikim <i>et al.</i>	(BESIII Collab.)
PDG	12	PR D86 010001	J. Beringer <i>et al.</i>	(PDG Collab.)
ABLIKIM	11	PR D83 012003	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim <i>et al.</i>	(BESIII Collab.)

PDG2022

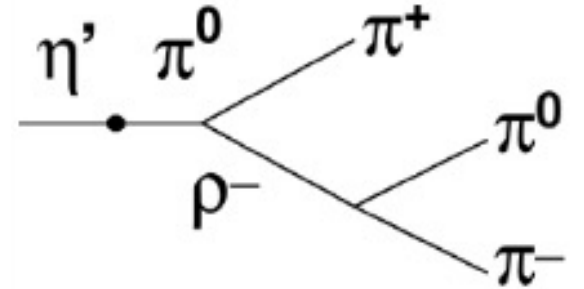
New decays

$\eta' \rightarrow 2(\pi^+\pi^-), \pi^+\pi^-\pi^0\pi^0$	PRL112, 251801(2014)
$\eta' \rightarrow \gamma e^+e^-$	PRD92, 012001(2015)
$\eta' \rightarrow \omega e^+e^-$	PRD92, 051101(2015)
$\eta' \rightarrow \rho\pi$	PRL118, 012001(2017)
$\eta' \rightarrow \gamma\gamma\pi^0$	PRD96, 012005(2017)
$\eta' \rightarrow \pi^+\pi^-\bar{u}u^-$	PRD103, 072006(2021)
$\eta' \rightarrow e^+e^-e^+e^-$	PRD105, 112010(2022)

Observation of $\eta' \rightarrow \rho^+ \pi^-$



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



D. Gross et al., PRD19,2188(1979)

N. Beisert et al., Nucl. Phys. A716,186(2003)

Search for η' and X(1835) Decays into $\pi^+ \pi^- \pi^0$

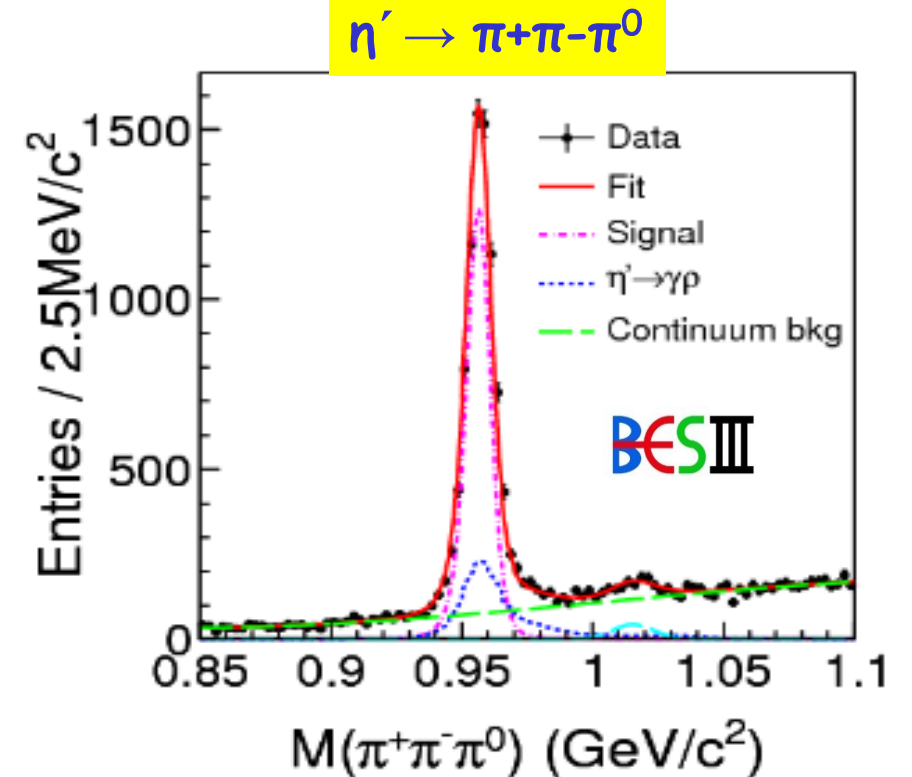
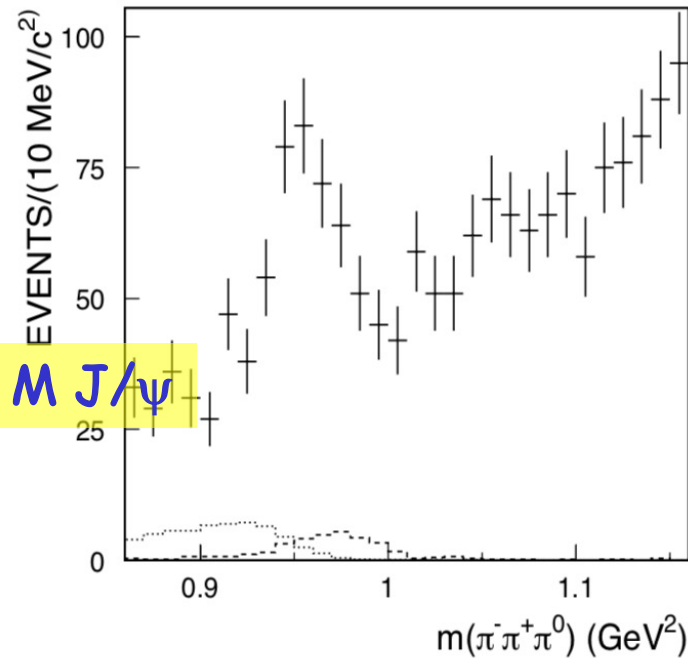
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 Haibo Li¹ Hongbang Liu¹ Xiaoyan Shen¹
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September 29, 2008

Abstract

Based on the 58 million J/ψ events accumulated with the BESII detector at the BEPC, the isospin violating decay mode, $\eta' \rightarrow \pi^+ \pi^- \pi^0$, is analyzed via $J/\psi \rightarrow \gamma \eta'$. The branching fraction ratio of $\eta' \rightarrow \pi^+ \pi^- \pi^0$ to $\eta' \rightarrow \pi^+ \pi^- \eta$ is determined to be $(1.14 \pm 0.19)\%$ and the corresponding branching fraction of $\eta' \rightarrow \pi^+ \pi^- \pi^0$ is $(5.08 \pm 0.82) \times 10^{-3}$, which are consistent with the previous measurements by CLEO Collaboration. No significant X(1835) signal is observed in the analysis, and the upper limit of the product branching fraction is measured to be $B(J/\psi \rightarrow \gamma X(1835)) \cdot B(X(1835) \rightarrow \pi^+ \pi^- \pi^0) < 3.9 \times 10^{-5}$

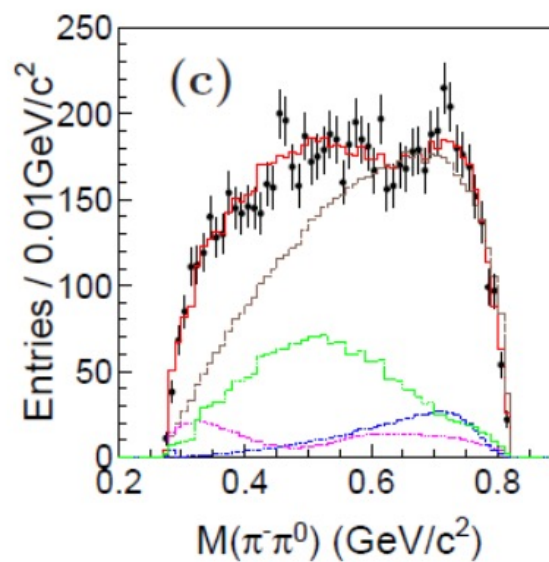
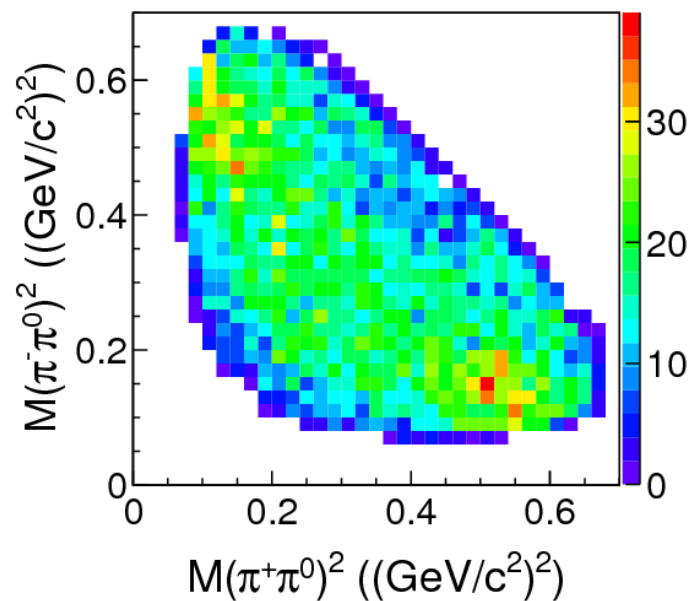
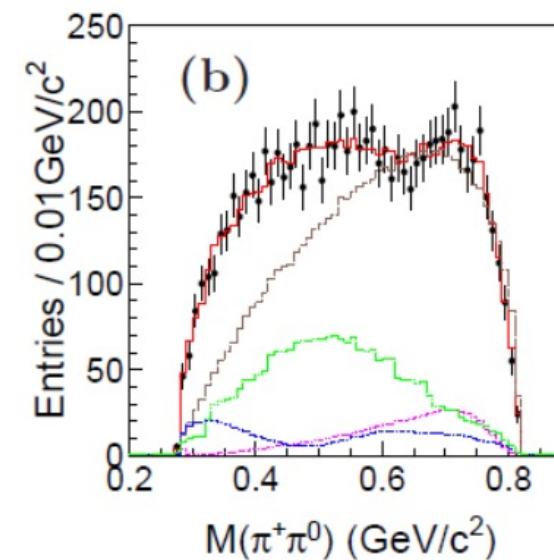
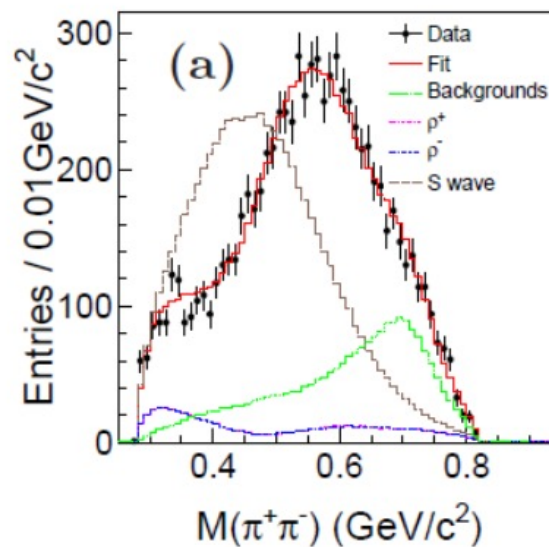
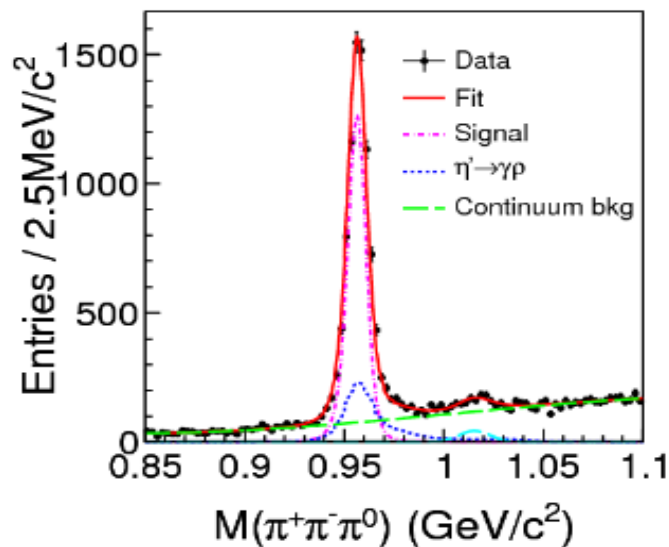
BESII: 58 M J/ψ



Observation of $\eta' \rightarrow \rho^+ \pi^-$

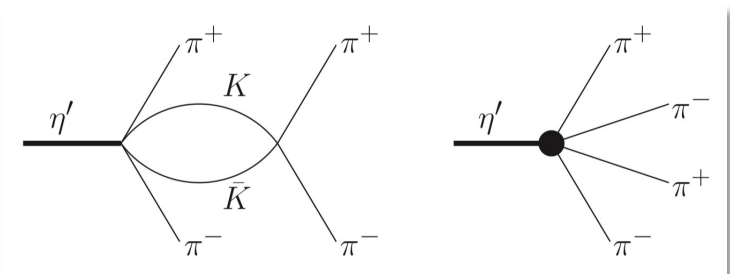
PRL118, 012001(2017)

$\eta' \rightarrow \pi^+ \pi^- \pi^0$



Decay Mode	$\mathcal{B} (\times 10^{-4})$
$\pi^+ \pi^- \pi^0$	$35.91 \pm 0.54 \pm 1.74$
$\pi^0 \pi^0 \pi^0$	$35.22 \pm 0.82 \pm 2.60$
$\rho^+ \pi^-$	$3.72 \pm 0.30 \pm 0.63 \pm 0.92$
$\rho^- \pi^+$	$3.72 \pm 0.30 \pm 0.63 \pm 0.92$
$(\pi^+ \pi^- \pi^0)_S$	$37.63 \pm 0.77 \pm 2.22 \pm 4.48$

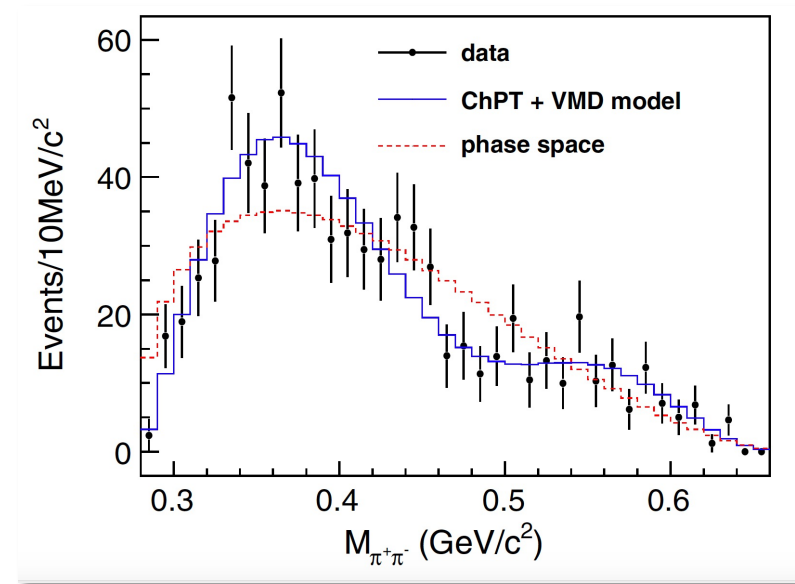
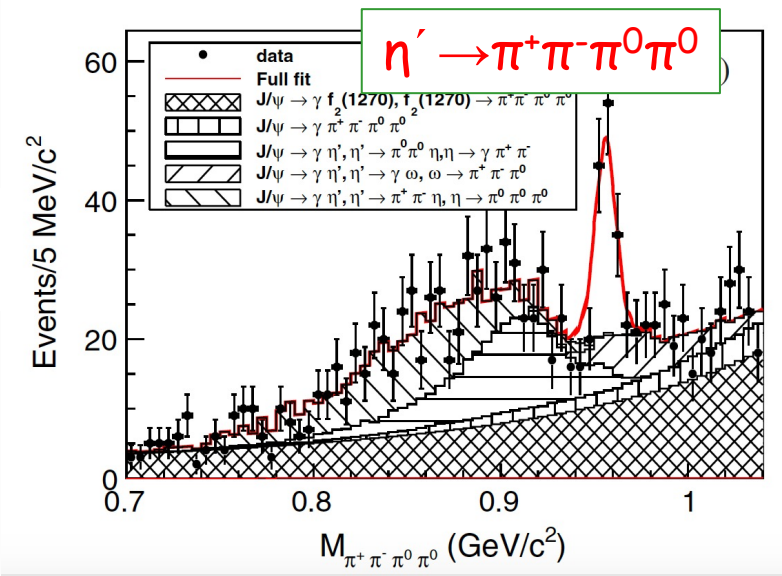
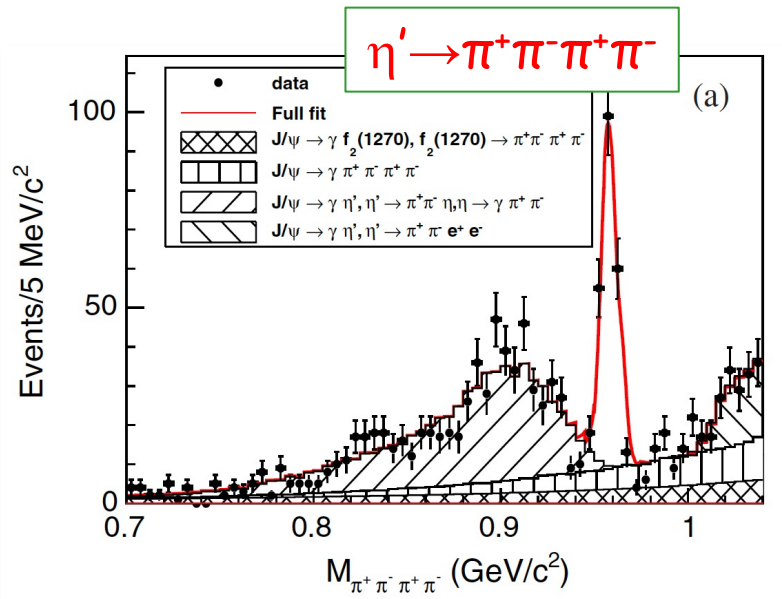
Observation of $\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0$



**ChPT+VMD:
only occur at $O(p^6)$**

$B(\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-) = (1.0 \pm 0.3) \times 10^{-4}$
 $B(\eta' \rightarrow \pi^+\pi^-\pi^0\pi^0) = (2.4 \pm 0.7) \times 10^{-4}$

F.K. Guo et al, PRD 85,014014 (2012)

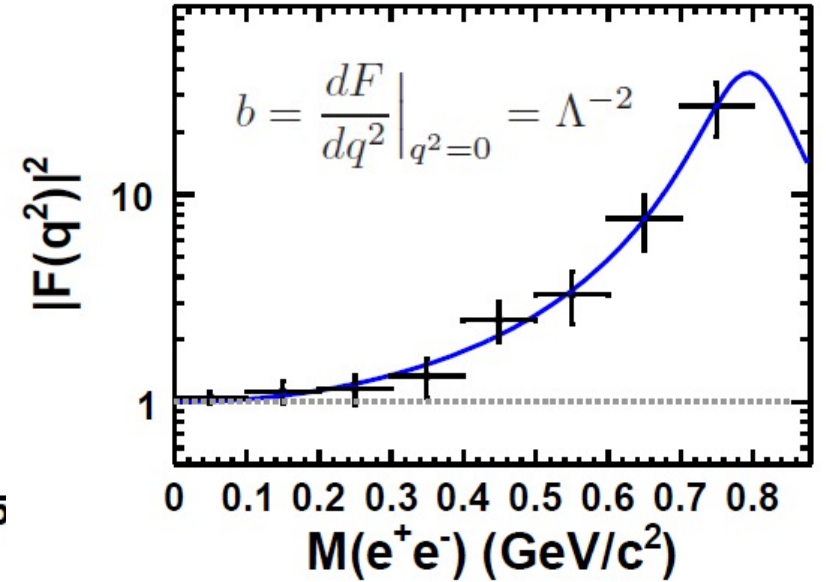
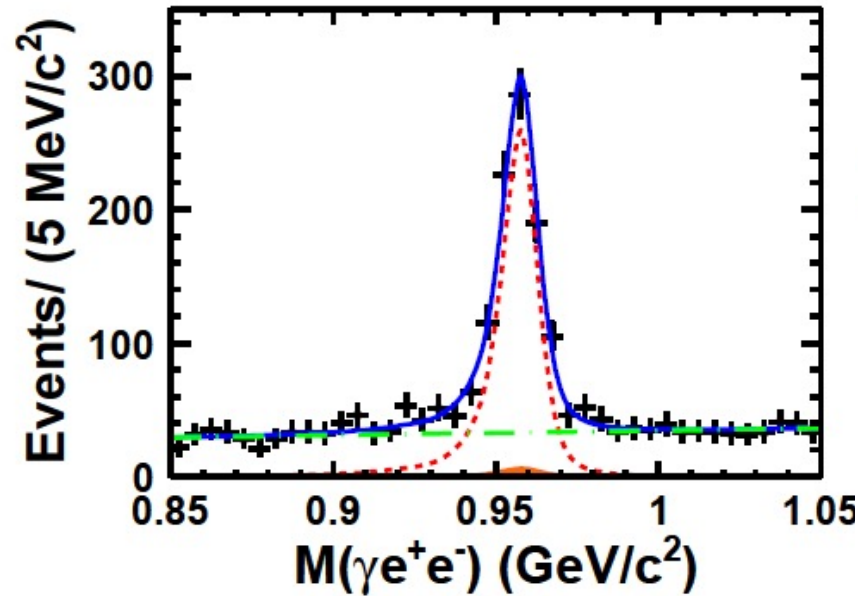
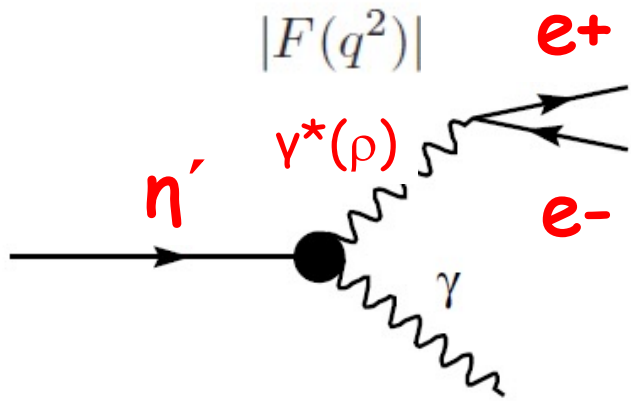


PRL112,251801(2014)

$B(\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-) = (8.63 \pm 0.69 \pm 0.64) \times 10^{-5}$
 $B(\eta' \rightarrow \pi^+\pi^-\pi^0\pi^0) = (1.82 \pm 0.35 \pm 0.18) \times 10^{-4}$

Amplitude analysis in progress!

Observation of $\eta' \rightarrow \gamma e^+ e^-$



$$B(\eta' \rightarrow \gamma e^+ e^-) = (4.69 \pm 0.20 \pm 0.23) \times 10^{-4}$$

$$4.2 \times 10^{-4} \quad \text{EMT, PRC61,035206}$$

$$b_{\eta'} = 1.60 \pm 0.17 \pm 0.08 \text{ GeV}^{-2}$$

Theoretical predictions:

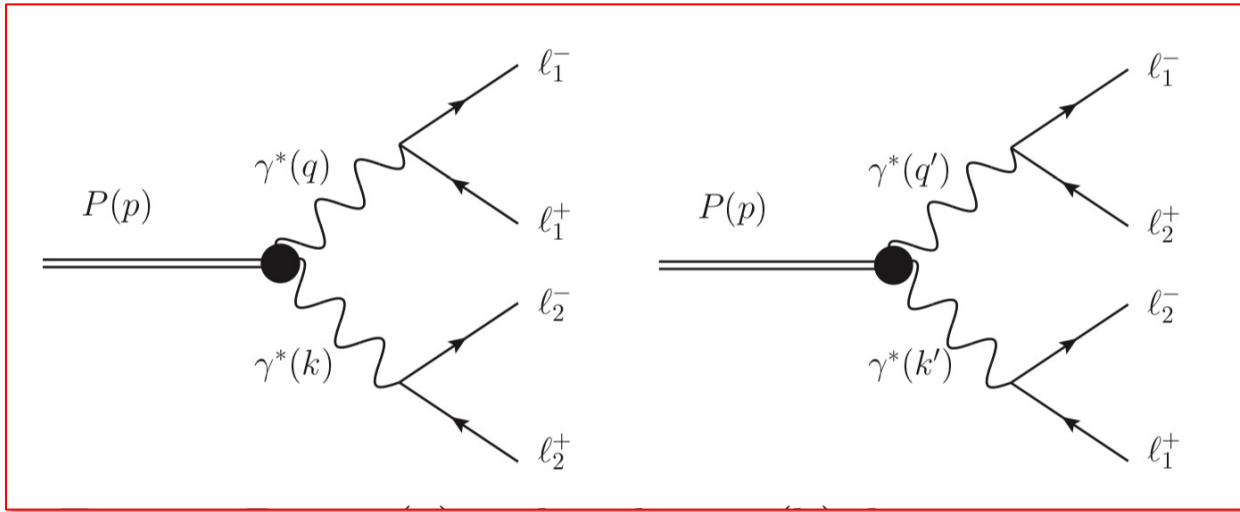
$$b_{\eta'} = 1.45 \text{ GeV}^{-2} \quad \text{VMD}$$

$$b_{\eta'} = 1.60 \text{ GeV}^{-2} \quad \text{ChPT}$$

$$b_{\eta'} = 1.53^{+0.15}_{-0.08} \text{ GeV}^{-2} \quad \text{Dispersion}$$

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

Chinese Physics C42 (2018) 023109

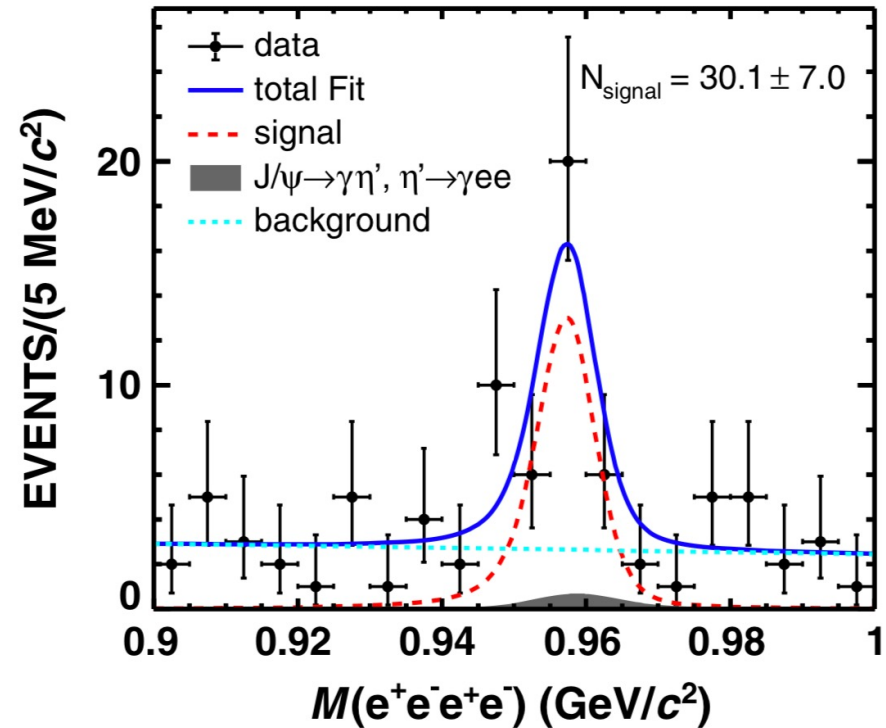


$\eta' \rightarrow e^+e^-e^+e^-$	$2.10(45) \times 10^{-6}$
$\eta' \rightarrow \mu^+\mu^-\mu^+\mu^-$	$1.69(36) \times 10^{-8}$
$\eta' \rightarrow e^+e^-\mu^+\mu^-$	$6.39(91) \times 10^{-7}$

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

$$B(\eta' \rightarrow e^+e^-e^+e^-) = (4.5 \pm 1.0 \pm 0.5) \times 10^{-6}$$

PRD 105, 112010 (2022)

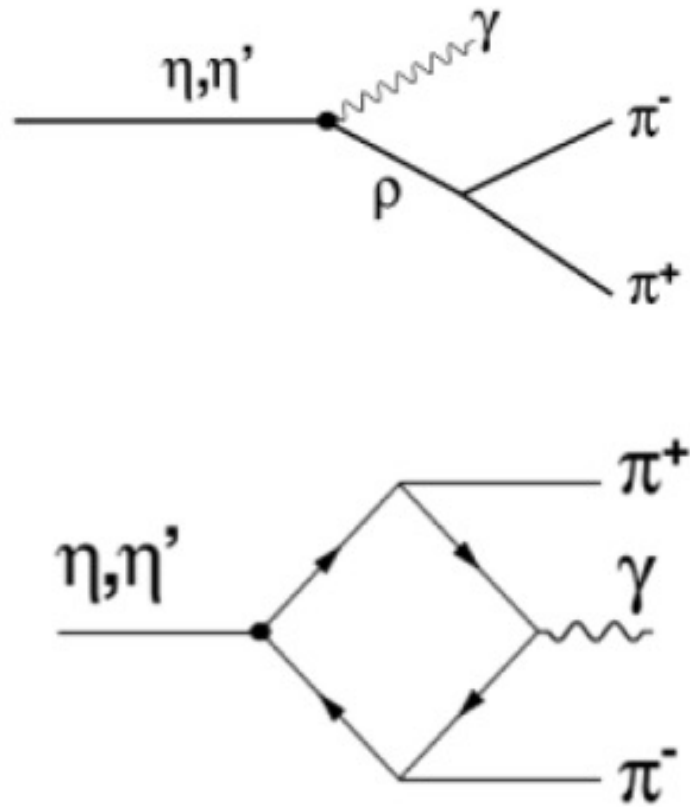


New decay mechanisms

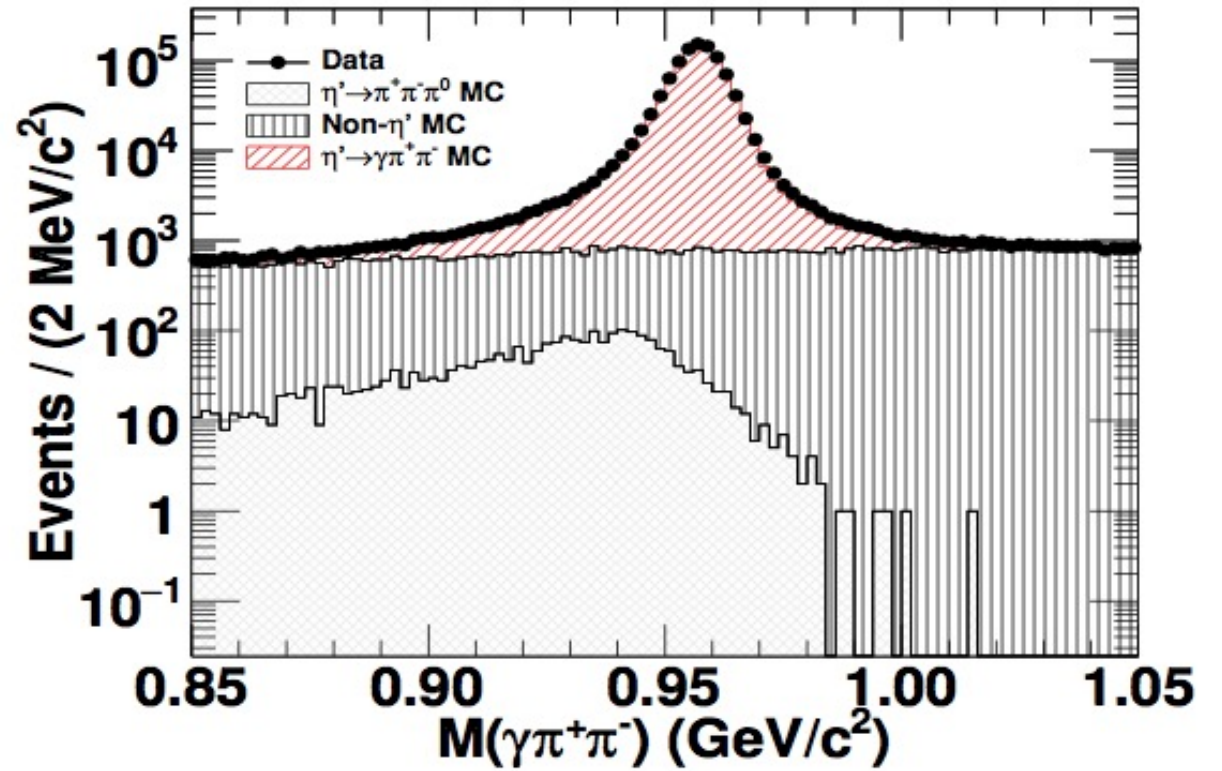
Precision study of $\eta' \rightarrow \gamma \pi^+ \pi^-$ PRL120, 242003(2018)

Evidence of $\eta' \rightarrow \pi^0 \pi^0 \eta$ PRL130, 081901(2023)

$\eta' \rightarrow \gamma\pi^+\pi^-$ decay dynamics



$\sim 0.9M$ events



high term of ChPT \rightarrow box anomaly

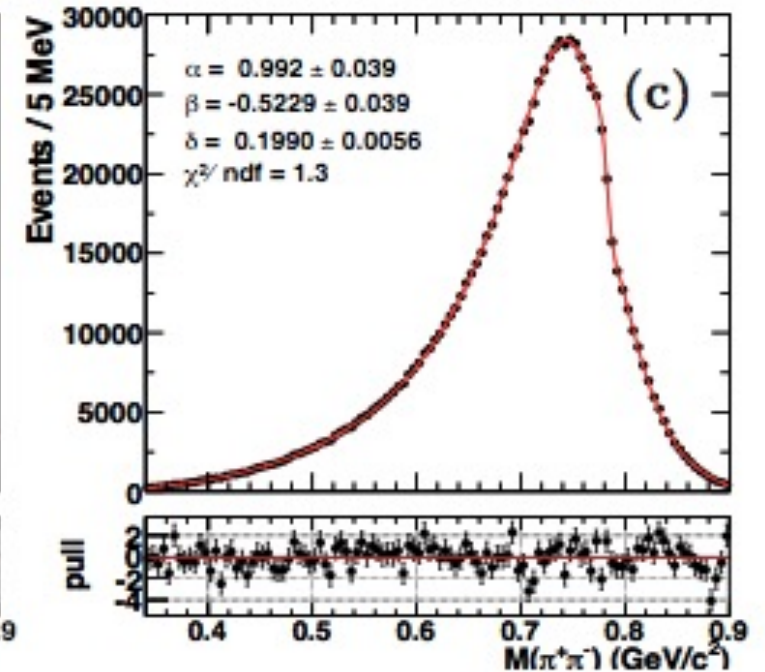
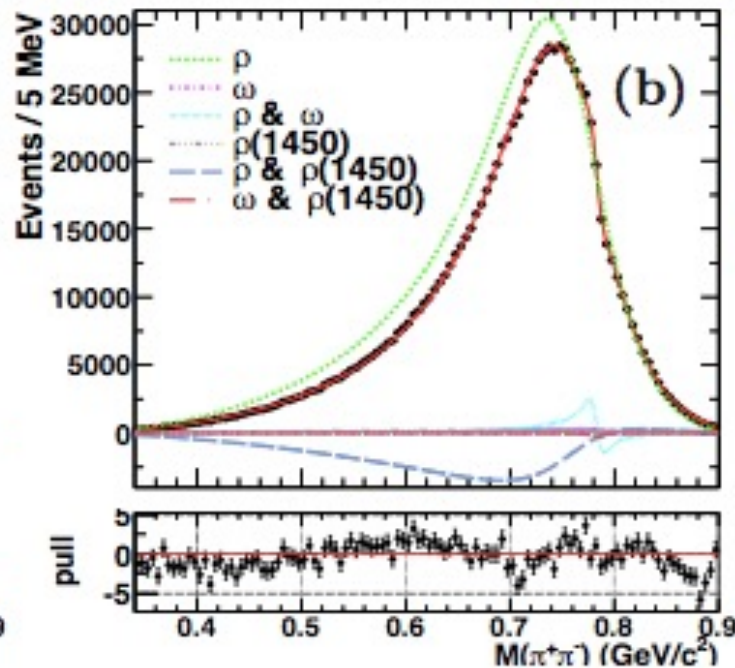
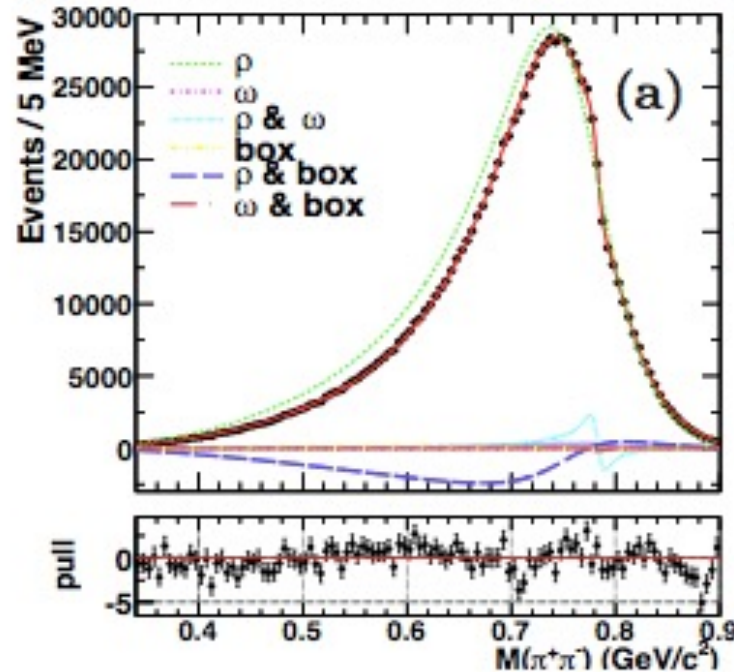
PRL120,242003(2018)

Model-(in)dependent fit

fit with $\rho(770)$ - ω -box anomaly

fit with $\rho(770)$ - ω - $\rho(1450)$

$$P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi} + \beta O(s_{\pi\pi}^2) + \delta BW_{\omega}$$



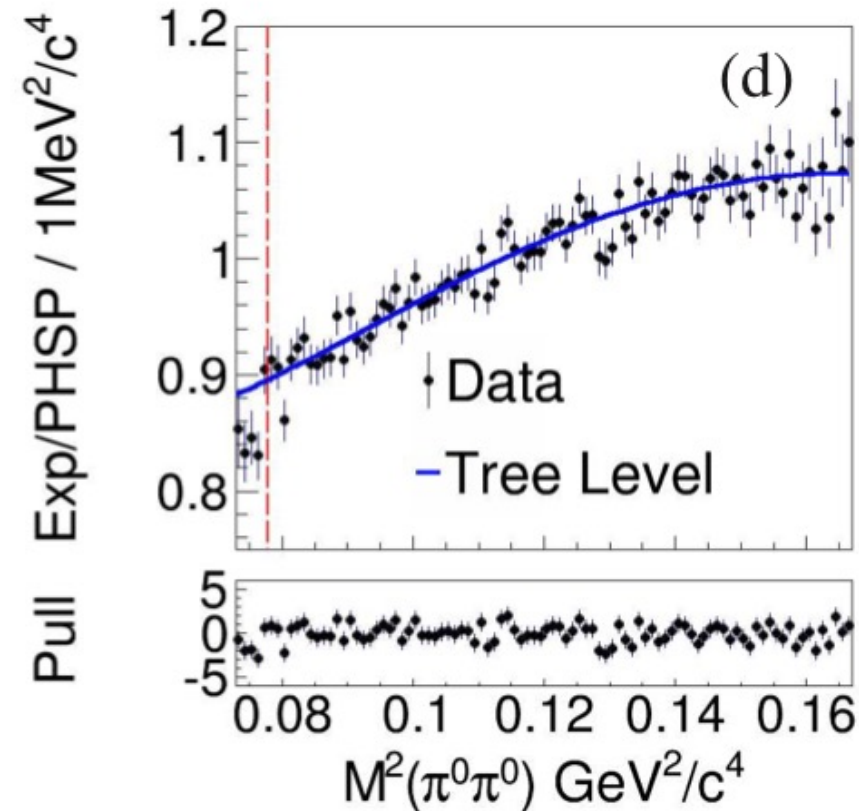
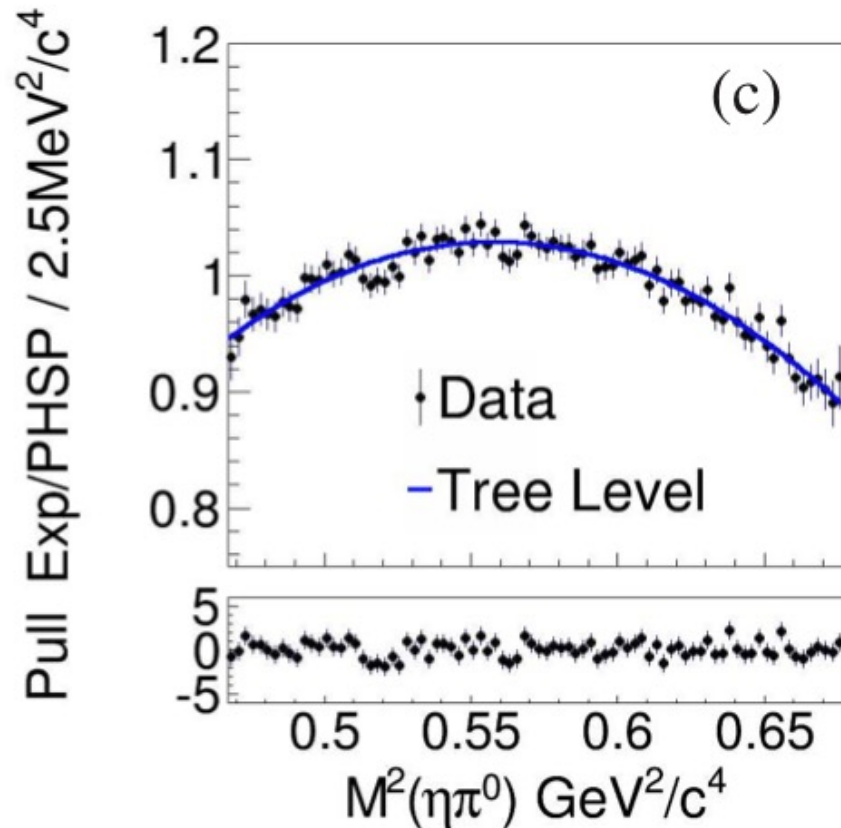
✓ $\rho(770)$ - ω cannot describe data well

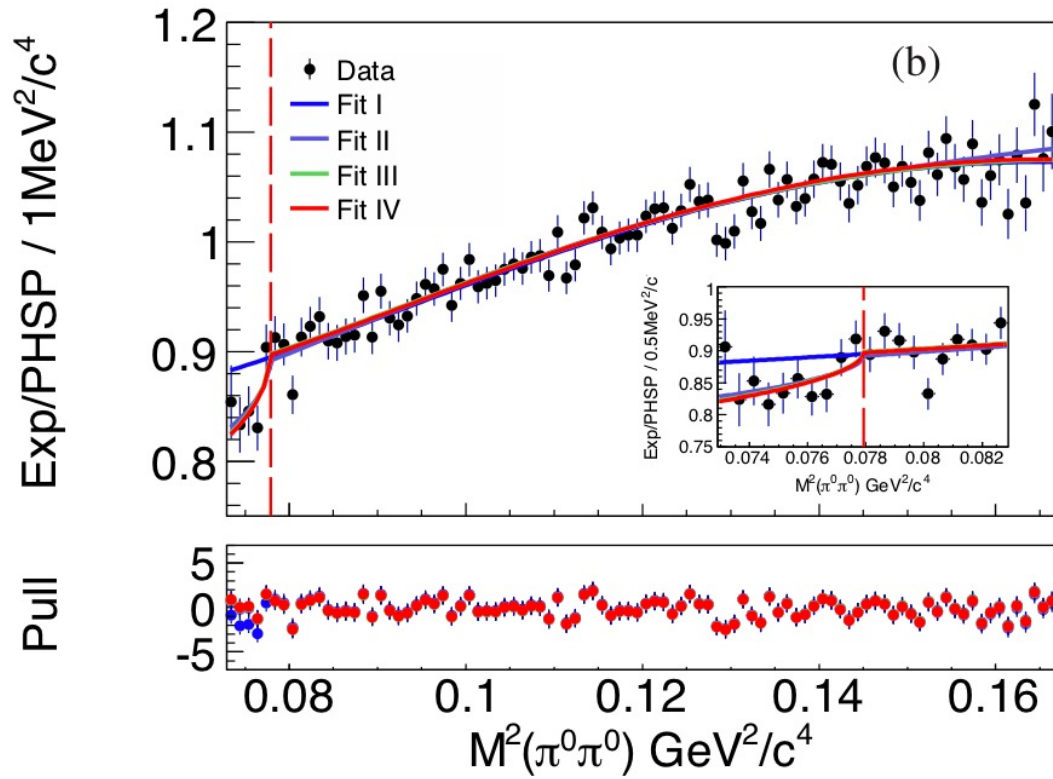
✓ Extra contribution (maybe $\rho(1450)$ or box-anomaly) is also necessary

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

PRL130,081901(2023)

- Investigation on $\pi\pi$ and $\pi\eta$ final interactions
- The cusp effect is sizeable in this decay





■ Non-relativistic effective field theory

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

■ Fits at different cases

■ Evidence of the cusp effect @ 3.5σ !

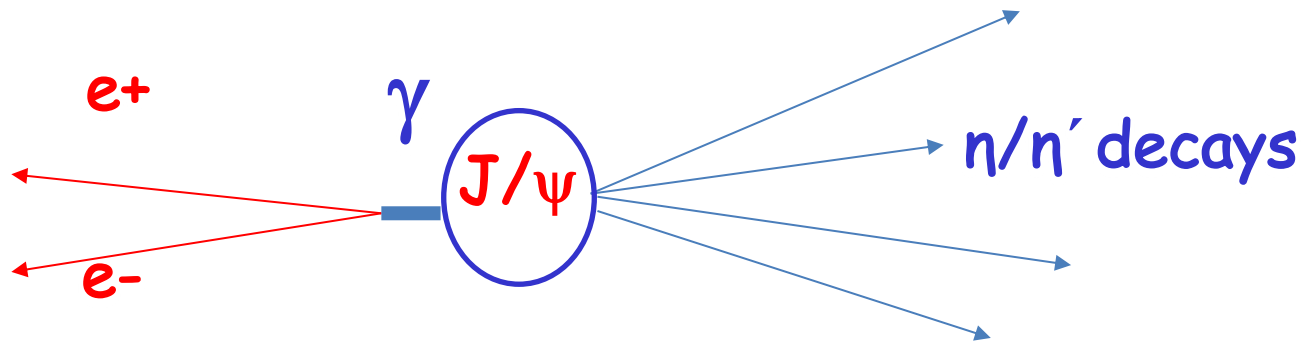
Parameters	Fit I	Fit II	Fit III	Fit IV
a	$-0.075 \pm 0.003 \pm 0.001$	-0.207 ± 0.013	-0.143 ± 0.010	$-0.077 \pm 0.003 \pm 0.001$
b	$-0.073 \pm 0.005 \pm 0.001$	-0.051 ± 0.014	-0.038 ± 0.006	$-0.066 \pm 0.006 \pm 0.001$
d	$-0.066 \pm 0.003 \pm 0.001$	-0.068 ± 0.004	-0.067 ± 0.003	$-0.068 \pm 0.004 \pm 0.001$
$a_0 - a_2$	-	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

New approaches

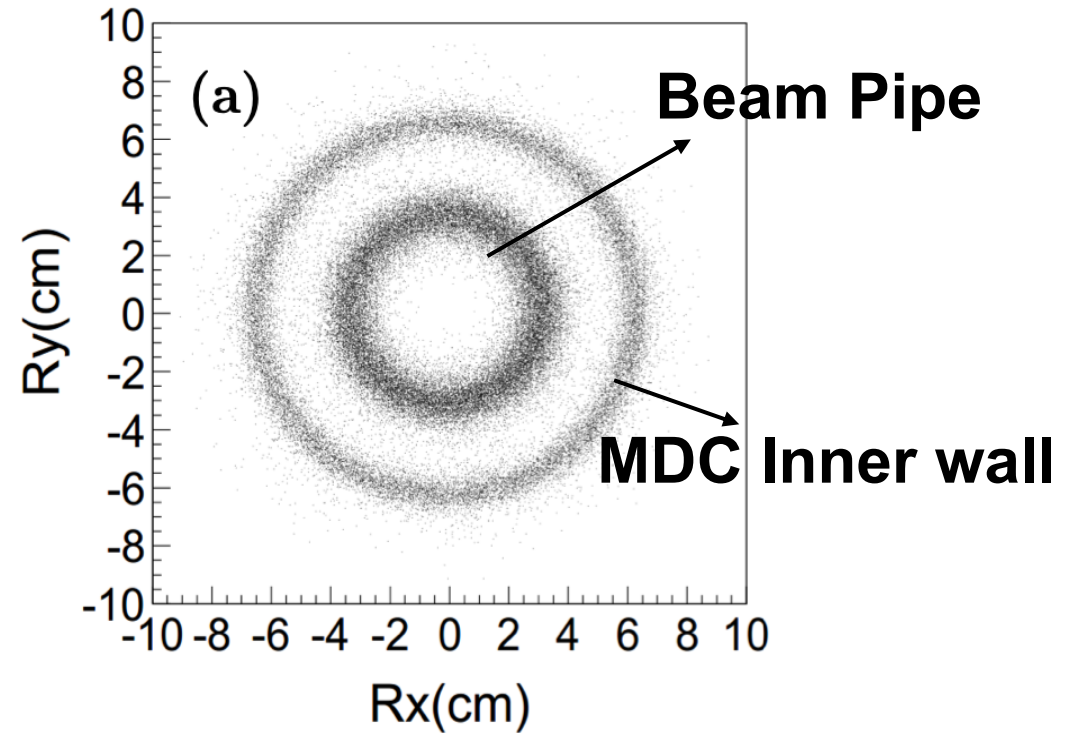
Absolute Measurement of BFs of η' decay modes PRL122, 142002(2019)
Novel approach to investigate η decays in progress

γ conversion: η/η' inclusive decays

- A novel way to measure the absolute BFs of η/η' decays
- Excellent momentum resolution for electrons @MDC

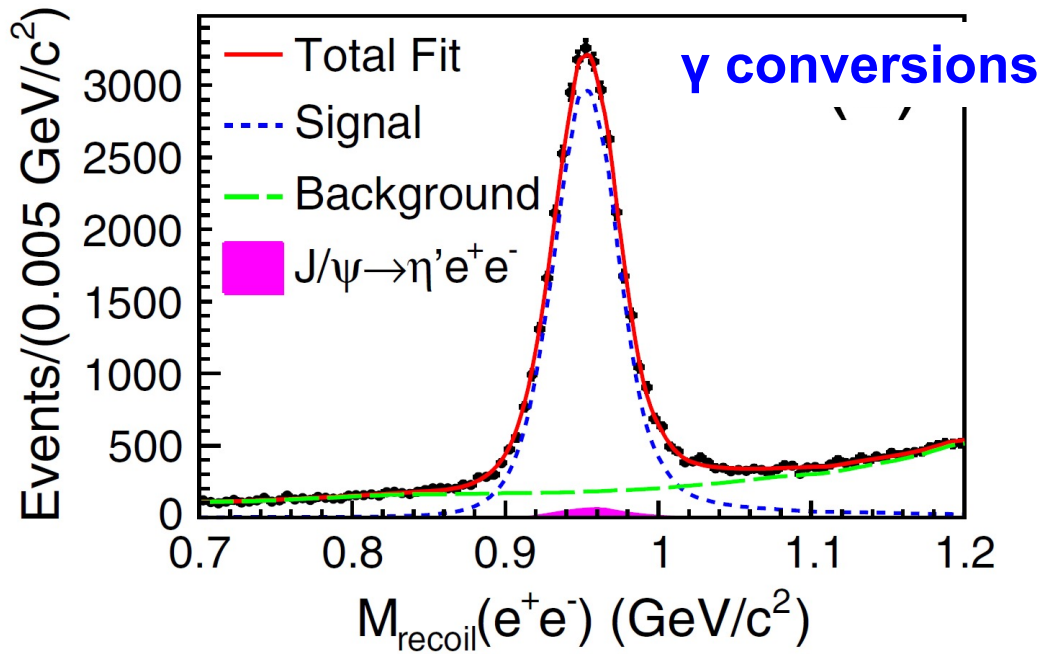


$$B(\eta' \rightarrow X) = \frac{N_{\eta' \rightarrow X}^{\text{obs}}}{\epsilon_{\eta' \rightarrow X}} \frac{\epsilon}{N_{J/\psi \rightarrow \gamma \eta'}^{\text{obs}}}$$



First Measurement of Absolute BFs of η' / η decays

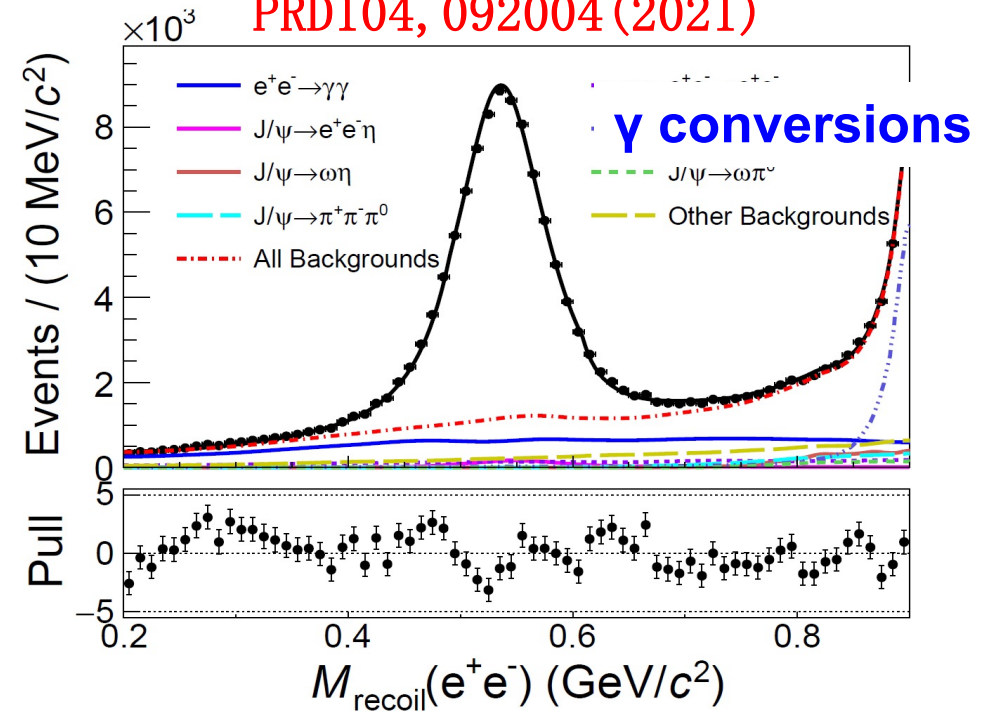
PRL122, 142002 (2019)



Decay mode	$\mathcal{B}(\eta' \rightarrow X)(\%)$	
	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

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

PRD104, 092004 (2021)



X	This work	PDG
$\gamma\gamma$	$39.86 \pm 0.04 \pm 0.99$	39.41 ± 0.20
$\pi^0\pi^0\pi^0$	$31.96 \pm 0.07 \pm 0.84$	32.68 ± 0.23
$\pi^+\pi^-\pi^0$	$23.04 \pm 0.03 \pm 0.54$	22.92 ± 0.28
$\pi^+\pi^-\gamma$	$4.38 \pm 0.02 \pm 0.10$	4.22 ± 0.08

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

New approach to investigate η decays with $\eta' \rightarrow \pi^+ \pi^- \eta$

Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022)

η REFERENCES PDG2022

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BABUSCI	20A	JHEP 2010 047	D. Babusci <i>et al.</i>	(KLOE-2 Collab.)
ZHEVLAKOV	19	PR D99 031703	A.S. Zhevlakov <i>et al.</i>	(TMSK, MAINZ, TUBIN+)
ACHASOV	18B	PR D98 052007	M.N. Achasov <i>et al.</i>	(SND Collab.)
ADLARSON	18C	PL B784 378	P. Adlarson <i>et al.</i>	(WASA-at-COSY Collab.)
PRAKHOV	18	PR C97 065203	S. Prakhov <i>et al.</i>	(A2 Collab. at MAMI)
AAIJ	17D	PL B764 233	R. Aaij <i>et al.</i>	(LHCb Collab.)
ADLARSON	17B	PR C95 035208	P. Adlarson <i>et al.</i>	(A2 Collab. at MAMI)
ANASTASI	16A	JHEP 1605 019	A. Anastasi <i>et al.</i>	(KLOE-2 Collab.)
ARNALDI	16	PL B757 437	R. Arnaldi <i>et al.</i>	(NA60 Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ADLARSON	14A	PR C90 045207	P. Adlarson <i>et al.</i>	(WASA-at-COSY Collab.)
AGAKISHIEV	14	PL B731 265	G. Agakishiev <i>et al.</i>	(HADES Collab.)
NEFKENS	14	PR C90 025206	B.M.K. Nefkens <i>et al.</i>	(A2 Collab. at MAMI)
NIKOLAEV	14	EPJ A50 58	A. Nikolaev <i>et al.</i>	(MAMI-B, MAINZ, BONN)
ABLIKIM	13	PR D87 012009	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim <i>et al.</i>	(BESIII Collab.)
BABUSCI	13	PL B718 910	D. Babusci <i>et al.</i>	(KLOE/KLOE-2 Collab.)
BABUSCI	13A	JHEP 1301 119	D. Babusci <i>et al.</i>	(KLOE-2 Collab.)
AGAKISHIEV	12A	EPJ A48 64	G. Agakishiev <i>et al.</i>	(HADES Collab.)
GOSLAWSKI	12	PR D85 112011	P. Goslawski <i>et al.</i>	(COSY-ANKE Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim <i>et al.</i>	(BESIII Collab.)

- Production rate lower than η'
- Background from QED and J/ψ decays

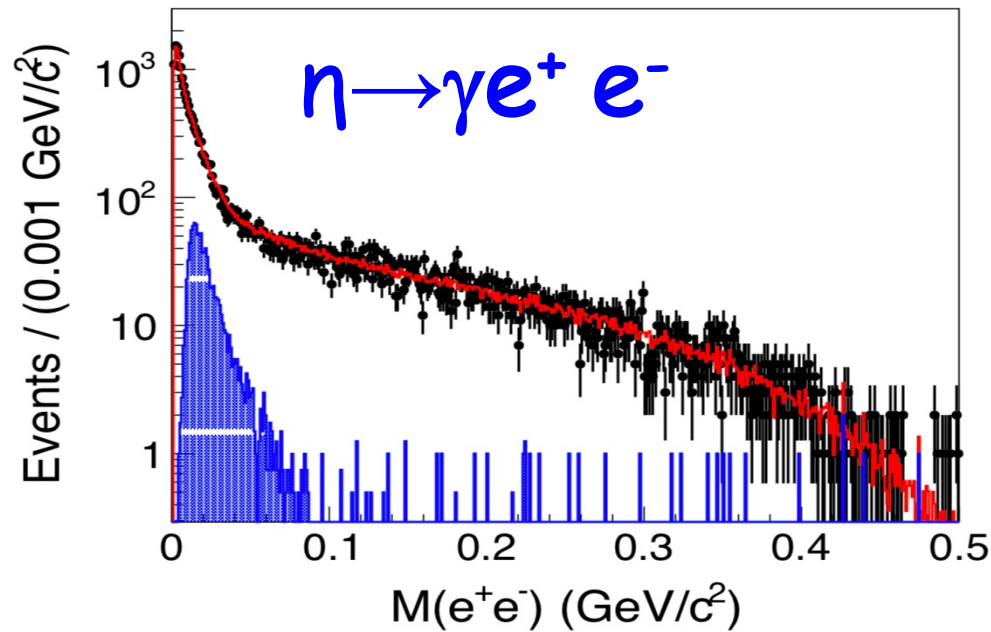
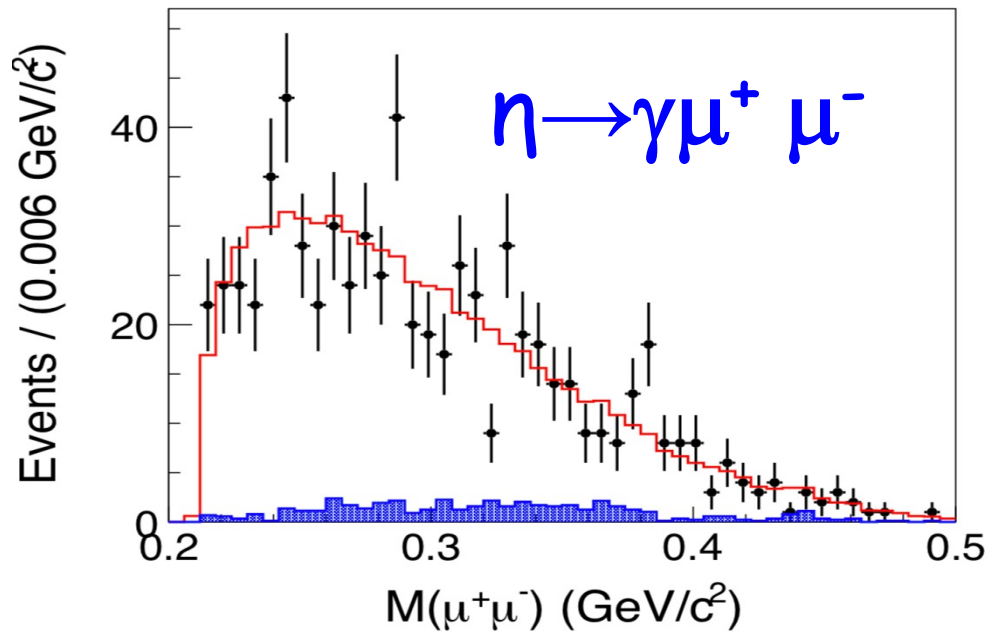
$$J/\psi \rightarrow \gamma \eta \rightarrow 1 \times 10^7 \eta$$

$$J/\psi \rightarrow \gamma \eta', \eta' \rightarrow \pi^+ \pi^- \eta \rightarrow 2.2 \times 10^7 \eta$$

One more η' constraint to suppress the background events !

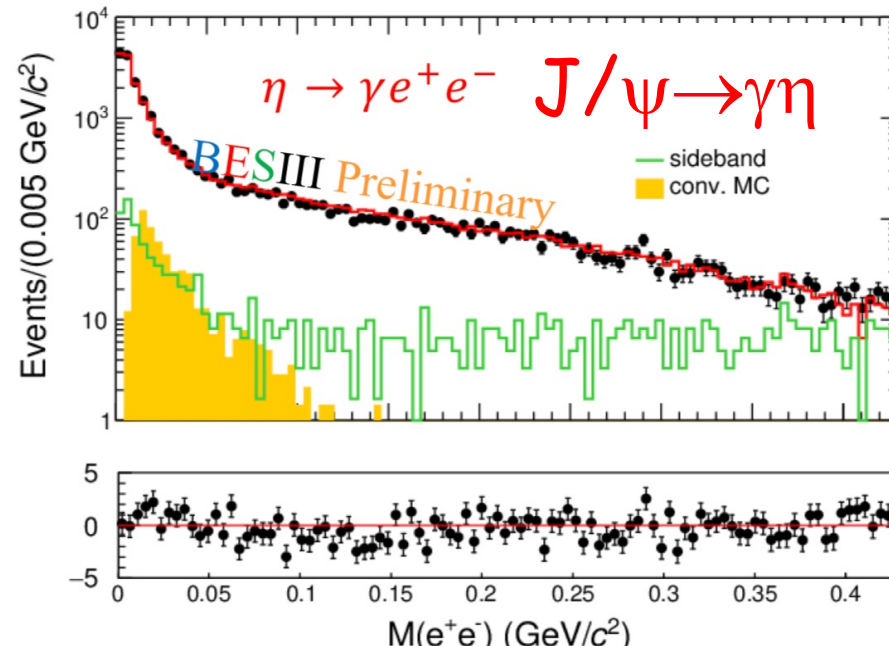
$$J/\psi \rightarrow \gamma \eta', \eta' \rightarrow \pi^+ \pi^- \eta$$

BAM-000716, 000637



● Help distinguish muons from pions

● Background level is low



Summary

- BESIII: a light meson factory
 - a unique place for light mesons
 - Allow to study light meson decays with high precision
- Significant progresses achieved on η/η' decays
 - η/η' : hadronic, radiative and rare decays
- More results are expected to come soon !
- Together with other experiments, the light meson physics will be into a precision era