Light Meson Decays at BESIII

Ilaria BALOSSINO

on behalf of the BESIII collaboration

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Light Meson Decays

- Improve the knowledge on low energy QCD
- Test Chiral Perturbation Theory predictions
- Study Form Factors
- Test fundamental symmetries
- Search for charge conjugation violation
- Search for new physics BSM

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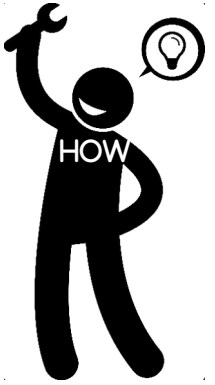
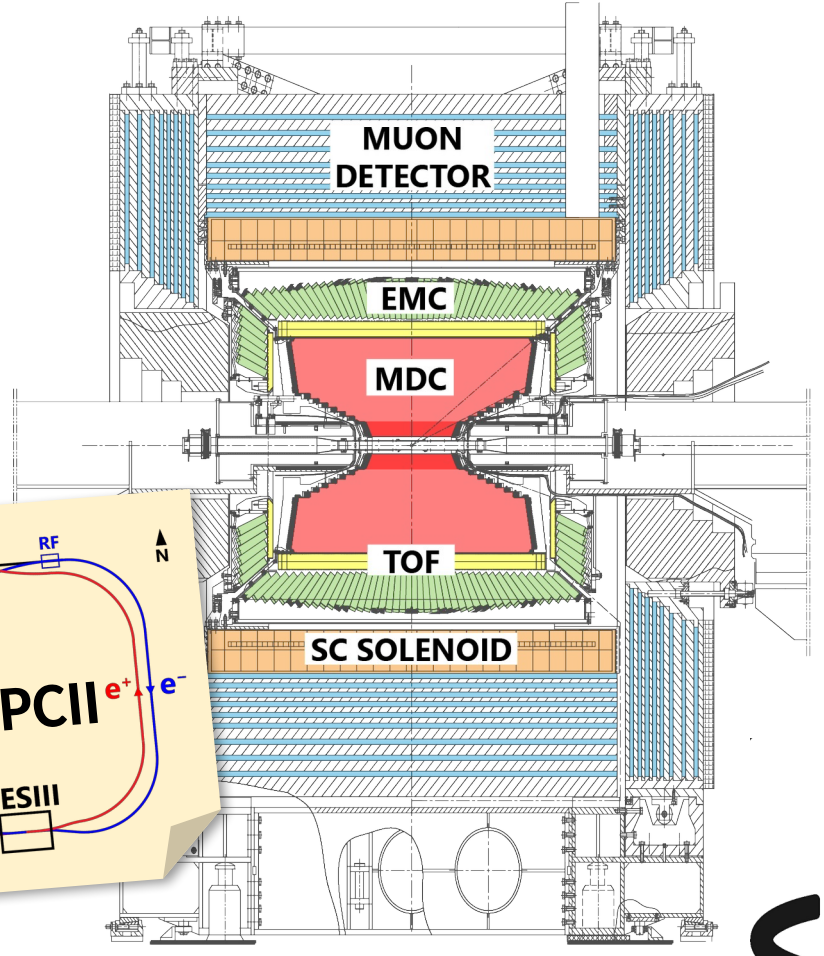
η/η' Decays



Institute of High Energy Physics



- Since 2009 → up until 2030
- Electron–Positron Collider
- Energy range: 2.00 ÷ 4.96 GeV
- Peak luminosity of the IP: 10^{33} cm^{-2} s^{-1}
- τ–charm physics

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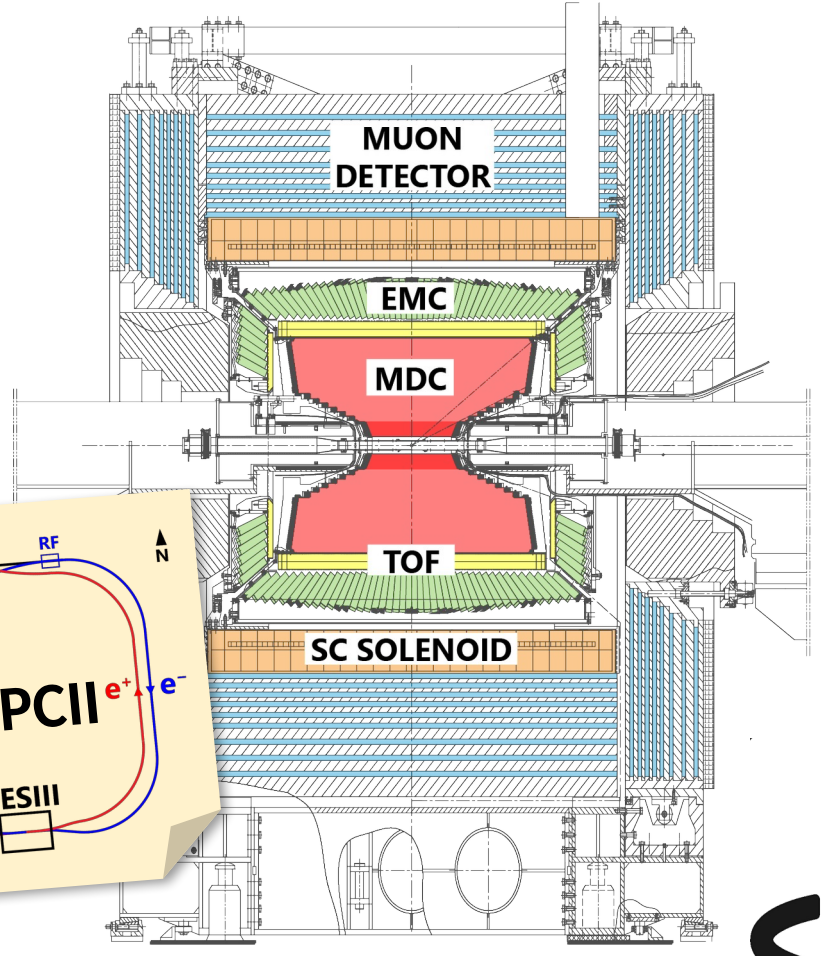

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10B of J/ψ !

Light Meson Factory

BESIII

$$J/\psi \to \gamma\,\eta/\eta' \Longrightarrow 1\times10^{7}\eta\,/\,5.2\times10^{7}\eta'$$

$$J/\psi \to \phi\,\eta/\eta' \Longrightarrow 4\times10^{6}\eta\,/\,2.5\times10^{6}\eta'$$

Hadronic decays

Radiative decays

Rare and forbidden decays

$\eta' \to 2(\pi^+\pi^-), \pi^+\pi^-\pi^0\pi^0$	First Observation - BR	PRL112, 251801 (2014)
$\eta' \to \gamma e^+e^-$	First Observation - BR - TFF	PRD92, 012001 (2015)
$\eta \to \pi^+\pi^-\pi^0, \quad \eta/\eta' \to \pi^0\pi^0\pi^0$	Matrix Elements - $\mathrm{m_u} - \mathrm{m_d}$	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)
$\eta \to \pi^+\pi^-\eta, \quad \eta' \to \pi^0\pi^0\eta$	Matrix elemts - 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 BR 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 violation asymmetries	PRD103, 092005 (2021)
$\eta' \to \pi^+\pi^-\mu^+\mu^-$	BR - Decay dynamics	PRD103, 072006 (2021)
Absolute BR of η decays	BRs	PRD104, 092004 (2021)
$\eta' \to \pi^0\pi^0\eta$	Cusp effect	PRL130, 081901 (2023)

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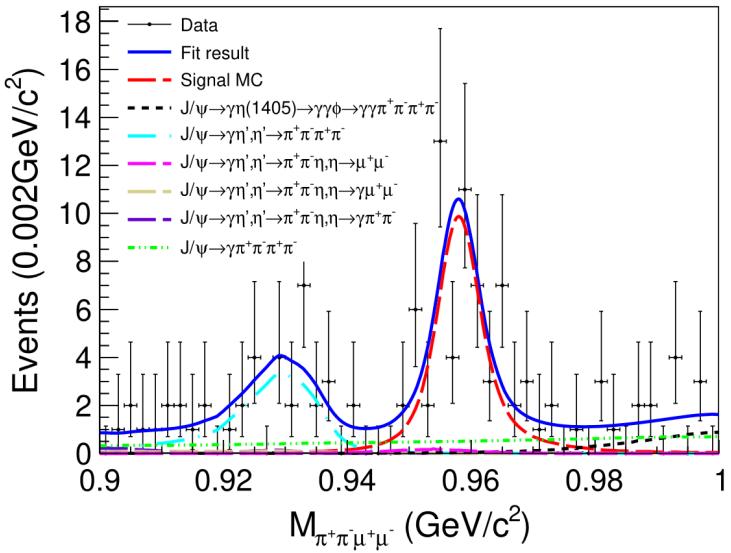
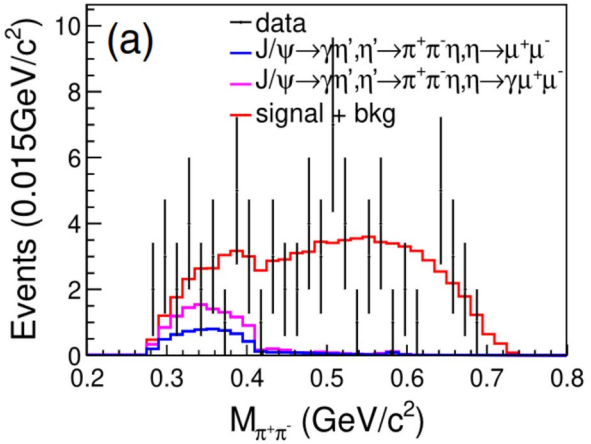
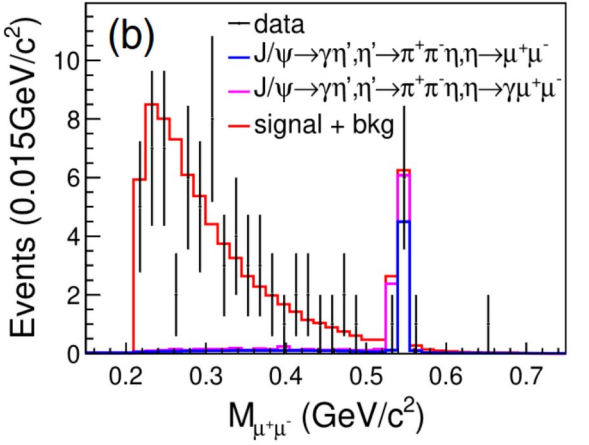
PRD103, 072006 (2021)



Good agreement with theoretical predictions;
Reasonable ability of the theoretical model to describe the **intermediate processes**





First observation with 8σ statistical significance

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

THEORY	Hidden Gauge Model	Modified Vector Meson Dominance Model	Chiral Unitary Approach
BR	$(2.20 \pm 0.30) \times 10^{-5}$	$(2.41 \pm 0.25) \times 10^{-5}$	$(1.57^{+0.96}_{-0.75}) \times 10^{-5}$
	arXiv: 1010.2378		EPJA 33(2007) 95

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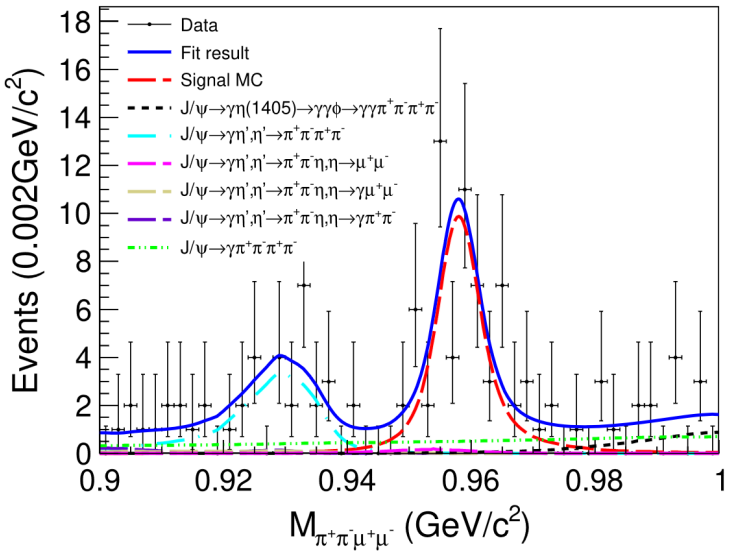

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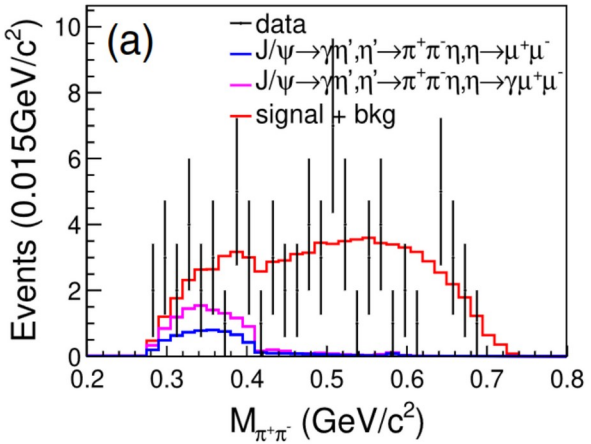

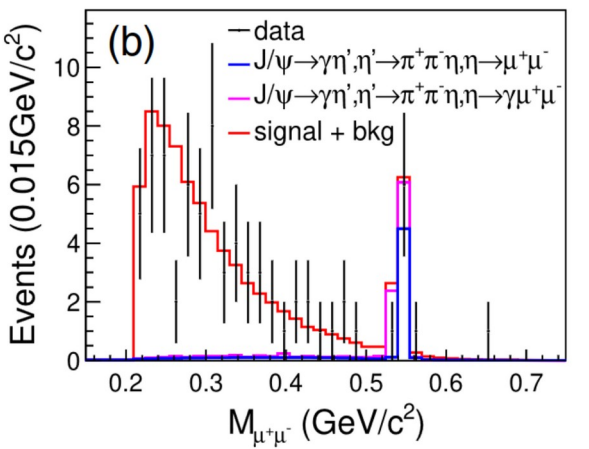

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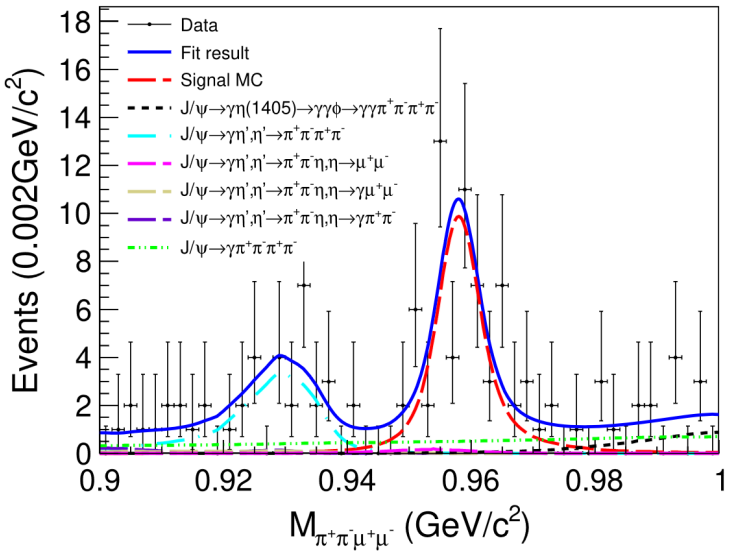

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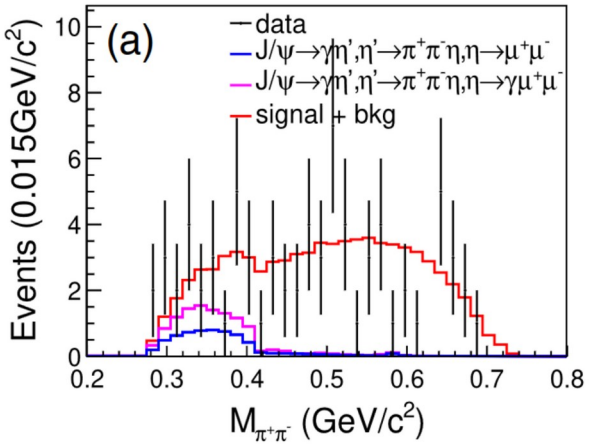

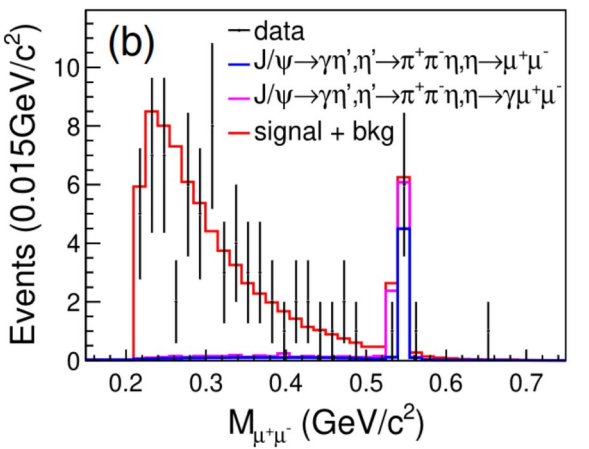

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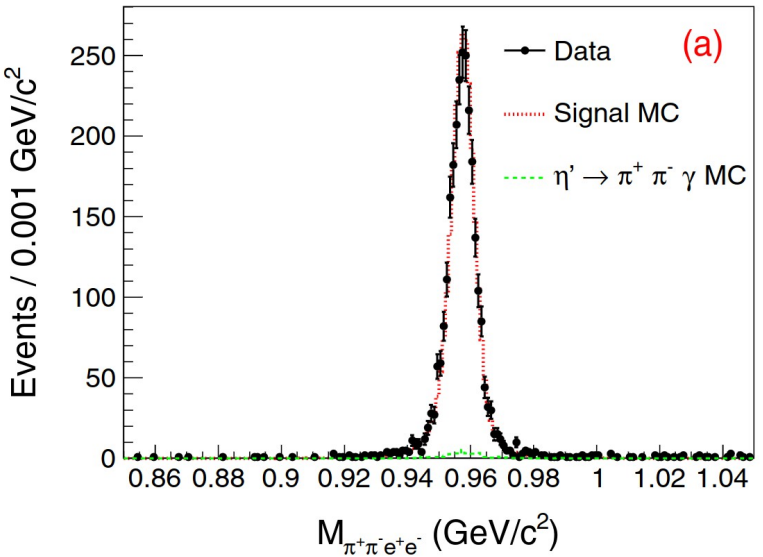
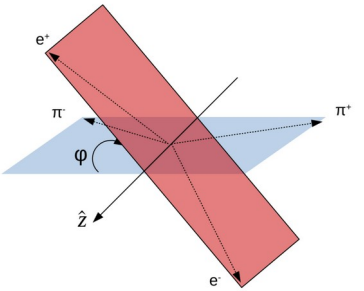
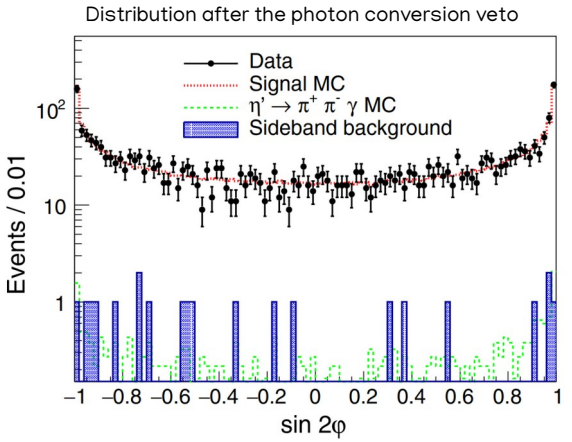




The angle between the two decay plan can be unambiguously determined



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N (x) = acceptance-corrected number of events in the corresponding angular region

PRD103, 092005 (2021)

Improved statistical uncertainty by a factor 2
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$$B(\eta' \to \pi^+\pi^- e^+ e^-) = (2.42 \pm 0.05_{\rm stat} \pm 0.08_{\rm syst}) \times 10^{-3}$$

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The CP-violating asymmetry

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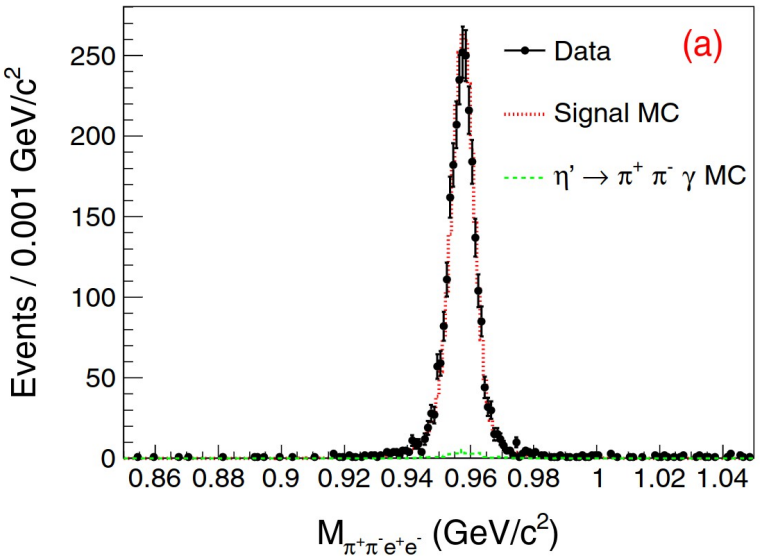

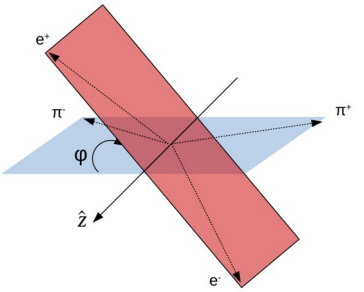

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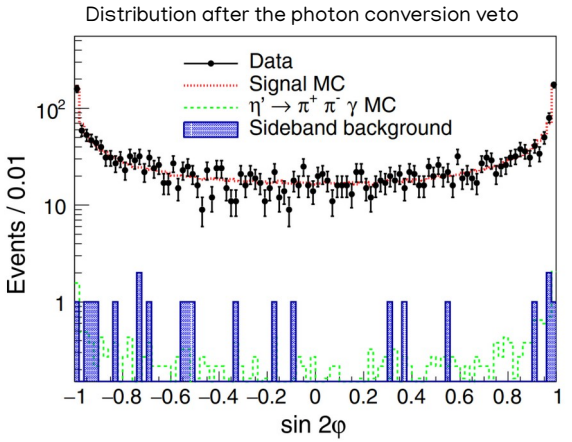

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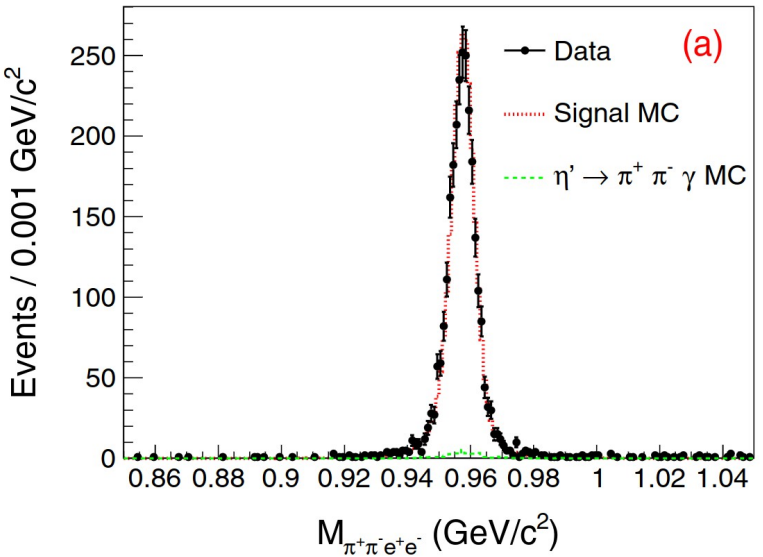

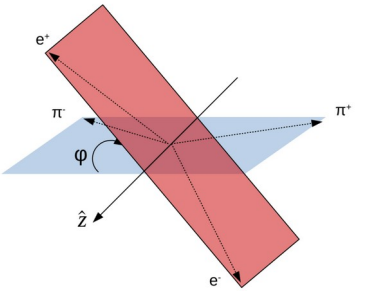

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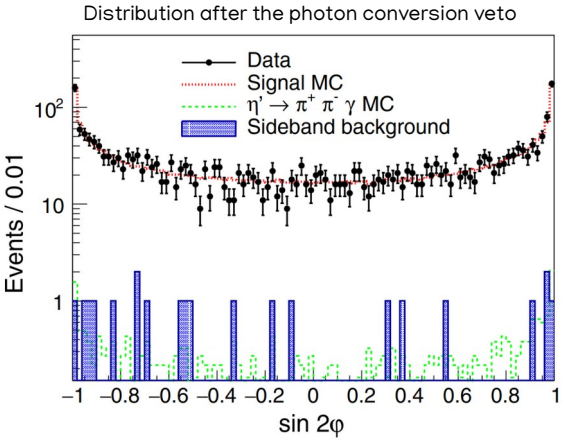

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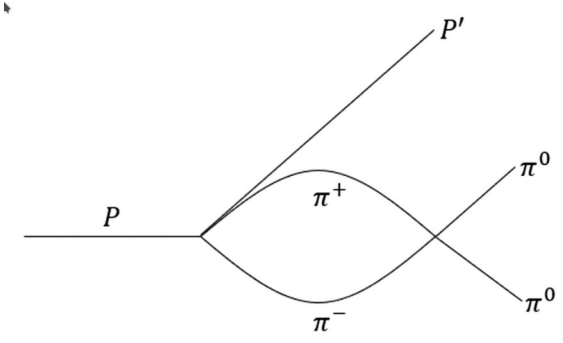
PRD103, 092005 (2021)

$\eta' \to \pi^0 \pi^0 \eta$

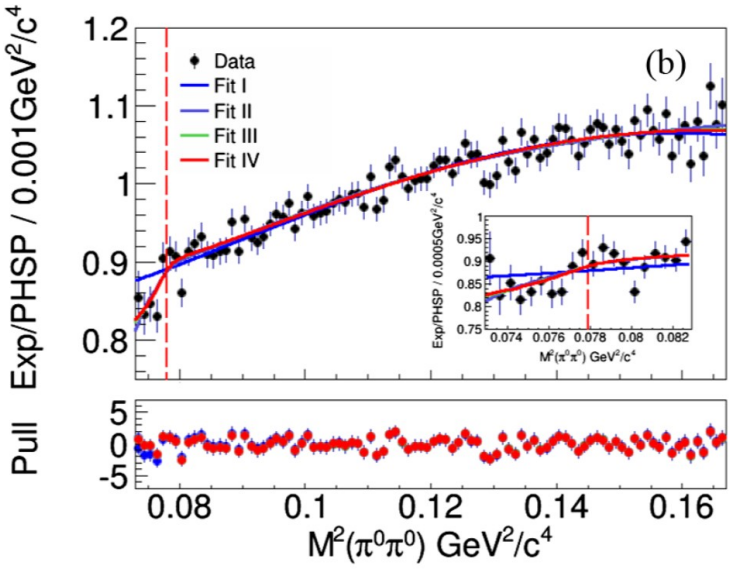
Sample 8 times larger than the previous analysis

- Study the fundamental properties of QCD at low energies
- Test effective ChPT
- Investigation on $\pi\pi$ and $\pi\eta$ final interactions
- Sizeable cusp effect in this decay



The S-wave charge-exchange rescattering $\pi^+\pi^- \to \pi^0\pi^0$ causes a prominent cusp at the center of mass energy corresponding to the summed mass of two charged pions.

PRL130, 081901 (2023)



	FIT I	FIT II	FIT III	FIT IV
Statistical Significance	-	3.4σ	3.7σ	3.6σ

with CUSP effect

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- Investigation on ππ and πη final interactions
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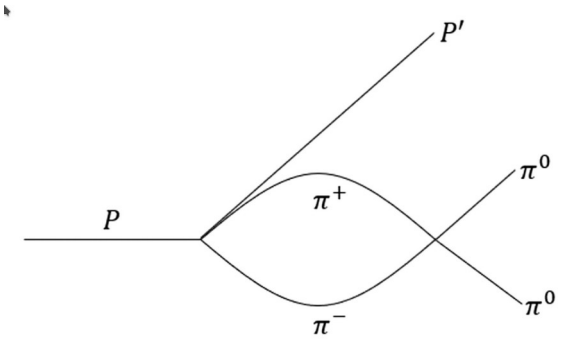

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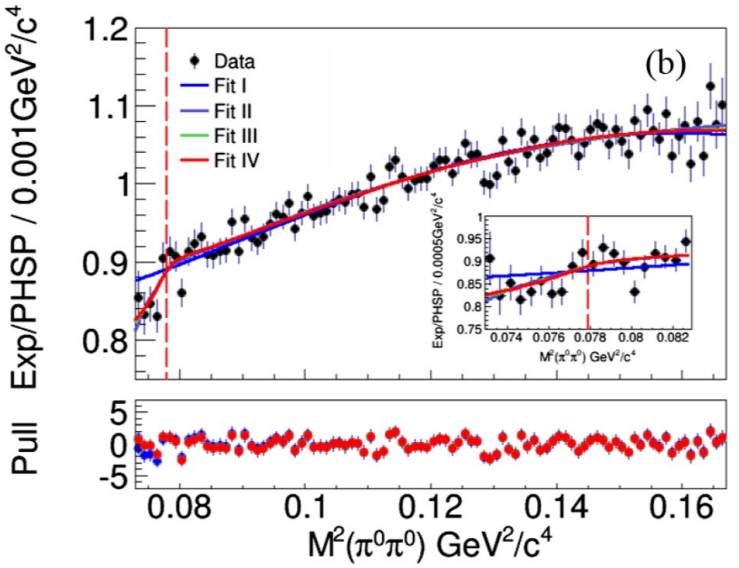

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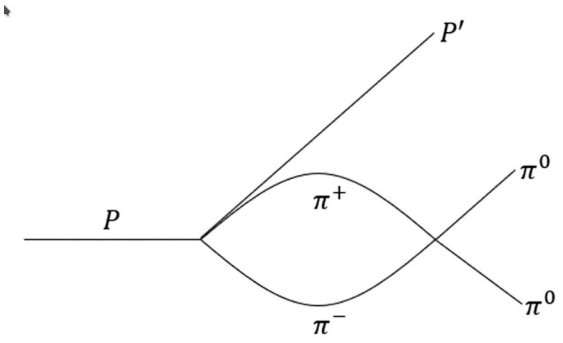

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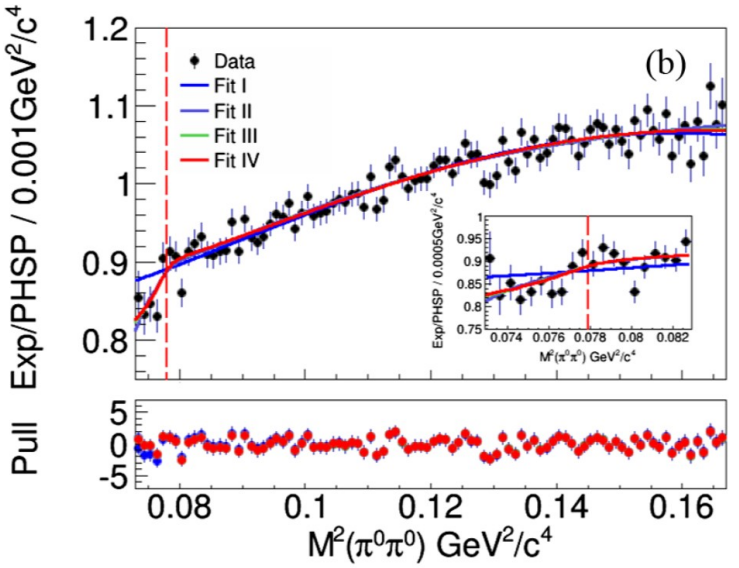

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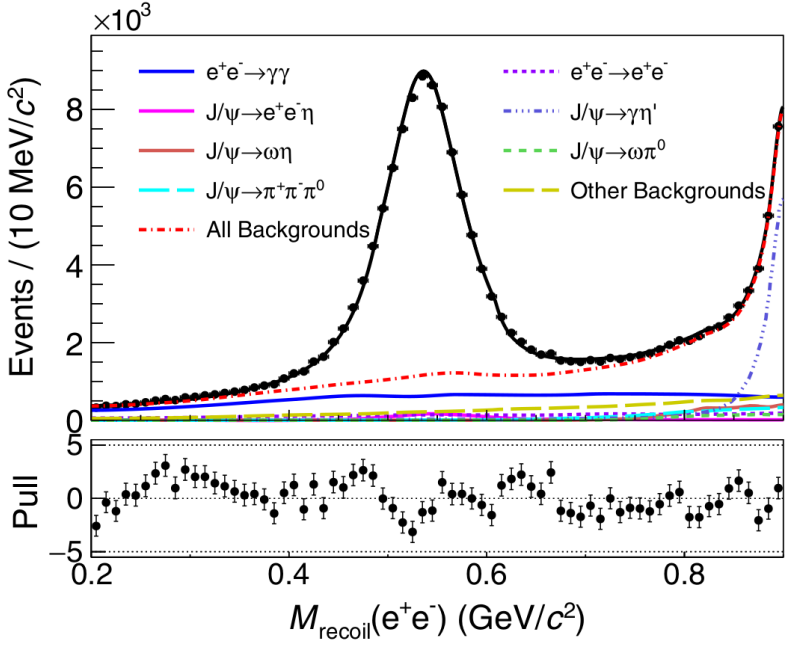
Absolute BFs of η/η' decays

η' → PRL122, 142002 (2019)

As the BFs of the rare decays are obtained via normalization to the dominant decay modes, a precise determination of the BFs of the dominant decay modes of the η and η' is essential

- Reconstruct the inclusive photon spectrum from radiative J/ψ decays
- The radiative photon converts to e^+e^-
- Excellent momentum resolution for electrons @MDC



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

In agreement within 2σ with the world avarage value with **improved precision**

$$B(J/\psi \to \gamma\eta) = (1.108 \pm 0.027) \times 10^{-3}$$

Prog. Theor. Exp. Phys. 2020, 083C01 (2020)

PRD104, 092004 (2021)

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

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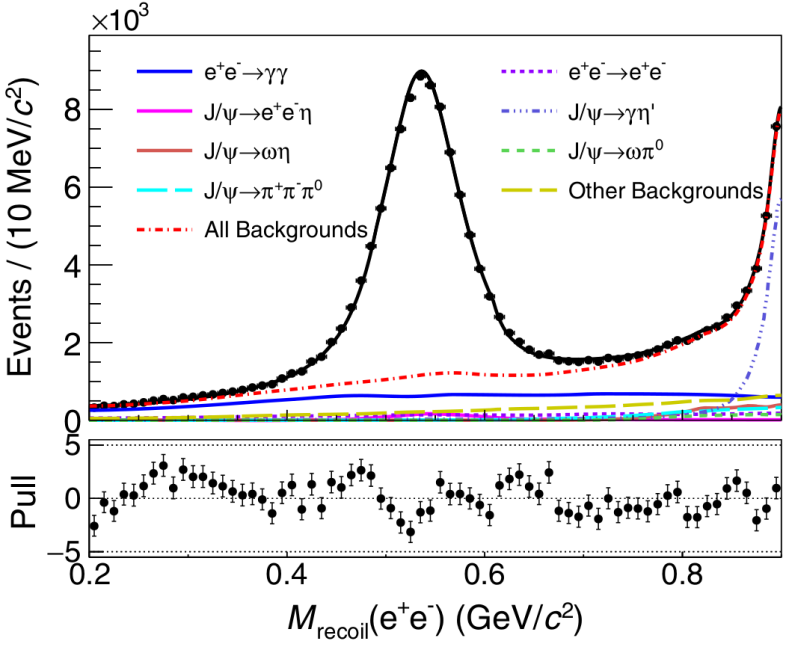

$$B(J/\psi \to \gamma\eta) = (1.067 \pm 0.005_{\rm stat} \pm 0.023_{\rm syst}) \times 10^{-3}$$

In agreement within 2σ with the world avarage value with **improved precision**

$$B(J/\psi \to \gamma\eta) = (1.108 \pm 0.027) \times 10^{-3}$$

Prog. Theor. Exp. Phys. 2020, 083C01 (2020)

PRD104, 092004 (2021)

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Absolute BFs of η/η' decays

η' → PRL122, 142002 (2019)

As the BFs of the rare decays are obtained via normalization to the dominant decay modes, a precise determination of the BFs of the dominant decay modes of the η and η' is essential

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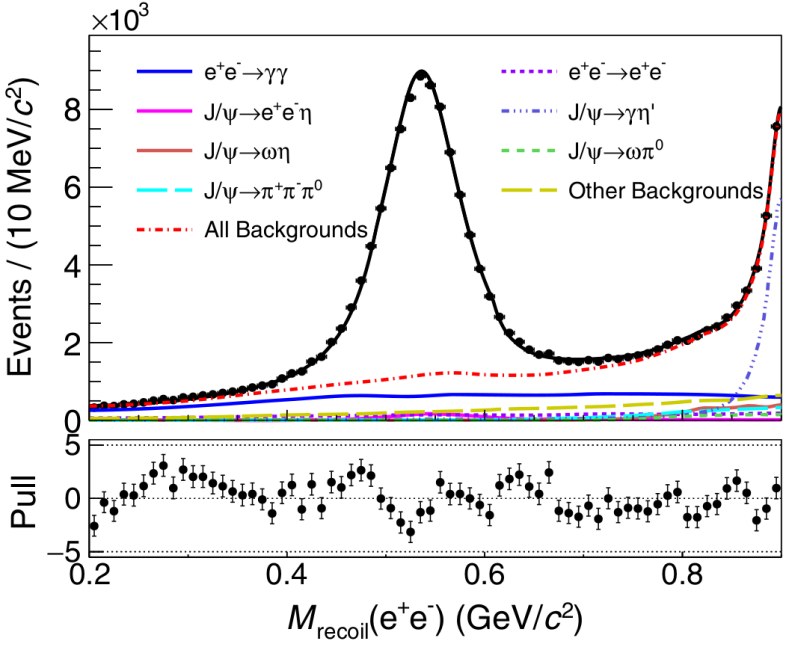

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PRD104, 092004 (2021)

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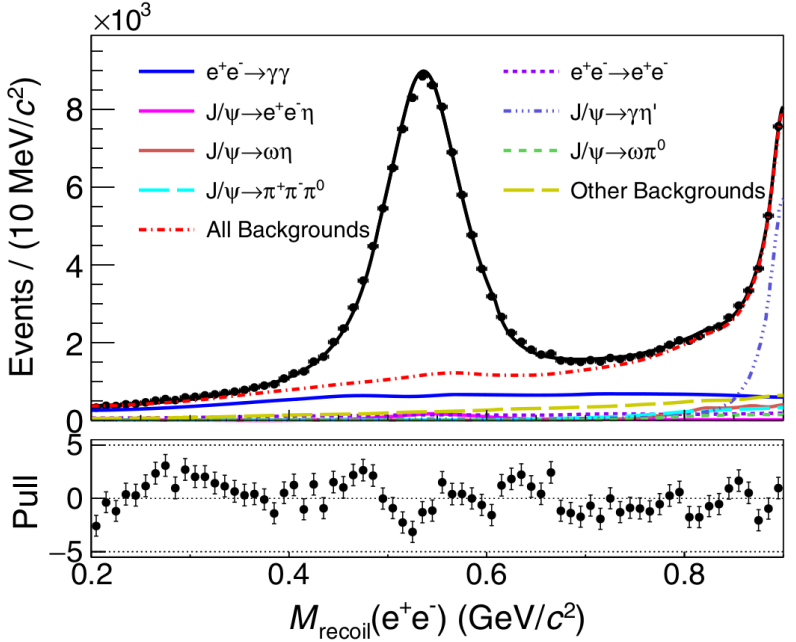

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10B of J/ψ !

Light Meson Factory

- Improve the knowledge on low energy QCD
- Test Chiral Perturbation Theory predictions
- Study Form Factors
- Test fundamental symmetries
- Search for charge conjugation violation
- Search for new physics BSM

$\eta' \to \pi^+\pi^- e^+ e^-$	BR - CP violation asymmetries	PRD103, 092005 (2021)
$\eta' \to \pi^+\pi^- \mu^+ \mu^-$	BR - Decay dynamics	PRD103, 072006 (2021)
Absolute BR of η decays	BRs	PRD104, 092004 (2021)
$\eta' \to \pi^0\pi^0\eta$	Cusp effect	PRL130, 081901 (2023)

HIGH STATISTICS

HIGH PRECISION

$$J/\psi \to \gamma\,\eta/\eta' \Longrightarrow 1\times10^7\eta\,/\,5.2\times10^7\eta'$$

$$J/\psi \to \phi\,\eta/\eta' \Longrightarrow 4\times10^6\eta\,/\,2.5\times10^6\eta'$$

BESIII

10B of J/ψ !

Light Meson Factory

MORE IS EXPECTED

- ...
- Dalitz plots
- Rare and forbidden decays
- Form factors
- ...

TO MOVE INTO A PRECISE ERA

10B of J/ψ !

Light Meson Factory

MORE IS EXPECTED

- …
- Dalitz plots
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- …

TO MOVE INTO A PRECISE ERA

THANKS


backup

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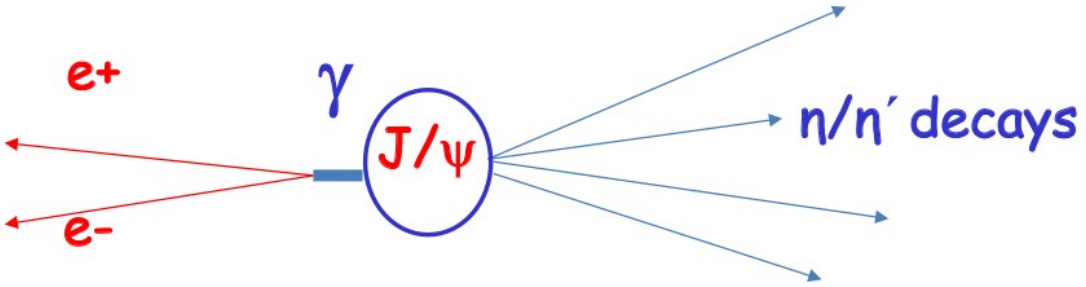
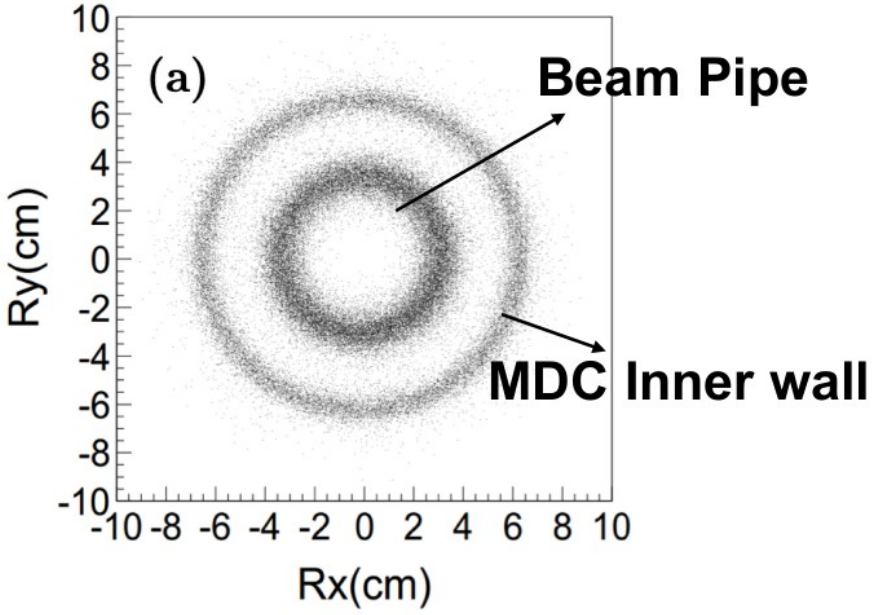
γ conversion: η/η′ inclusive decays

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



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



First Measurement of Absolute BFs of η′ /η decays

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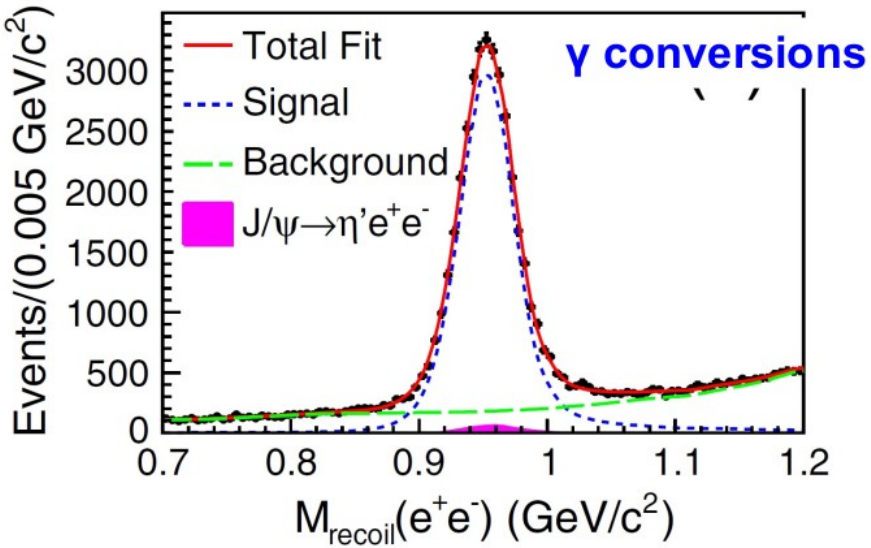
(for the BESIII Collaboration)
Institute of High Energy Physics, Beijing

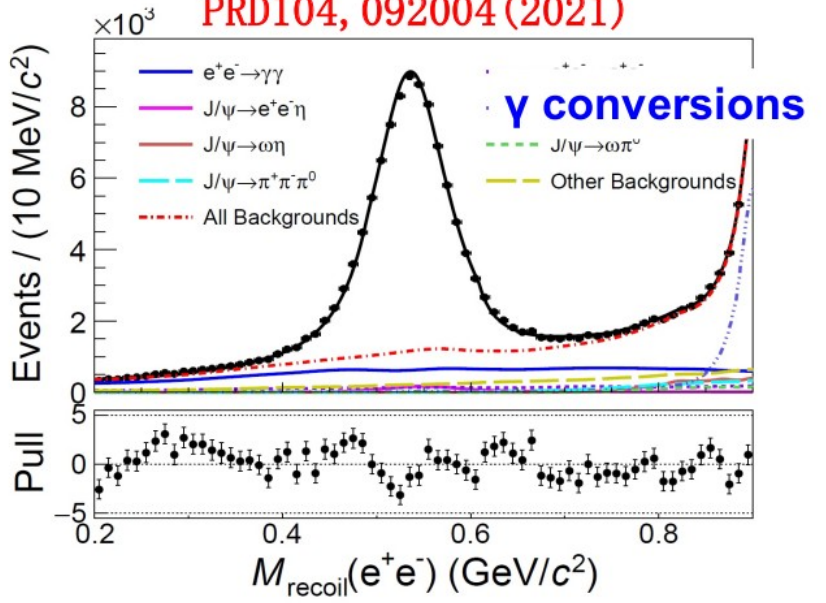
PRL122, 142002 (2019)



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

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

PRD104, 092004 (2021)



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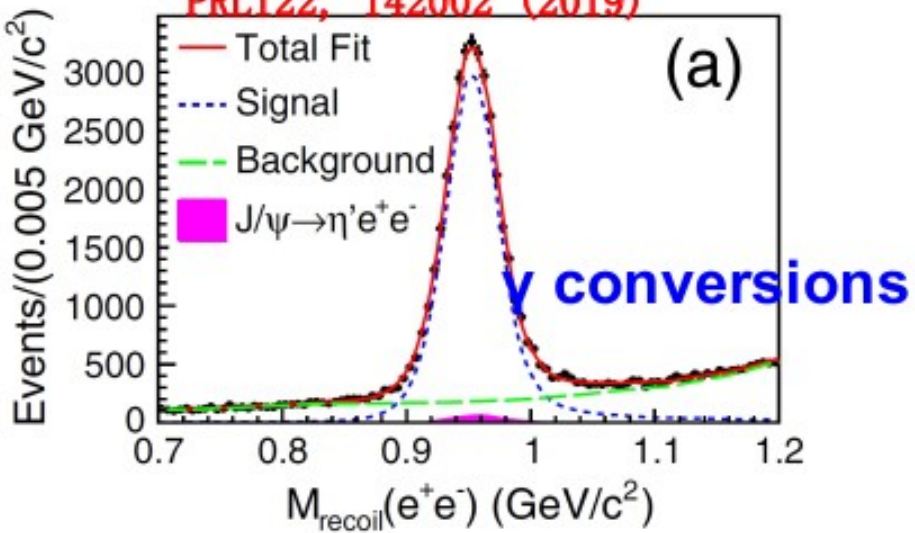
Absolute BFs of η′ decays

PRL122, 142002 (2019)



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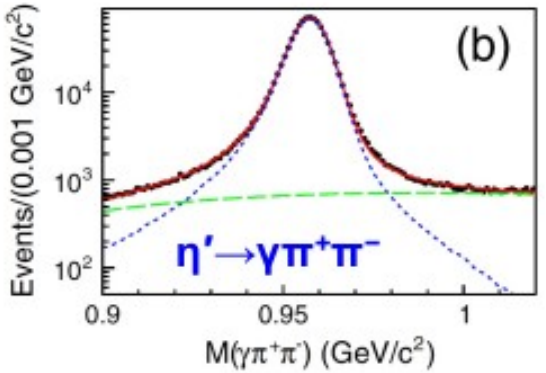
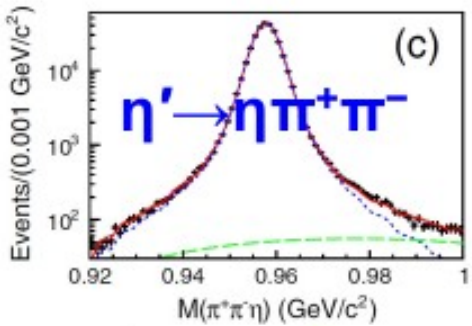
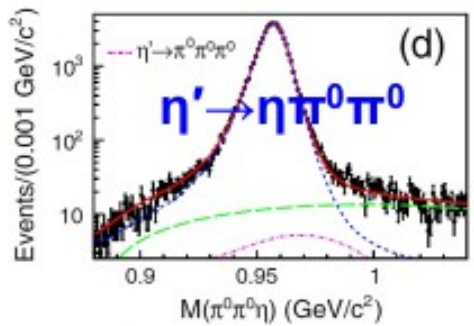
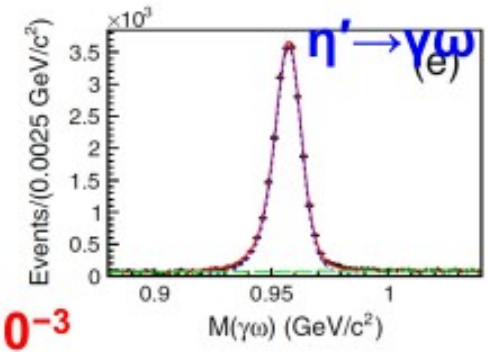
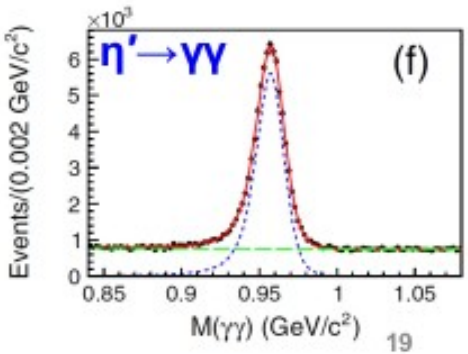




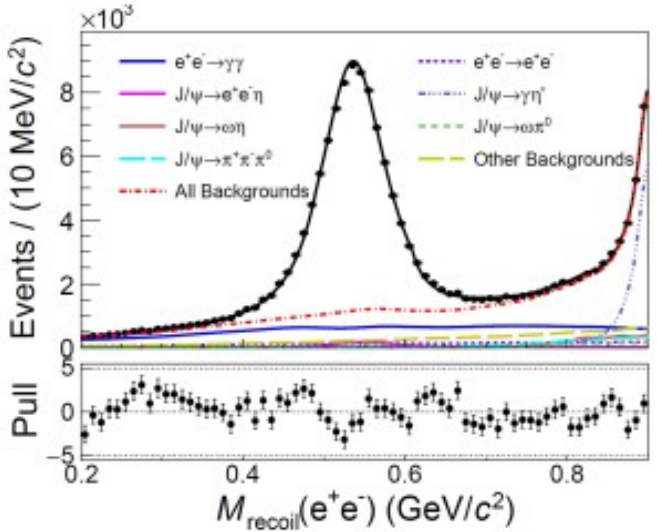


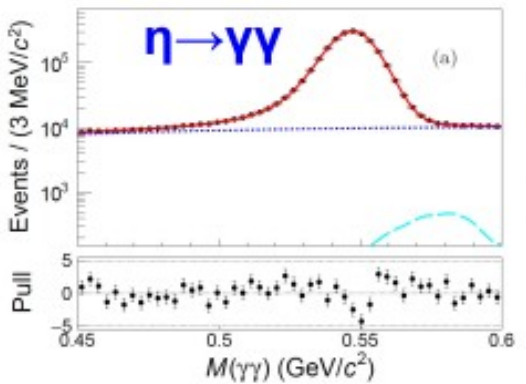


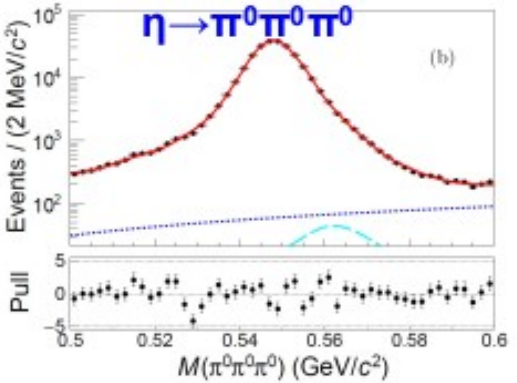


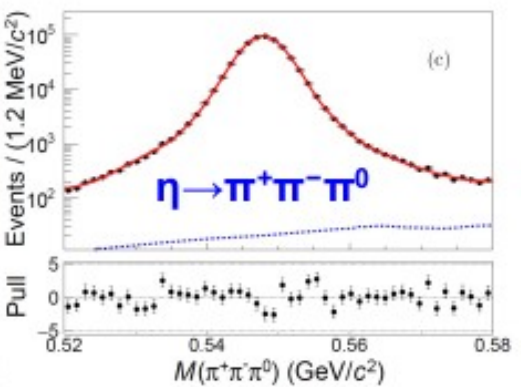
Absolute BFs of η decays

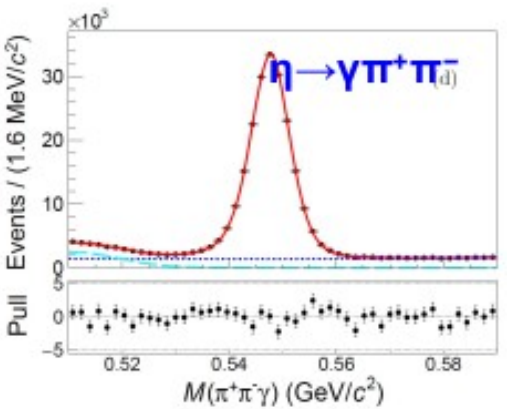
PRD104, 092004 (2021)











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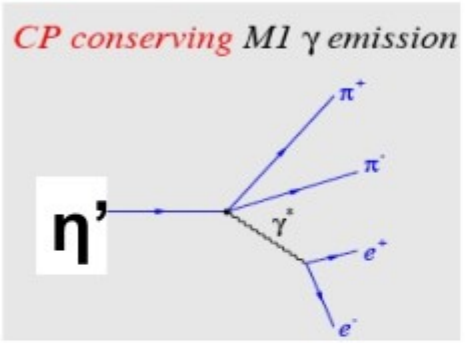
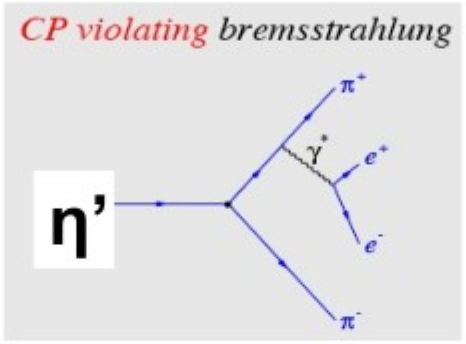
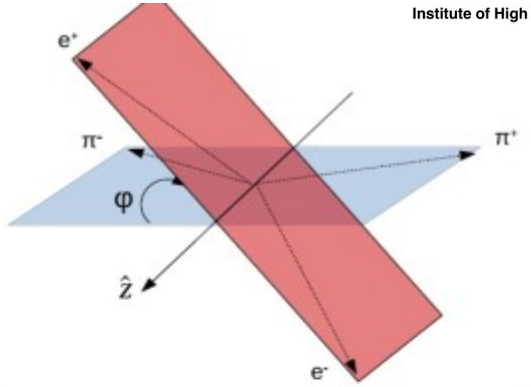
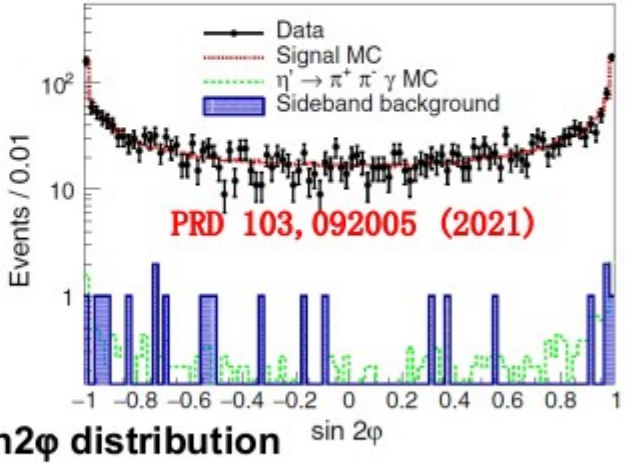
Search for CP violation in $\eta' \to \pi^+\pi^- e^+ e^-$









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]

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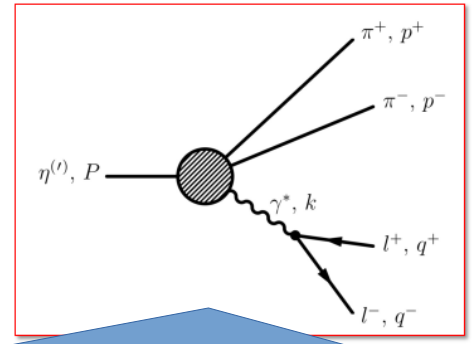
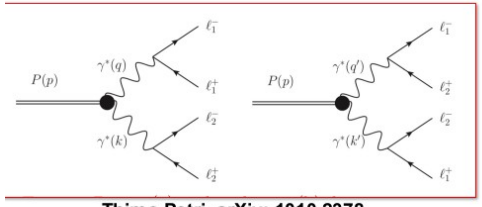
$\eta' \to \pi^+\pi^- l^+ l^-$



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

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



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→ $(g-2)_\mu$
- No experimental evidence yet!