Light Meson Decays at BESIII

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(on behalf of BESIII collaboration)

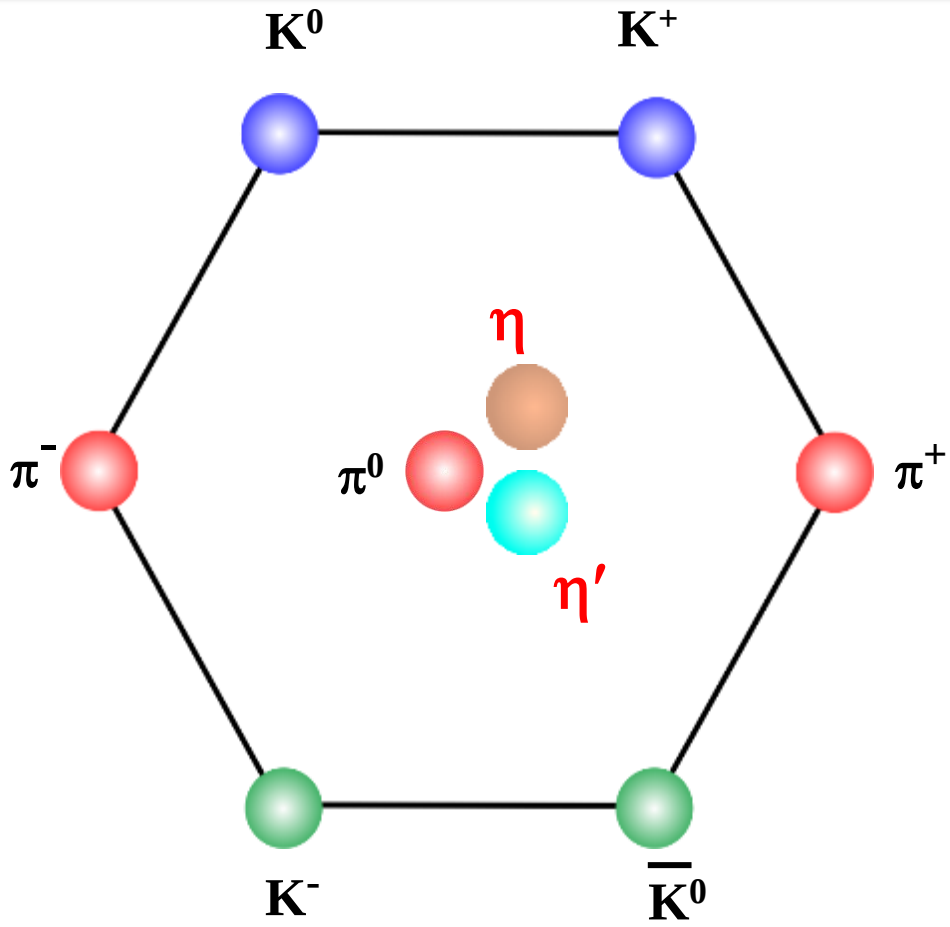
17th International Workshop on Meson Physics

KRAKÓW, POLAND

22nd - 27th June 2023

Light Meson Physics

- Play 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

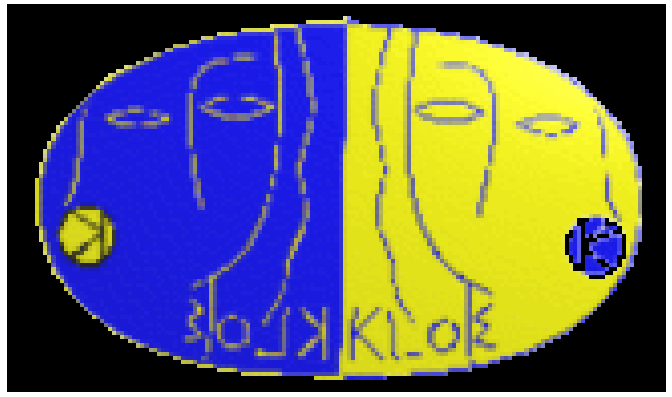


Source of η/η´ events

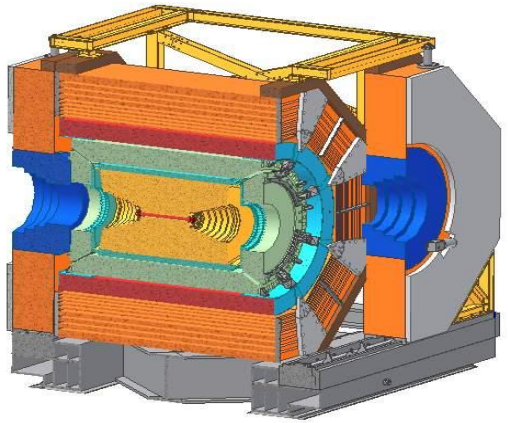
CLAS(12)

Crystal Ball

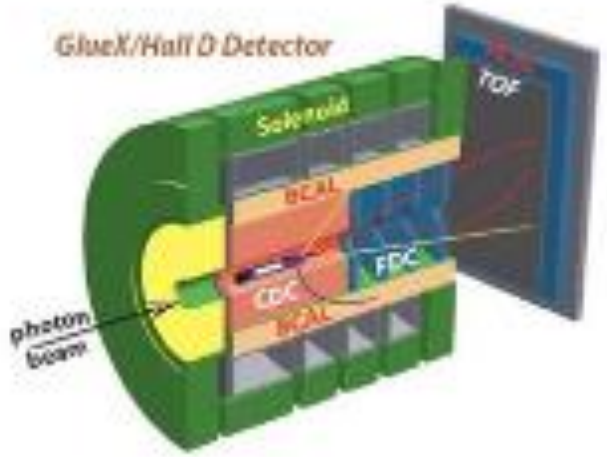
WASA-at-COSY



KLOE-2



BESIII

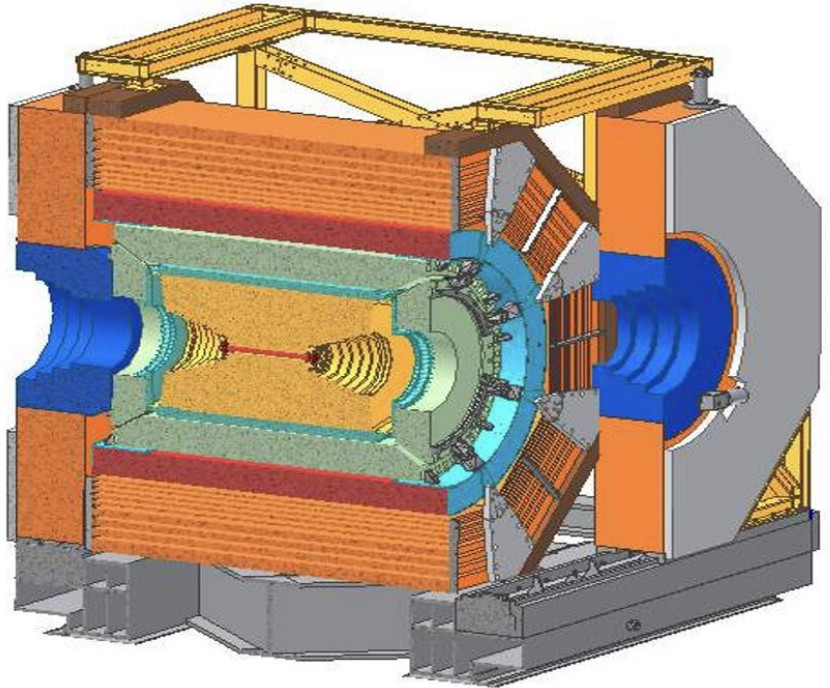


GlueX

Bird view of BEPCII

Storage ring

Linac

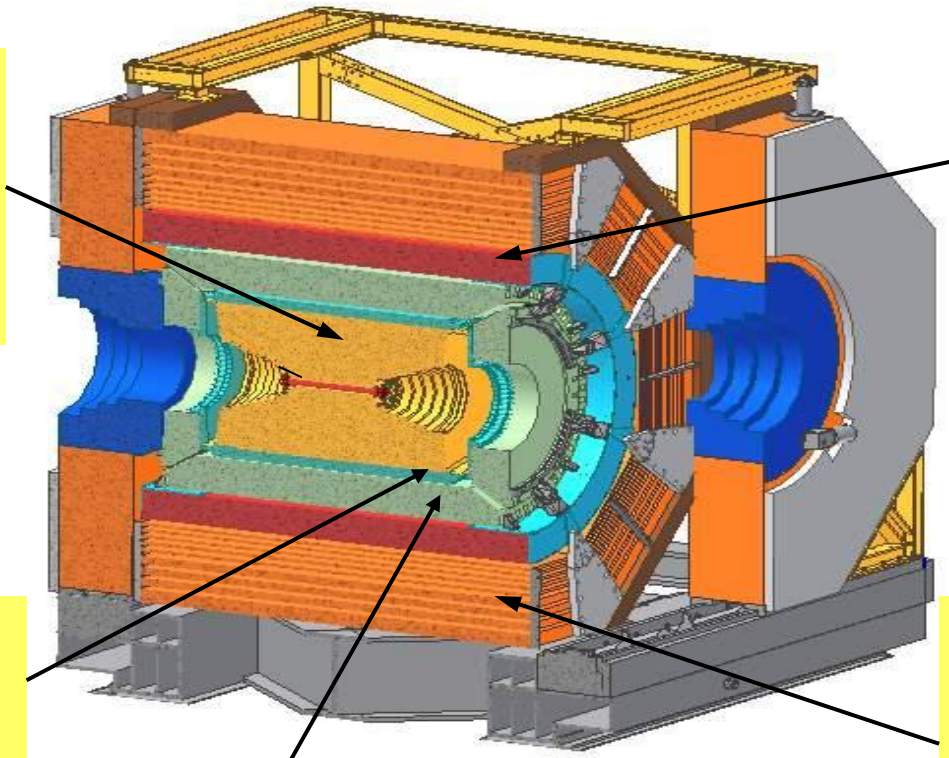


The BESIII Detector

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

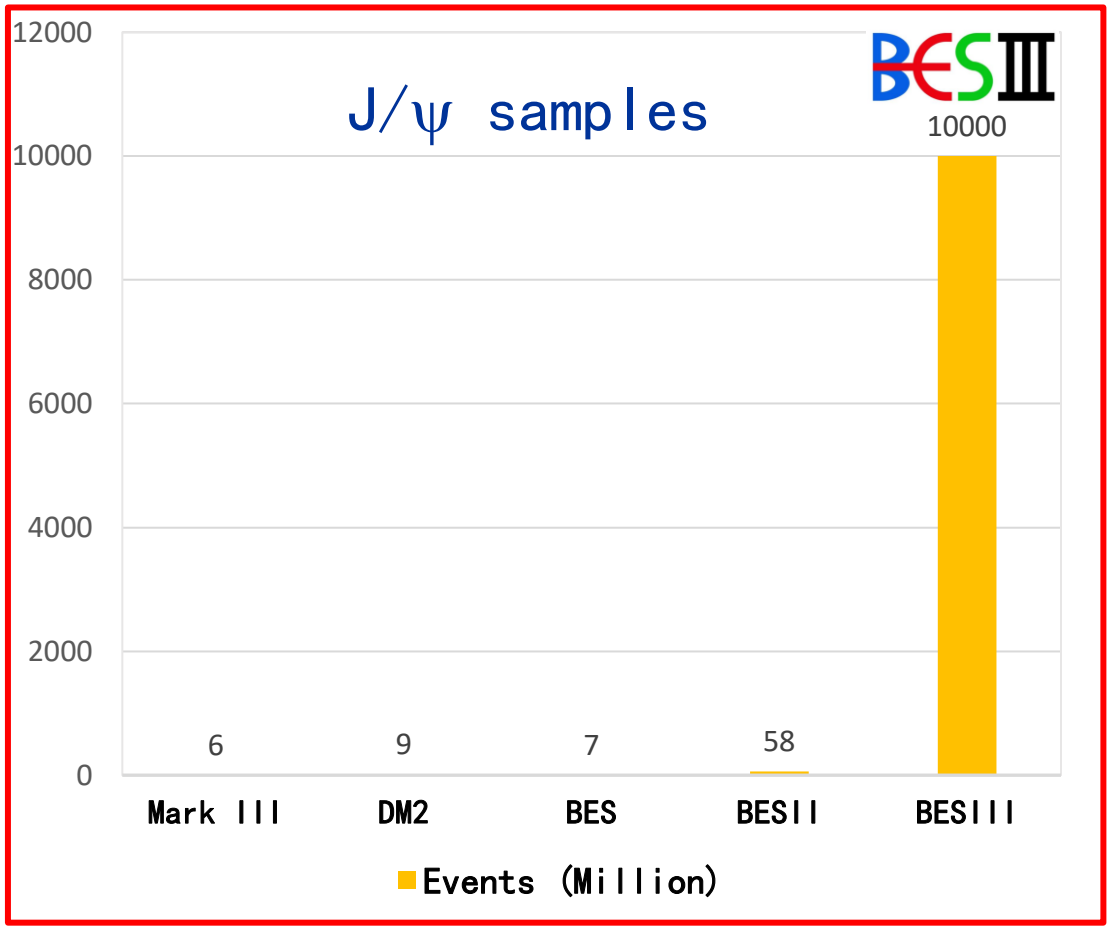
8- 9 layers RPC

$\delta R\Phi$=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

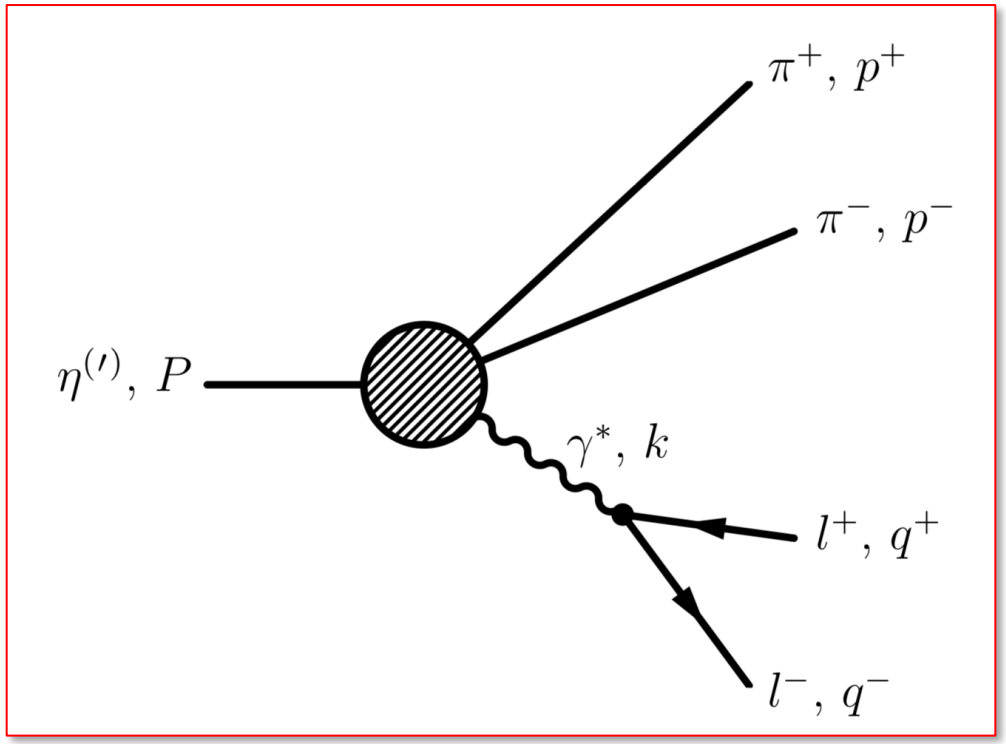
Hadronic decays

Radiative decays

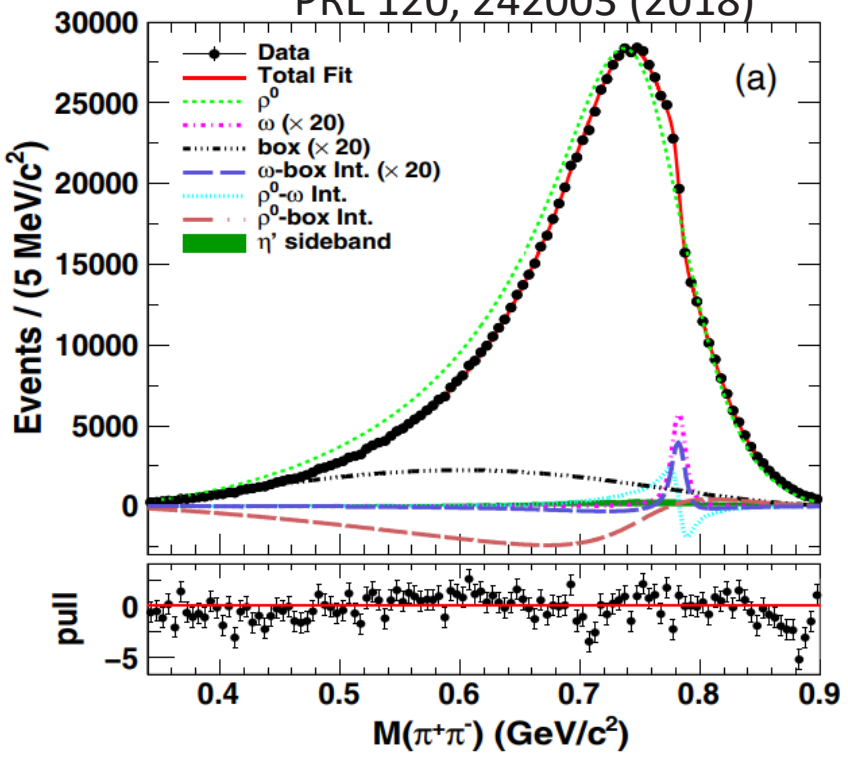
Rare/forbidden decays

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)
Absolute BF of η decays	BRs	PRD104,092004(2021)
$\eta'\to\pi^+\pi^-e^+e^-$	BR, CP-viol assymm	PRD103, 092005(2021)
$\eta'\to\pi^+\pi^-\mu^+\mu^-$	BR, decay dynamic	PRD103, 072006(2021)
$\eta'\to e^+e^-e^+e^-$	BR, TFF	PRD 105,112010(2022)
$\eta'\to\eta\pi^0\pi^0$	Cusp effect	PRL130,081901(2023)
$\eta\to\pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$	Matrix elements, cusp effect	PRD107,092007(2023)

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



PRL 120, 242003 (2018)



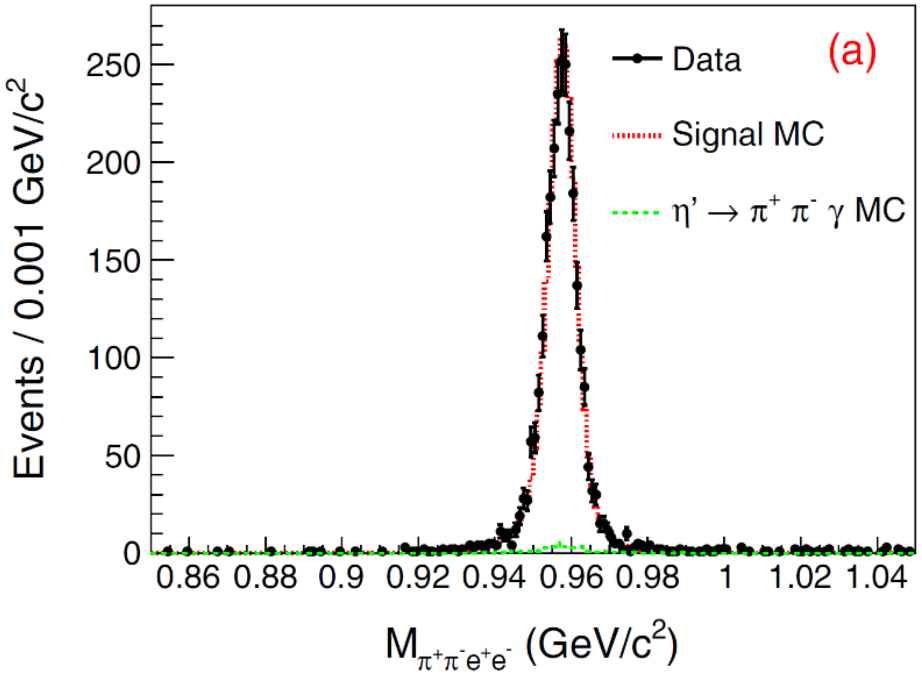
$\eta' \to \pi^+\pi^- l^+ l^-$ has similar structure of $\eta' \to \pi^+\pi^-\gamma$, replacing the γ with an off-shell one that decays into a lepton pair

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

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

PRD103,092005(2021)

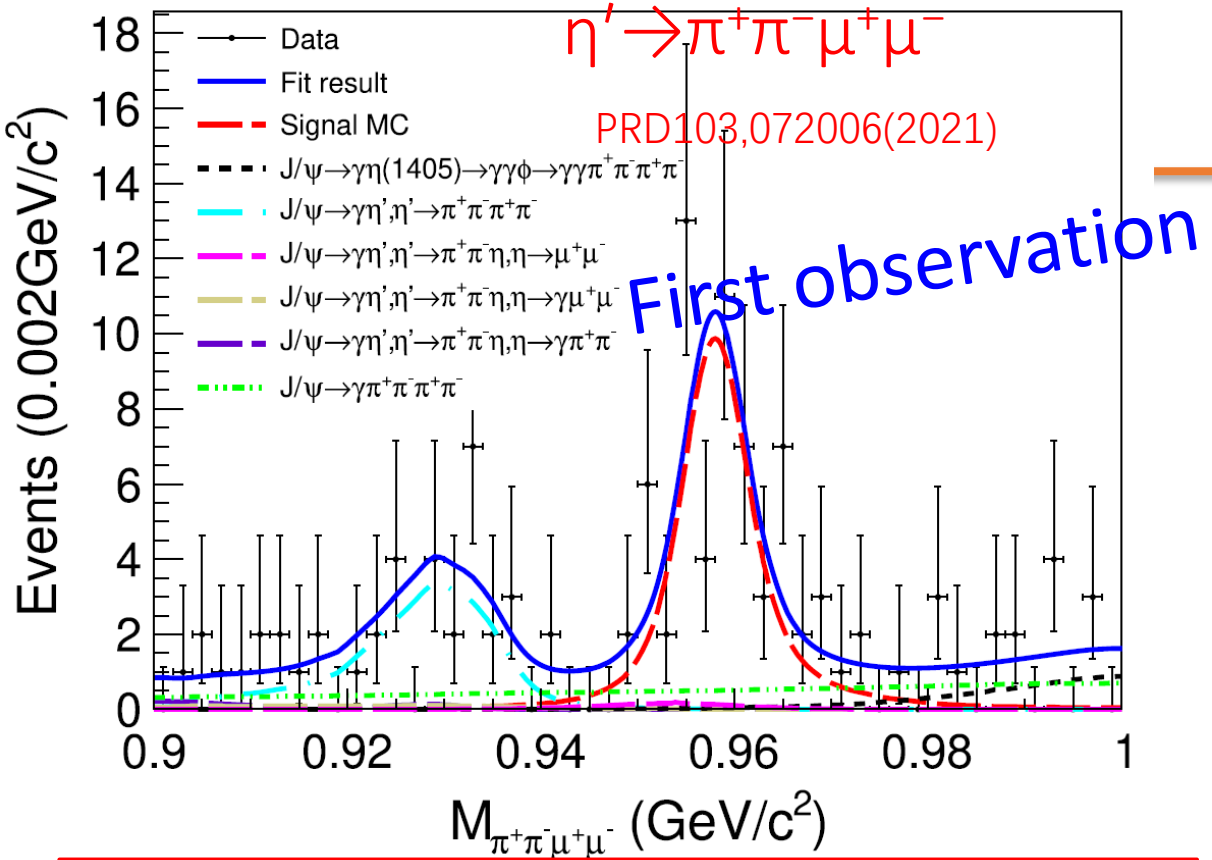
1.3 B J/ψ



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

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

PRD103,072006(2021)



First observation

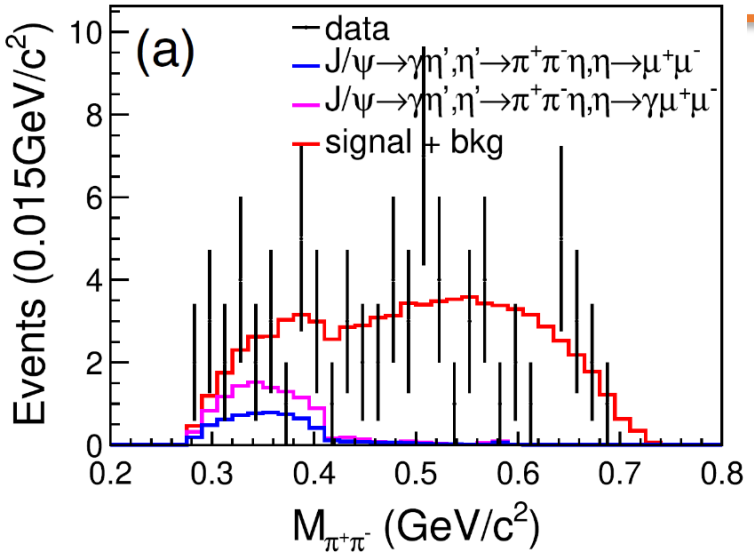
$$\mathcal{B}(\eta' \to \pi^+\pi^-\mu^+\mu^-) = (1.97 \pm 0.33(\text{stat}) \pm 0.19(\text{syst})) \times 10^{-5}$$

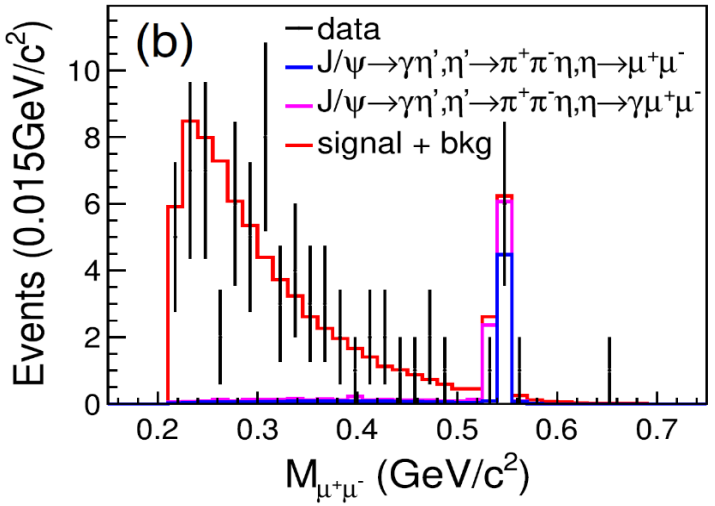
	hidden gauge Model	modified VMD	chiral unitary approach
Br($\eta' \to \pi^+\pi^-e^+e^-$)	$(2.17\pm0.21)\times10^{-3}$	$(2.27\pm0.13)\times10^{-3}$	$(2.13^{+0.17}_{-0.31})\times10^{-3}$
Br($\eta' \to \pi^+\pi^-\mu^+\mu^-$)	$(2.20\pm0.30)\times10^{-5}$	$(2.41\pm0.25)\times10^{-5}$	$(1.57^{+0.96}_{-0.75})\times10^{-5}$

Thimo Petri, arXiv: 1010.2378

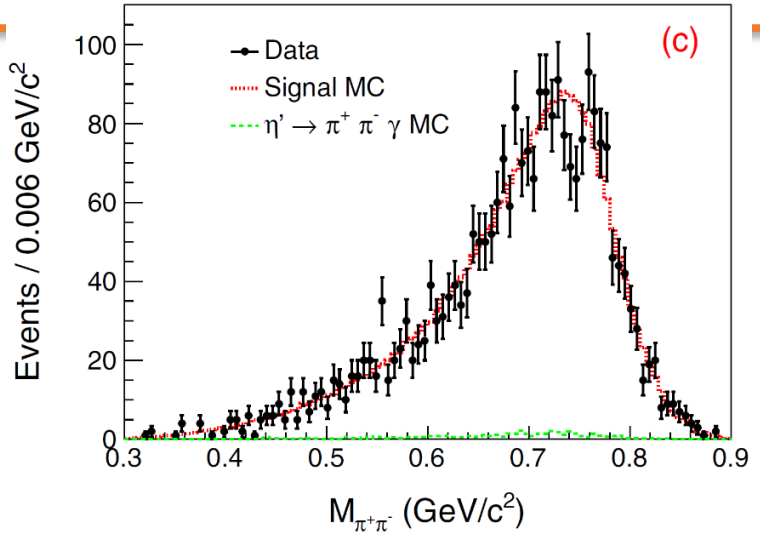
B. Borasoy, R. Nissler, EPJA 33(2007) 95

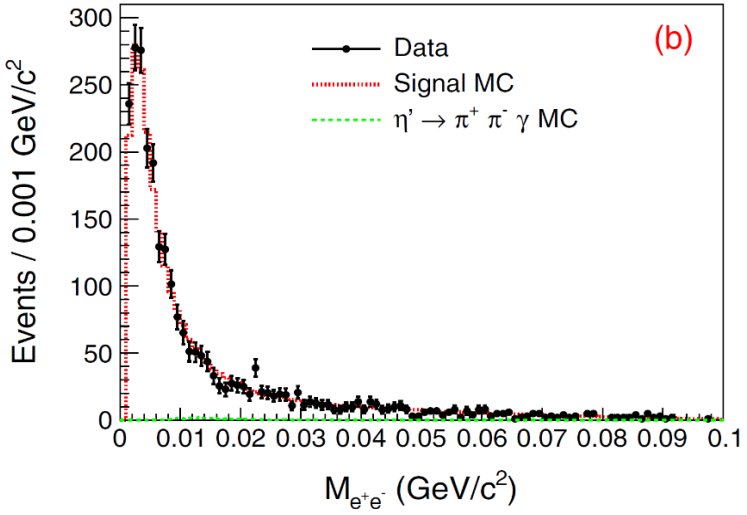
$\eta' \to \pi^+\pi^-\mu^+\mu^-$





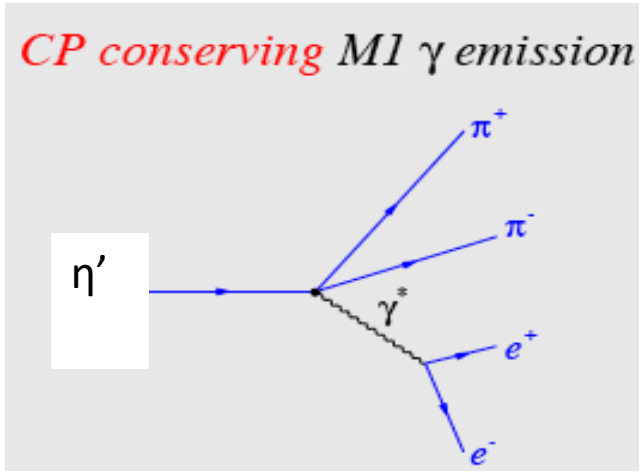
$\eta' \to \pi^+\pi^-e^+e^-$

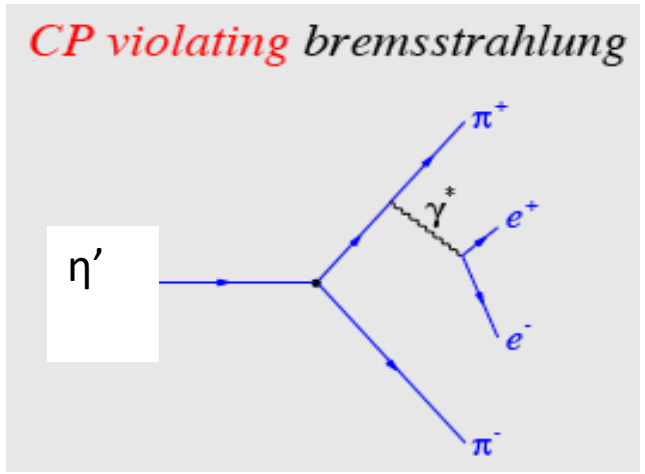


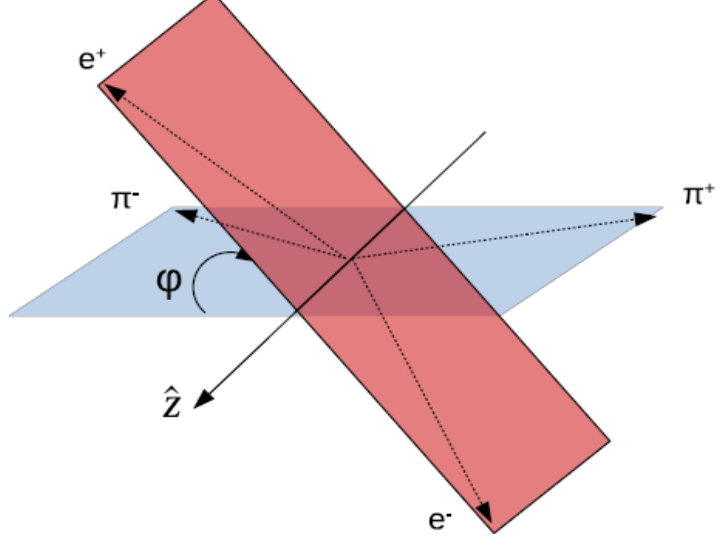


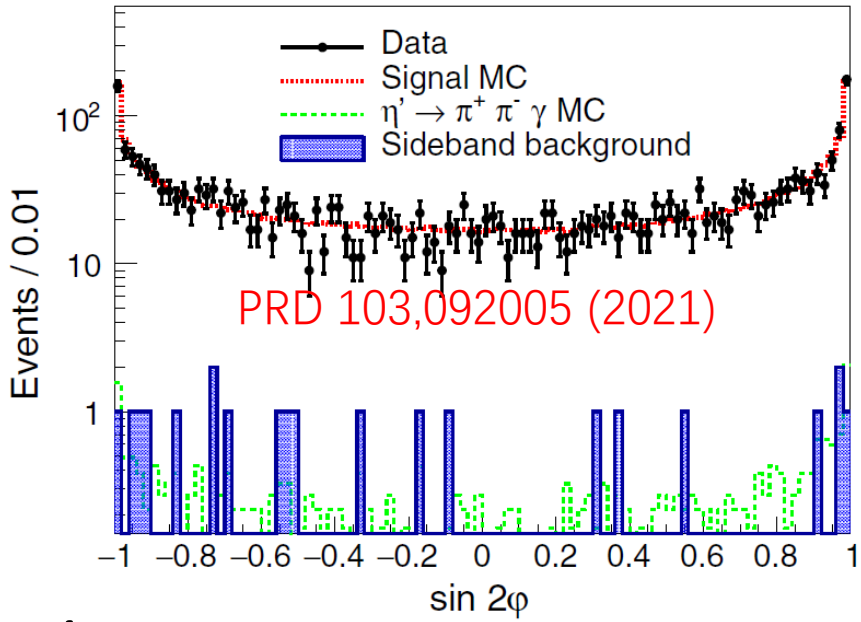
With high statistics of 10 billion J/ψ events, possible to access the transition form factor

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









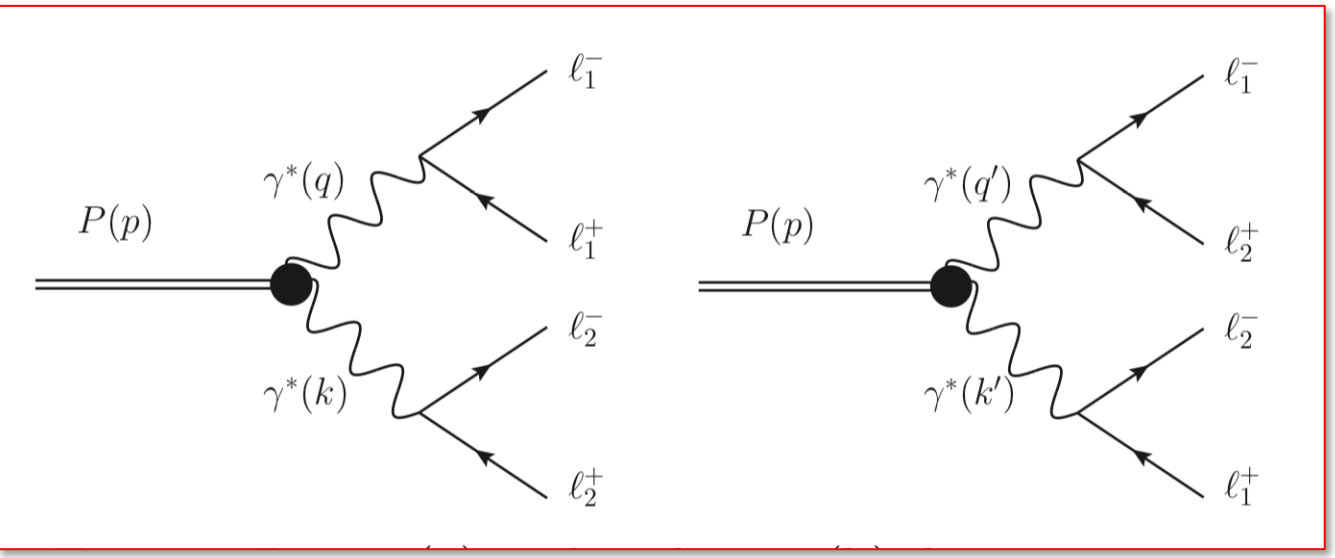
- **A new sources of CP violation outside flavor-changing processes**
- **CP violation due to the interference between CP conserving (magnetic transition) and CP-violating (electric dipole transition)**

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

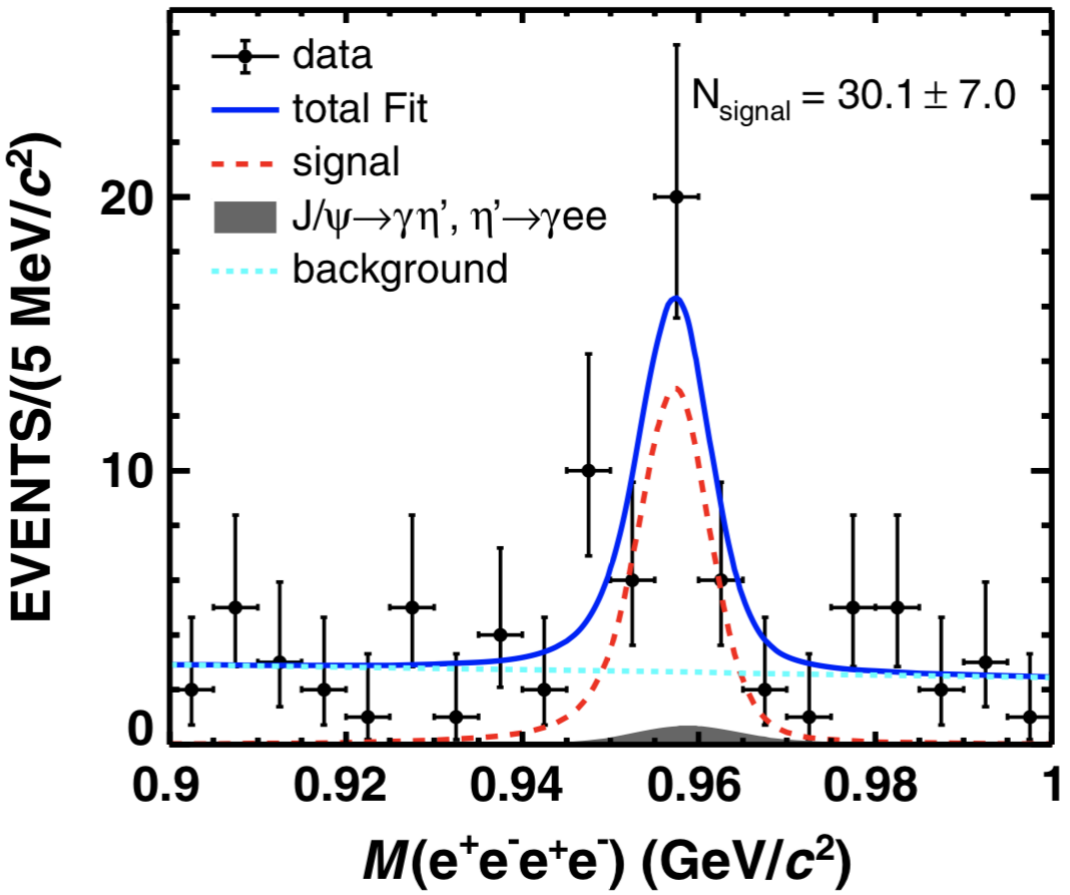
$\eta' \to e^+e^-e^+e^-$	$2.10(45)\times10^{-6}$
$\eta' \to \mu^+\mu^-\mu^+\mu^-$	$1.69(36)\times10^{-8}$
$\eta' \to e^+e^-\mu^+\mu^-$	$6.39(91)\times10^{-7}$

By means of data-driven approach based on the rational approximants applied to π^0, η, η' transition form factor data in space-like region

- 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) 10 B J/ψ



— Statistical significance 5.7σ

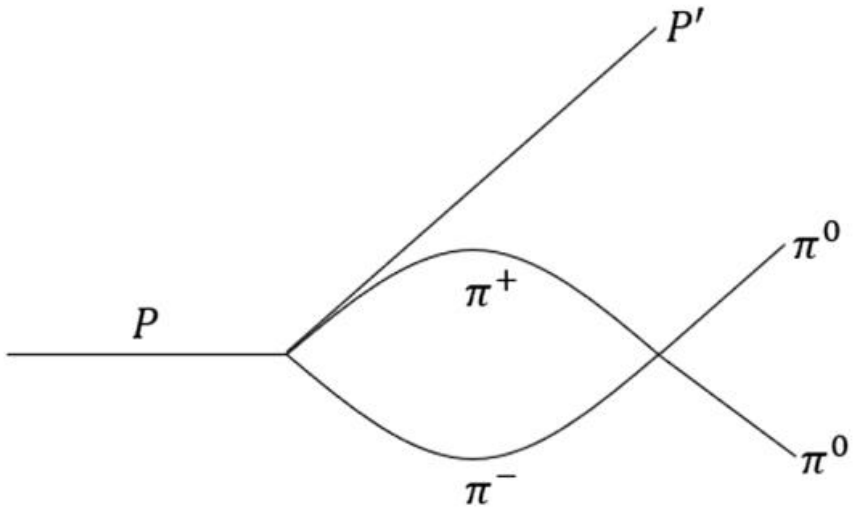
— BF in reasonable agreement with theoretical predictions

— insufficient for extraction of TFF, but provide information for η' TFF and couplings between η' and virtural photons.

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

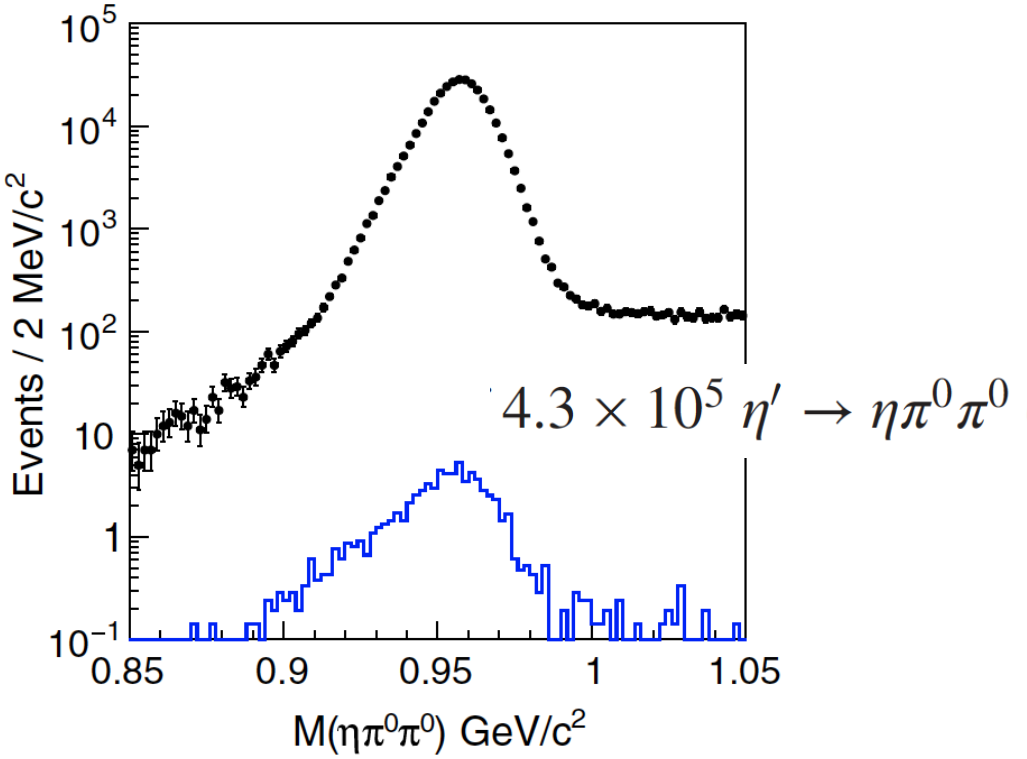
Evidence of the cusp effect in $\eta' \to \eta\pi^0\pi^0$

- S-wave charge-exchange rescattering: $\pi^+\pi^- \to \pi^0\pi^0$
- A prominent cusp at the center of mass energy
- Investigation on $\pi\pi$ and $\pi\eta$ final interactions
- Sizeable cusp effect in $\eta' \to \pi^0\pi^0\eta$

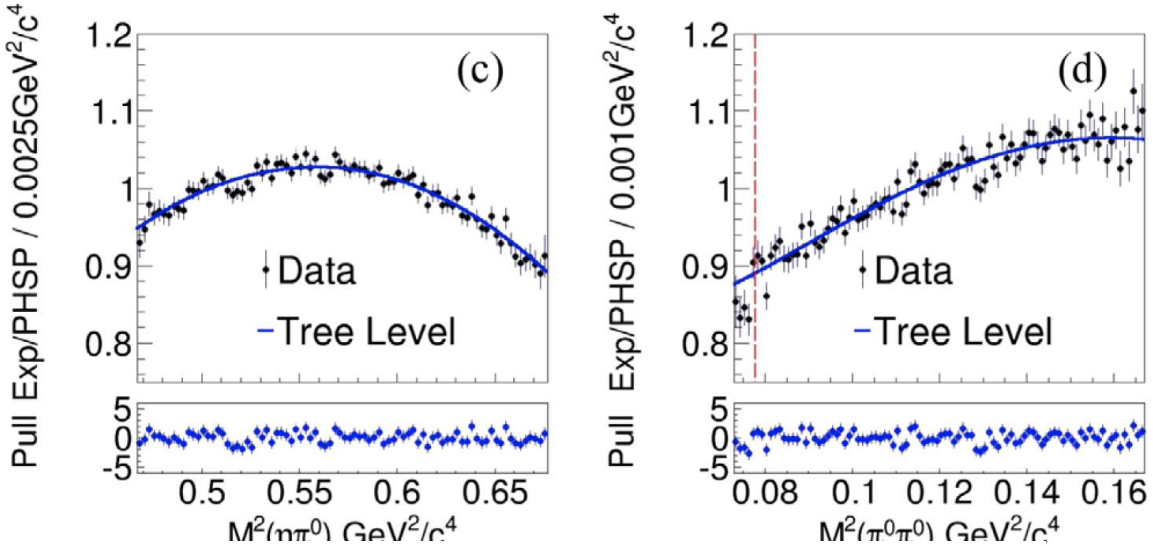


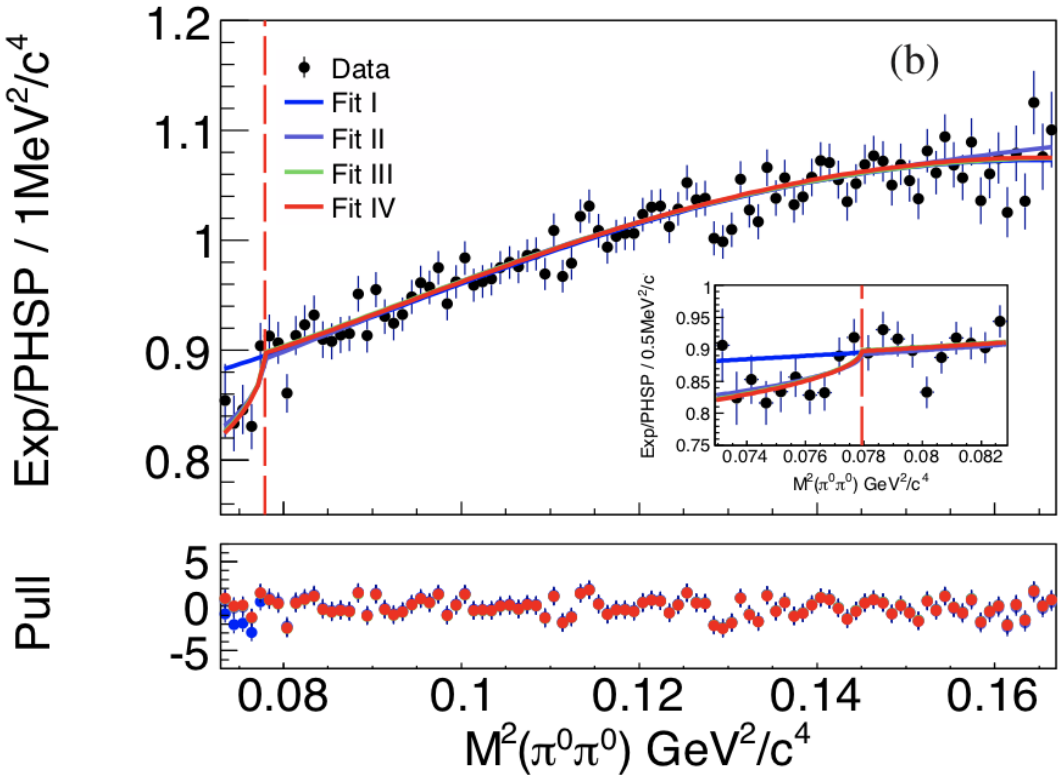
B. Kubis and S. P. Schneider, EPJC 62, 511 (2009)

S. Gonzalez-Solls, E. Passemar EPJC78, 758 (2018)



PRL130,081901(2023) 10 B J/ψ



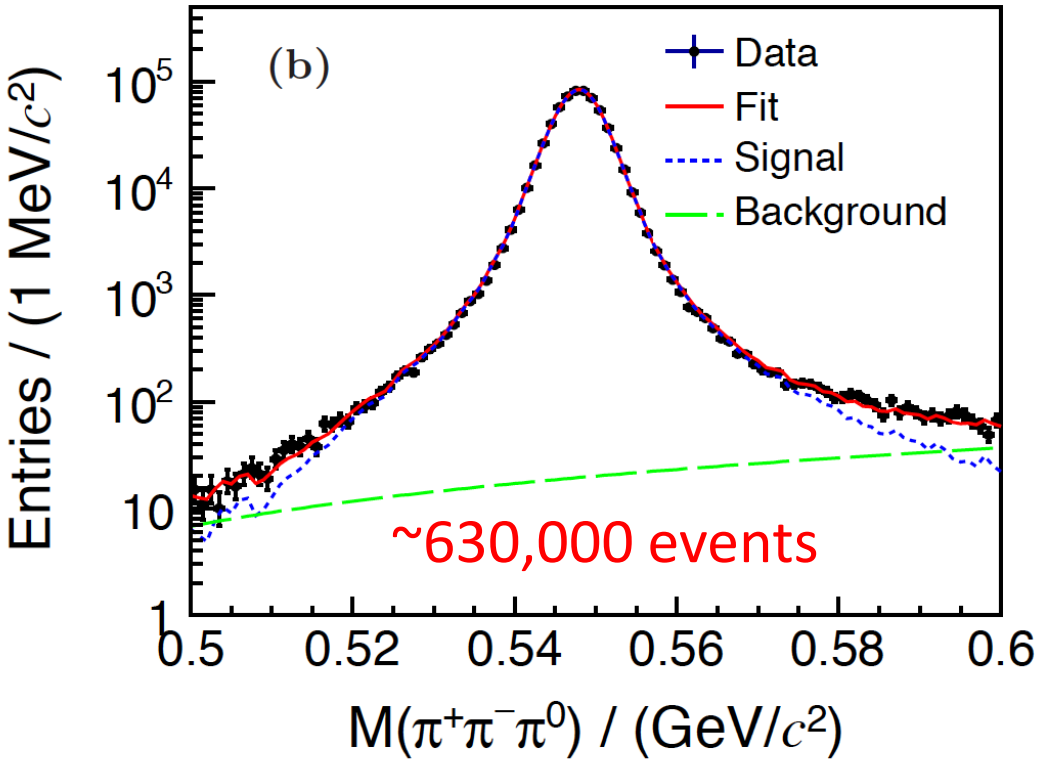


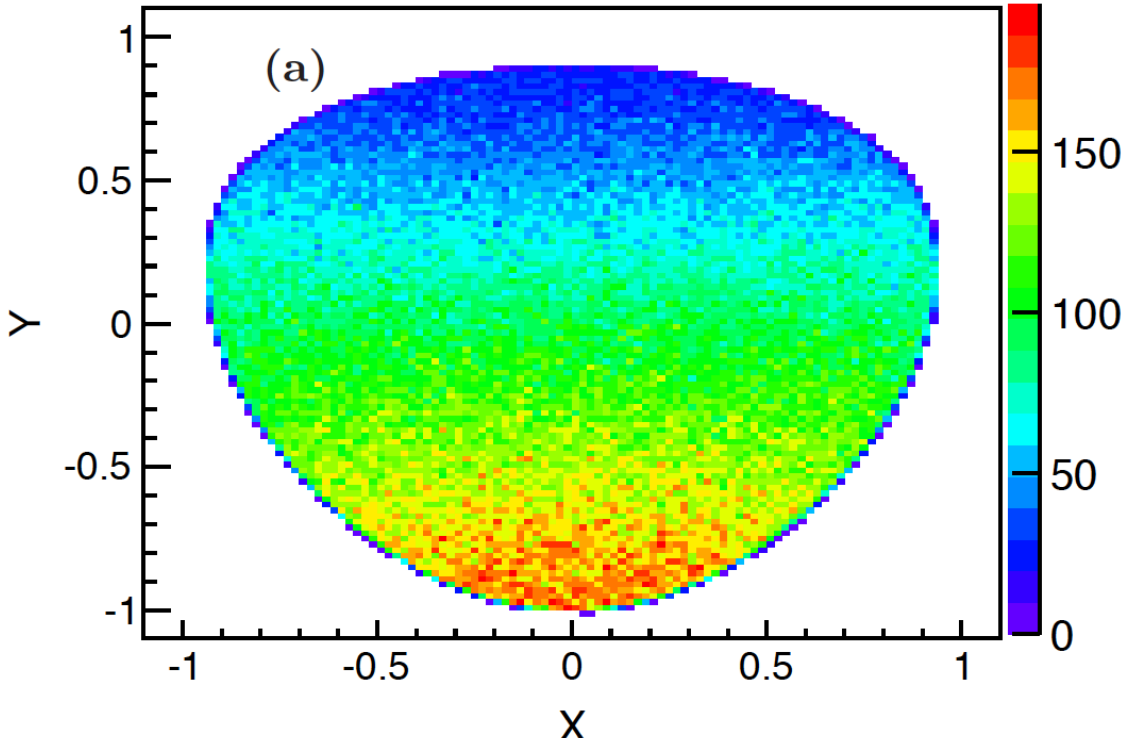
Dalitz analysis results with tree level contribution are consistent with previous BESIII result with only 1.3 B J/ψ

- **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**
- **ηπ interaction not included!**

Updated results on $\eta \to \pi^+\pi^-\pi^0, \eta \to \pi^+\pi^-\pi^0$

$\eta \to 3\pi$ violates isospin symmetry and is related to the difference of light-quark masses. Therefore, $\eta \to 3\pi$ offers a unique way to determine the quark mass.



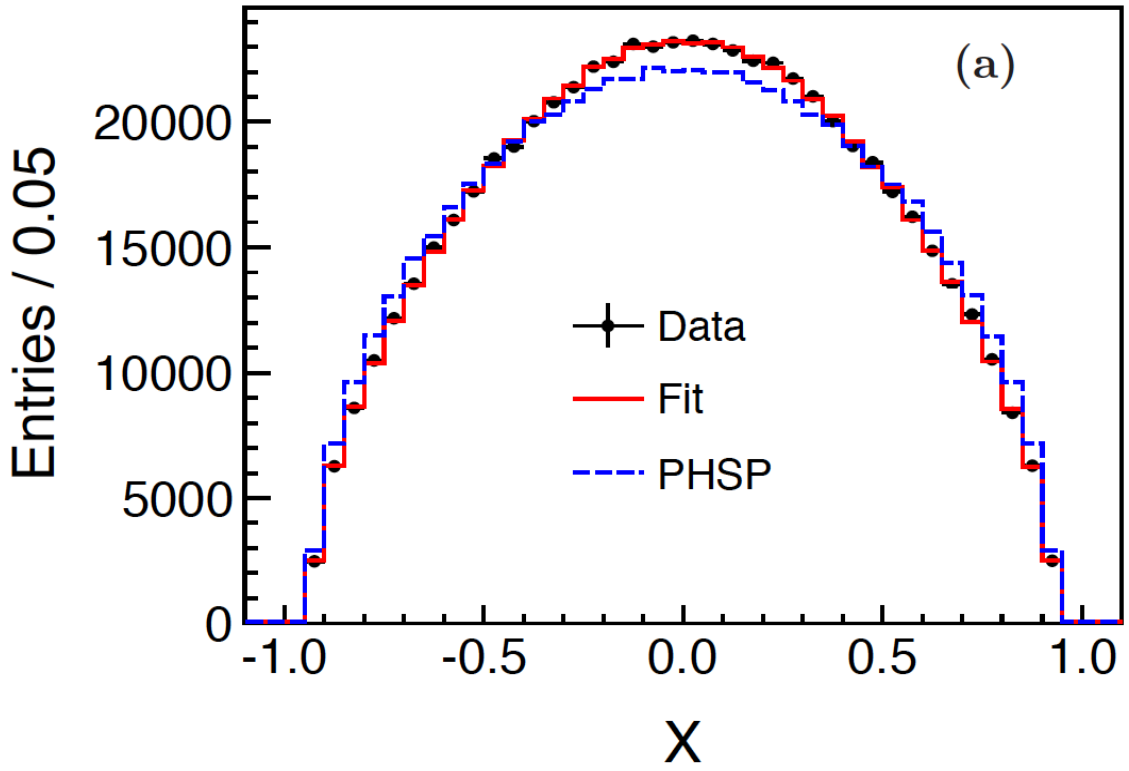


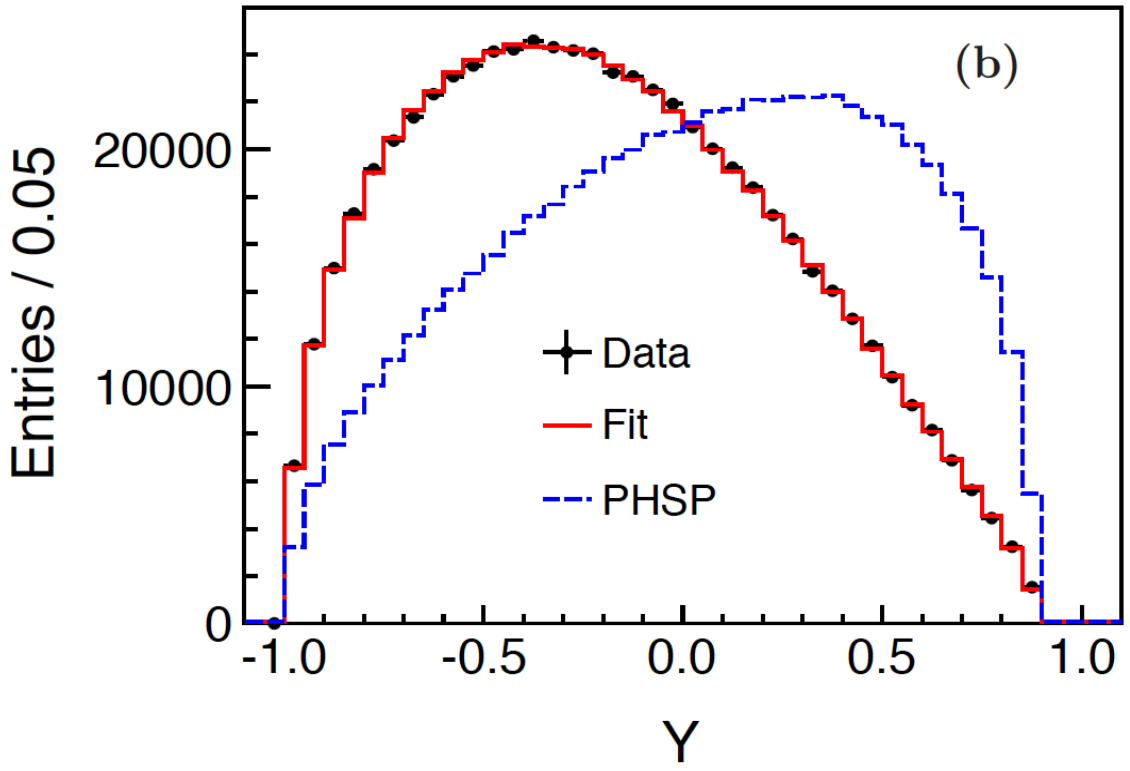
PRD107,092007(2023)

$$X = \frac{\sqrt{3}}{Q_\eta}(T_{\pi^+} - T_{\pi^-}), \qquad Y = \frac{3T_{\pi^0}}{Q_\eta} - 1$$

$\eta \to \pi^+\pi^-\pi^0$

$$|A(X,Y)|^2 \propto 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y + \cdots$$



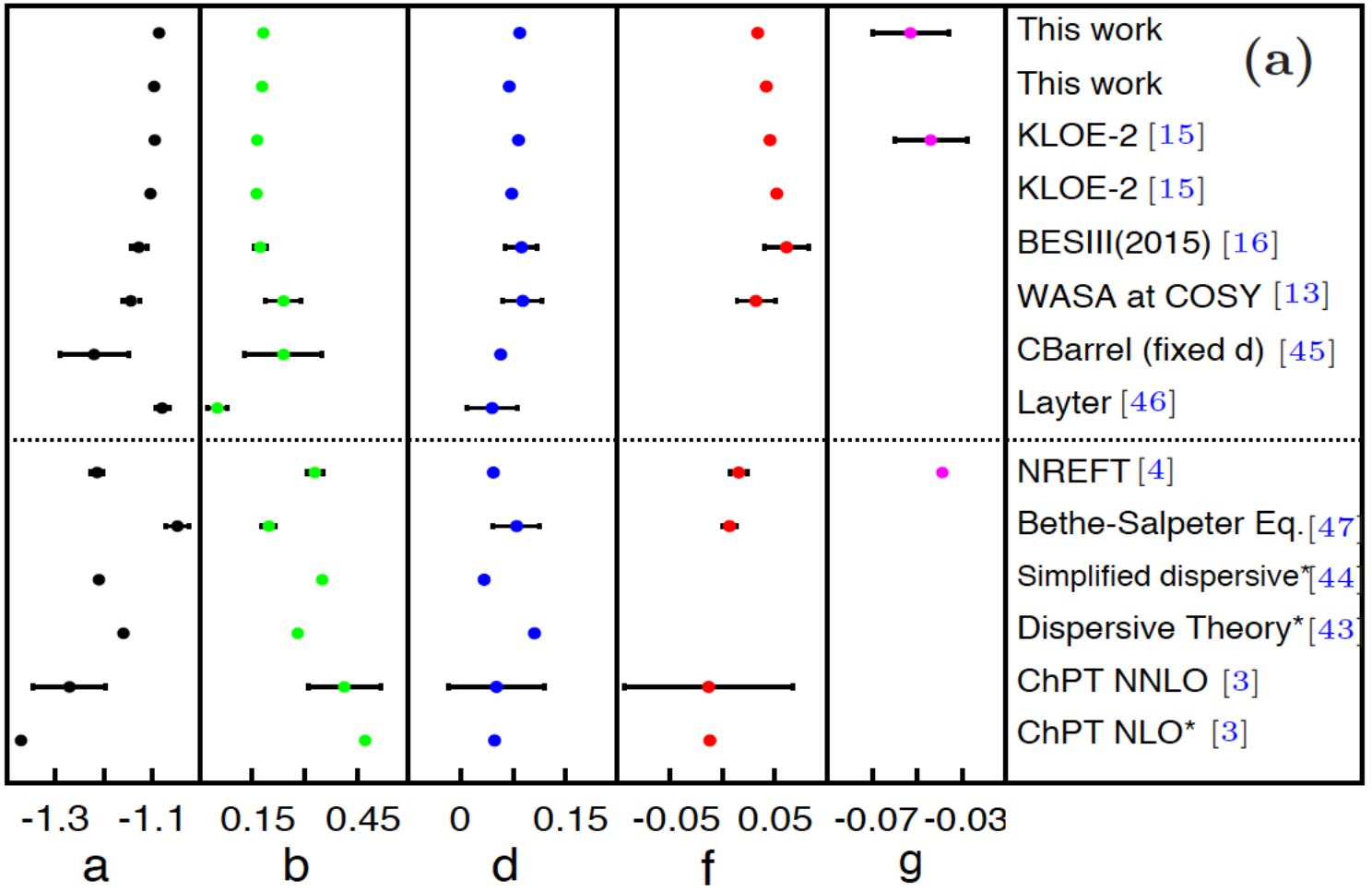


a, b, c, d, e, f, g are the Dalitz plot matrix elements

Comparison to experimental and theoretical results

$$
\begin{aligned}
a &= -1.097 \pm 0.005 \pm 0.001 \\
b &= 0.158 \pm 0.006 \pm 0.003 \\
d &= 0.070 \pm 0.006 \pm 0.001 \\
f &= 0.134 \pm 0.010 \pm 0.003
\end{aligned}
$$

$$
\begin{aligned}
a &= -1.086 \pm 0.006 \pm 0.001 \\
b &= 0.162 \pm 0.006 \pm 0.003 \\
d &= 0.083 \pm 0.007 \pm 0.001 \\
f &= 0.118 \pm 0.011 \pm 0.003 \\
g &= -0.053 \pm 0.017 \pm 0.003
\end{aligned}
$$

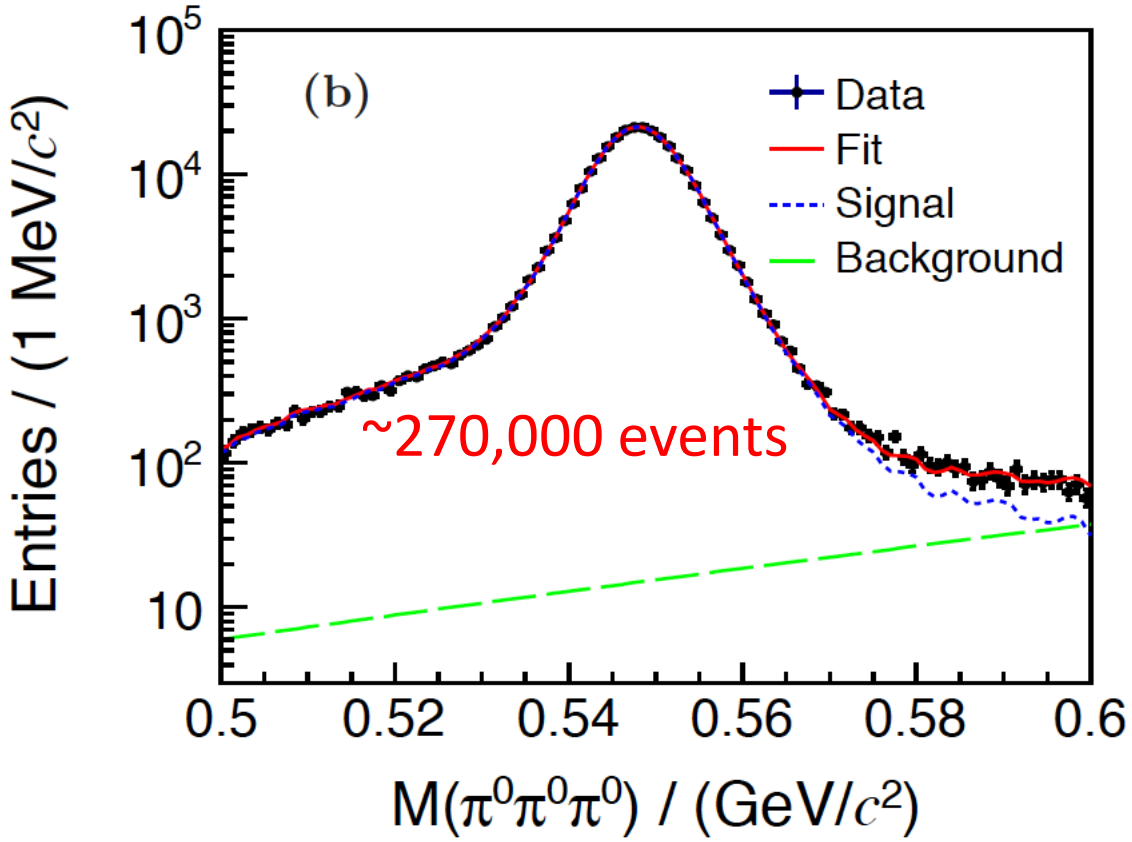


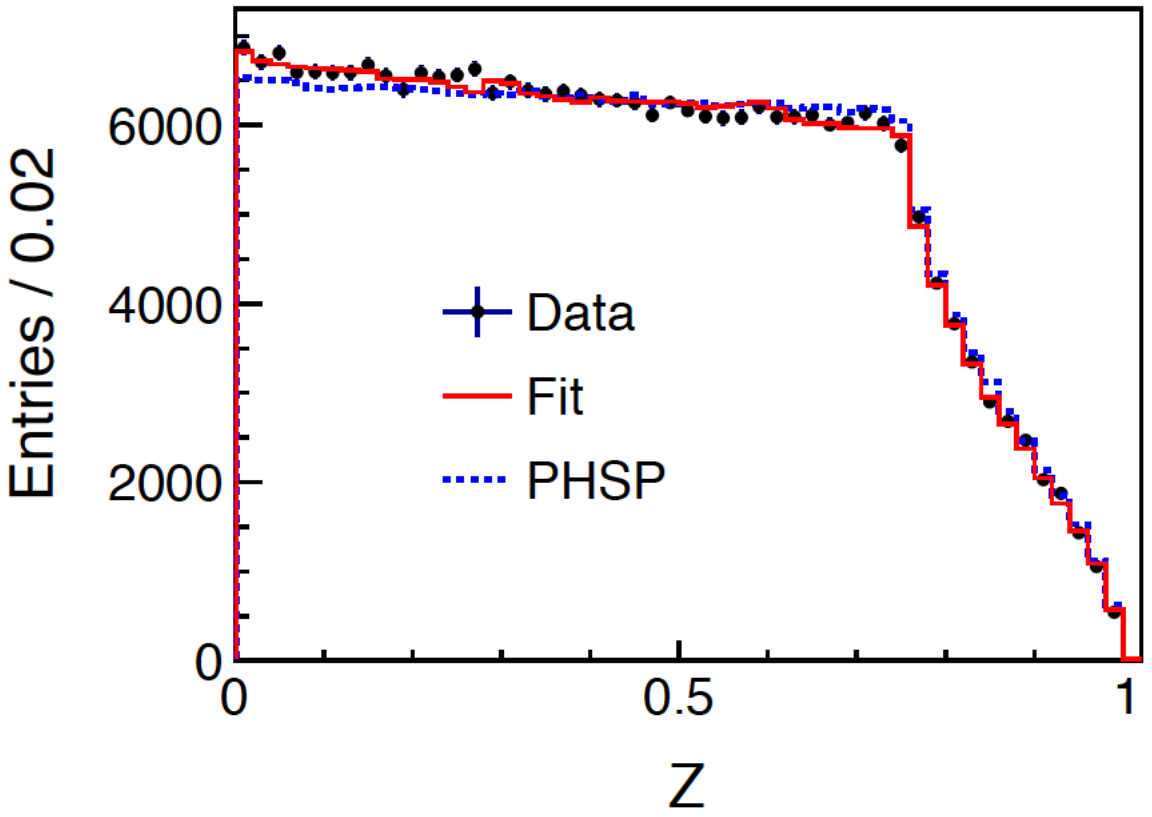
Dalitz matrix elements are extracted under different assumptions. Our results are consistent with KLOE-2 results. And can be compared directly with different models.

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

$$Z = X^2 + Y^2 = \frac{2}{3}\sum_{i=1}^{3}\left(\frac{3T_i}{Q_\eta} - 1\right)^2,$$

$$|A(X,Y)|^2 \propto 1 + 2\alpha Z$$

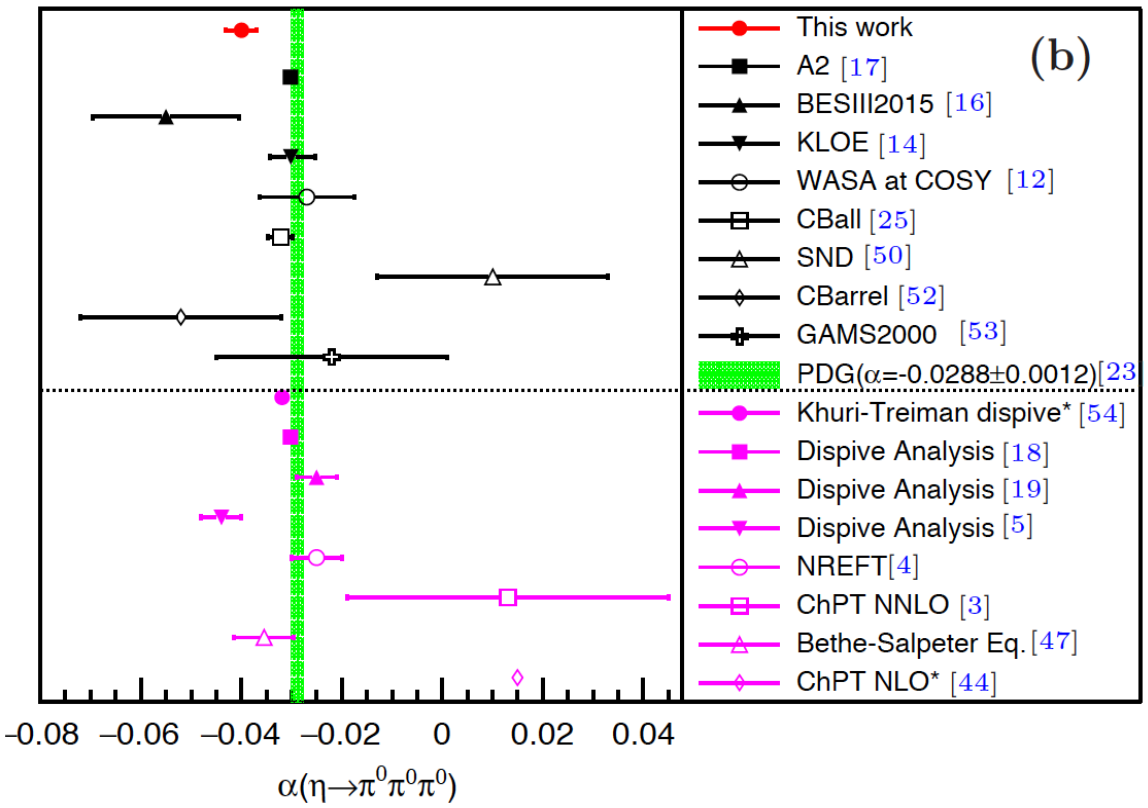




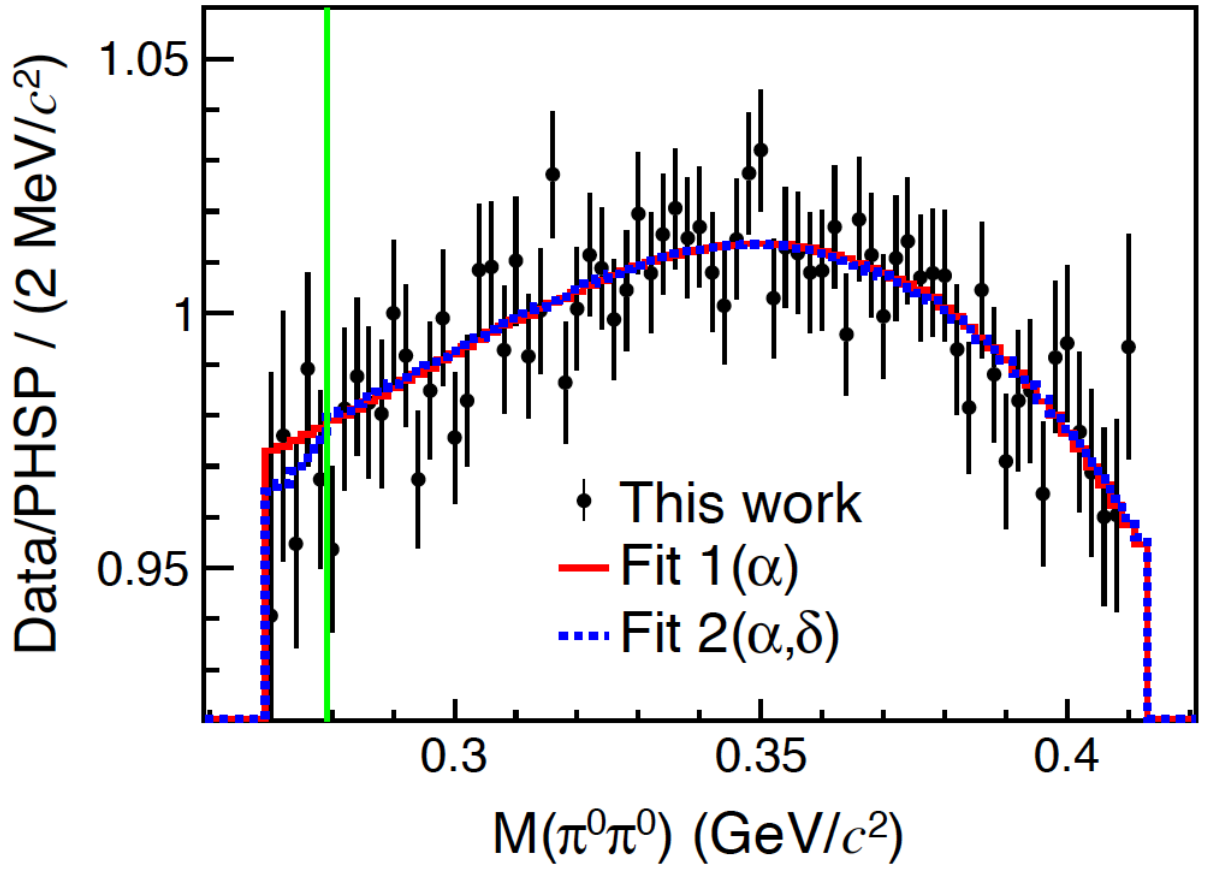
PRD107,092007(2023)

$$\alpha = -0.0406 \pm 0.0035 \pm 0.0008.$$

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



Deviations from A2: 2.8σ



No evident cusp effect

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**
  - **…….**


Thank you for your attention!