Light meson decays at BESIII

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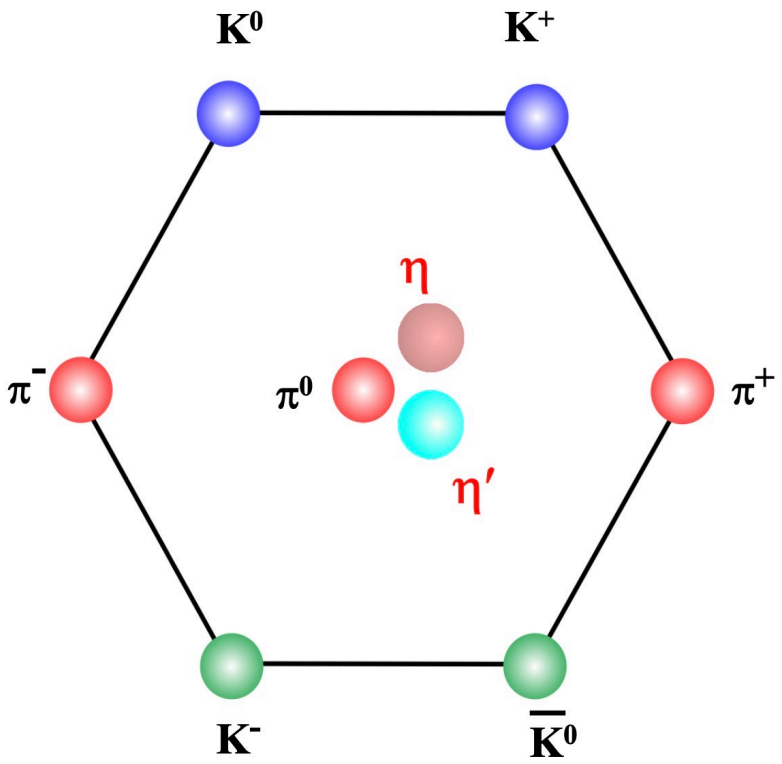
Outline

- Light meson physics
- BESIII: a light meson factory
- Recent η/η' decays at BESIII
- Summary

Light Meson Physics

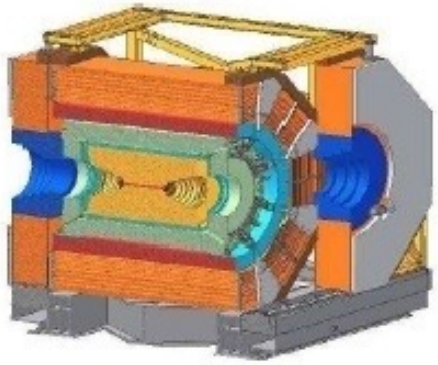
- Important roles in particle physics
  - ✓Strong interactions, Quark Model, CP violation ...
- Rich physics
  - ✓Test ChPT predictions
  - ✓EM Form Factors
  - ✓Test fundamental symmetries
  - ✓Probe new physics beyond the SM



Source of η/η' events

e^+e^- Collider

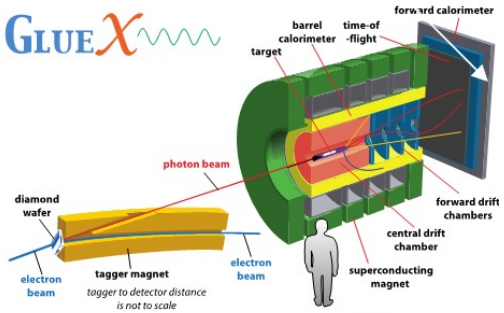
BESIII at BEPCII



KLOE-2

Fixed-target

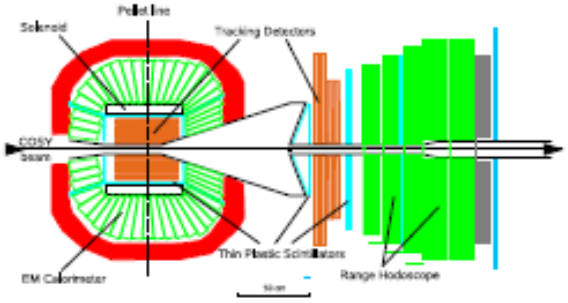
JEF at JLab



Crystal Ball

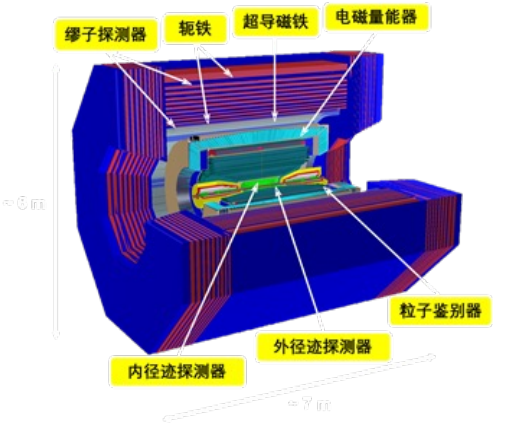
CLAS(12)

WASA at COSY

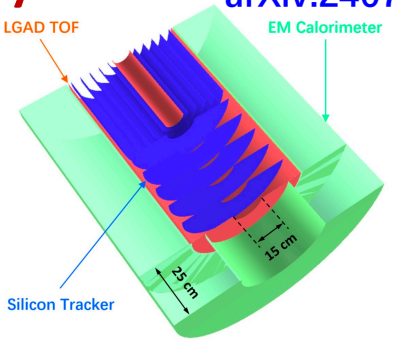


New Proposals

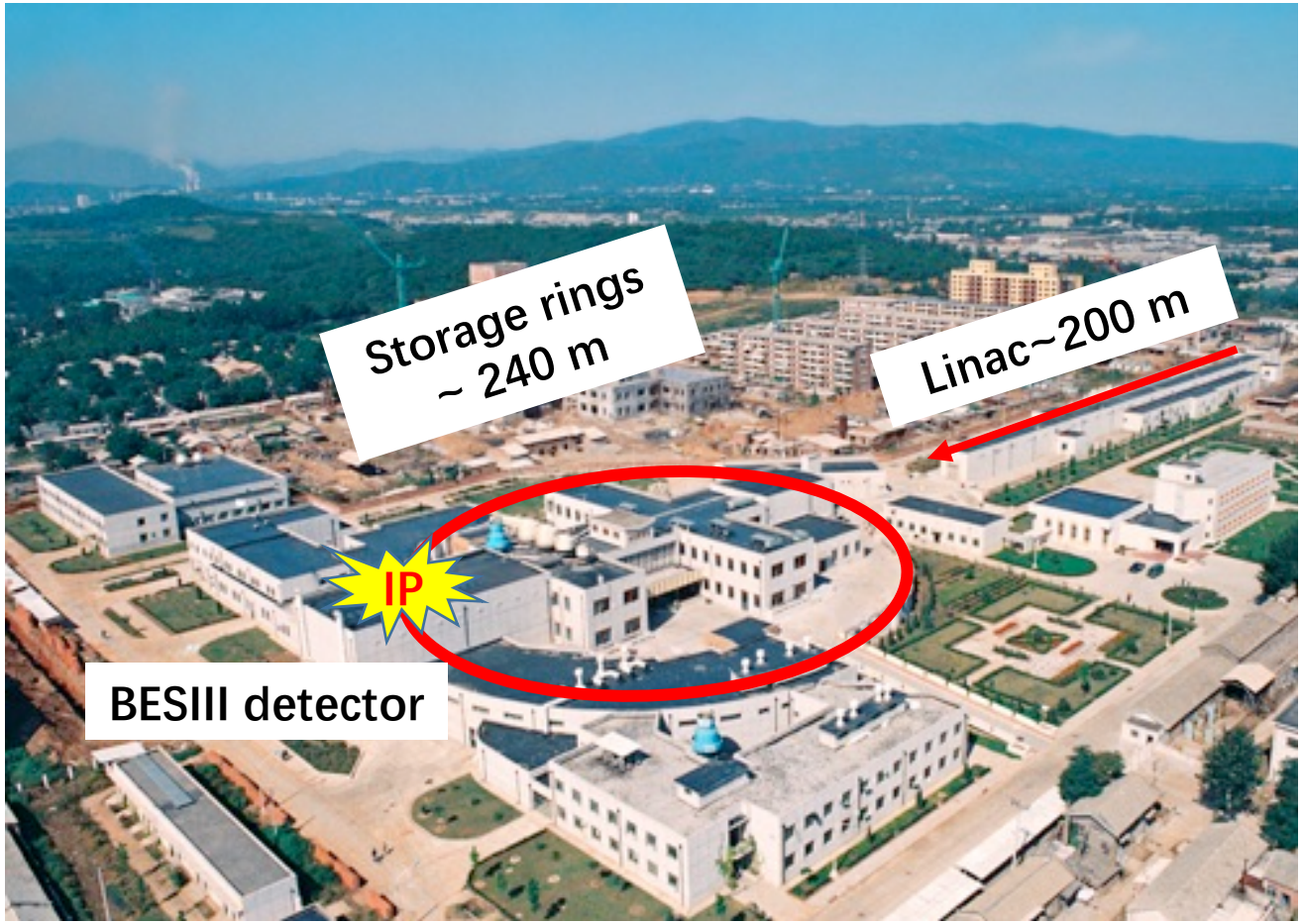
STCF



η factory at HIAF arXiv:2407.00874

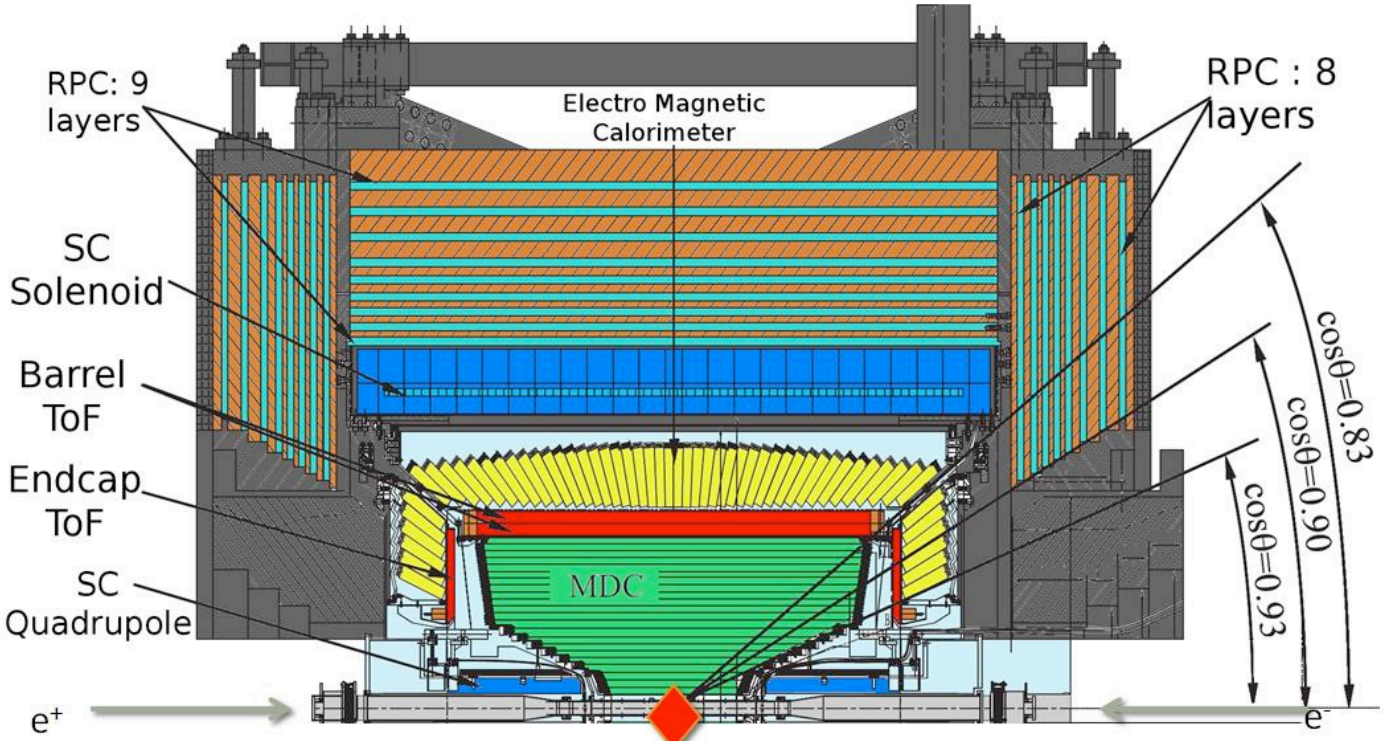


Beijing Electron and Positron Collider (BEPCII)



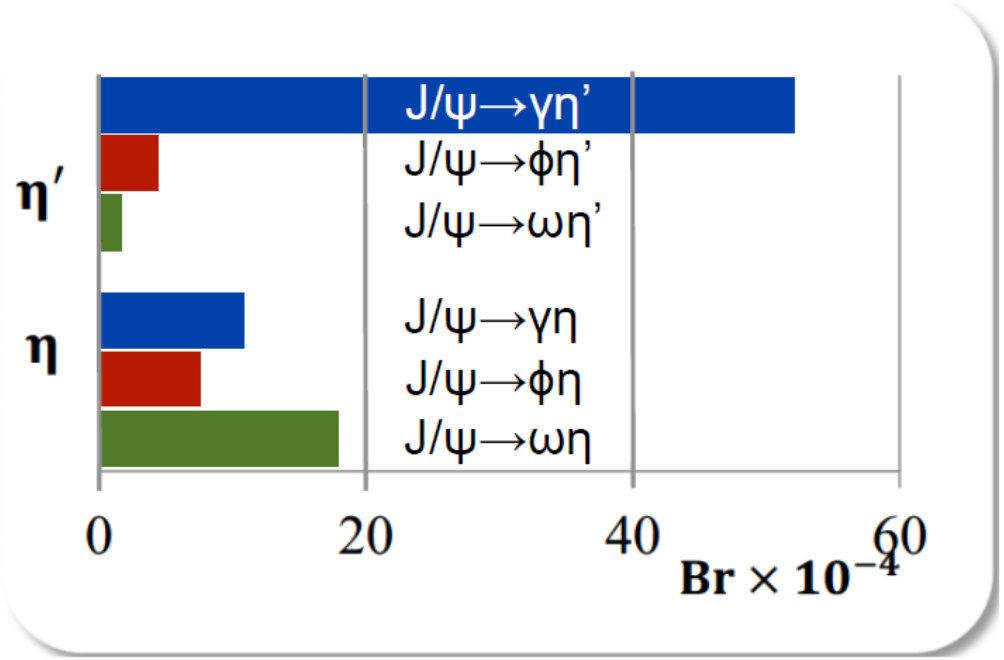
- Symmetric, double rings e^+e^- collider @ $\sqrt{s}$=2-4.9GeV
- Planning to upgrade to 5.6GeV (BEPCII-U)
- Peak luminosity $\approx 10^{33}cm^{-2}s^{-1}$ at $\sqrt{s}$=3.770GeV
- Crab-Waist interaction scheme with the crossing angle of 11 mrad
- Top-up operation since 2018

BESIII detector



- **Acceptance: 93% of 4π**
- **Main Drift Chamber**: small cell & gas
  - ✓ σ_{xy}=130 μm, σ_P/P=0.5%@1 GeV
  - ✓ $\sigma_{dE/dx}$=6%
- **Time of Flight (TOF)**
  - ✓ σ_T=70 ps for barrel layers
  - ✓ σ_T=110 ps (65 ps with updated MRPC) for endcaps
- **Super Conducting Solenoid**: 1.0T (0.9T for 2012)
- **Electromagnetic Calorimeter**: CsI Crystals
  - ✓ σ_E/E=2.5%@1 GeV
  - ✓ Position resolution 6mm@1GeV
- **RPC Muon ID**: 9 layer

η/η′ sample from J/ψ decays at BESIII



- High production rate of η/η′ in J/ψ decays
  - radiative decays: 5.2×10^7 η′, 1.1×10^7 η
  - hadronic decays: 6.5×10^6 η′, 2.5×10^7 η
- Unique opportunity to investigate the decays of η/η′

BESIII: an important role in η/η′ decays

PDG2024

Decay channel	Physics	Publication
$\eta' \to \rho\pi$	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)
$\omega \to \pi^+\pi^-\pi^0$	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)
Absolute BF of η decays	BRs	PRD104, 092004(2021)
$\eta' \to e^+e^-e^+e^-$	BR, TFF	PRD105, 112010(2022)
$\eta' \to \pi^+\pi^-\eta$, $\eta' \to \eta\pi^0\pi^0$	Matrix elements, Cusp effect	PRD97, 012003(2018) PRL130, 081901(2023)
$\eta \to \pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$		PRD107,092007(2023)
$\eta' \to 4\pi$	VMD, CP-Vio	PPRD101, 032001(2020) PRD 109, 032006 (2024)
$\eta' \to \pi^+\pi^-e^+e^-$, $\pi^+\pi^-u^+u^-$	BR, decay dynamic, CP-Vio	PRD103, 092005(2021) PRD103, 072006(2021) JHEP07, 135 (2024)
$\eta/\eta' \to \gamma e^+e^-$	TFF	PRD109, 072001 (2024)

η REFERENCES

ABLIKIM	23AN	PR D107 092007	M. Ablikim *et al.*	(BESIII Collab.)
HAYRAPETY...	23A	PRL 131 091903	A. Hayrapetyan *et al.*	(CMS Collab.)
ABLIKIM	21AM	PR D104 092004	M. Ablikim *et al.*	(BESIII Collab.)
BABUSCI	20A	JHEP 2010 047	D. Babusci *et al.*	(KLOE-2 Collab.)
ZHEVLAKOV	19	PR D99 031703	A.S. Zhevlakov *et al.*	(TMSK, MAINZ, TUBIN+)
ACHASOV	18B	PR D98 052007	M.N. Achasov *et al.*	(SND Collab.)
ADLARSON	18C	PL B784 378	P. Adlarson *et al.*	(WASA-at-COSY Collab.)
PRAKHOV	18	PR C97 065203	S. Prakhov *et al.*	(A2 Collab. at MAMI)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
ADLARSON	17B	PR C95 035208	P. Adlarson *et al.*	(A2 Collab. at MAMI)
ANASTASI	16A	JHEP 1605 019	A. Anastasi *et al.*	(KLOE-2 Collab.)
ARNALDI	16	PL B757 437	R. Arnaldi *et al.*	(NA60 Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim *et al.*	(BESIII Collab.)
ADLARSON	14A	PR C90 045207	P. Adlarson *et al.*	(WASA-at-COSY Collab.)
AGAKISHIEV	14	PL B731 265	G. Agakishiev *et al.*	(HADES Collab.)
NEFKENS	14	PR C90 025206	B.M.K. Nefkens *et al.*	(A2 Collab. at MAMI)
NIKOLAEV	14	EPJ A50 58	A. Nikolaev *et al.*	(MAMI-B, MAINZ, BONN)
ABLIKIM	13	PR D87 012009	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
BABUSCI	13	PL B718 910	D. Babusci *et al.*	(KLOE/KLOE-2 Collab.)
BABUSCI	13A	JHEP 1301 119	D. Babusci *et al.*	(KLOE-2 Collab.)
AGAKISHIEV	12A	EPJ A48 64	G. Agakishiev *et al.*	(HADES Collab.)
GOSLAWSKI	12	PR D85 112011	P. Goslawski *et al.*	(COSY-ANKE Collab.)
AB				:)

η′(958) REFERENCES

ABLIKIM	23AH	PRL 130 081901	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	22E	PR D105 112010	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	21I	PR D103 072006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	21J	PR D103 092005	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	20E	PR D101 032001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	19AW	PR D100 052015	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	19T	PRL 122 142002	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	18	PR D97 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	18C	PRL 120 242003	M. Ablikim *et al.*	(BESIII Collab.)
ADLARSON	18A	PR D98 012001	P. Adlarson *et al.*	(A2 Collab. at MAMI)
GONZALEZ-S...	18A	EPJ C78 758	S. Gonzalez-Solis, E. Passemar	(BEIJ, IND+)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
ABLIKIM	17	PRL 118 012001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	17T	PR D96 012005	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	16M	PR D93 072008	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15AD	PR D92 051101	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15O	PR D92 012001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15P	PR D92 012007	M. Ablikim *et al.*	(BESIII Collab.)
ACHASOV	15	PR D91 092010	M.N. Achasov *et al.*	(SND Collab.)
AKHMETSHIN	15	PL B740 273	R.R. Akhmetshin *et al.*	(CMD-3 Collab.)
PDG	15	RPP 2015 at pdg.lbl.gov		(PDG Collab.)
ABLIKIM	14M	PRL 112 251801	M. Ablikim *et al.*	(BESIII Collab.)
DONSKOV	14	MPL A29 1450213	S. Donskov *et al.*	(GAMS-4π Collab.)
PDG	14	CP C38 070001	K. Olive *et al.*	(PDG Collab.)
ABLIKIM	13	PR D87 012009	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13O	PR D87 092011	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13U	PR D88 091502	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	12E	PRL 108 182001	M. Ablikim *et al.*	(BESIII Collab.)
PDG	12	PR D86 010001	J. Beringer *et al.*	(PDG Collab.)
ABLIKIM	11	PR D83 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

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

X. L. Kang, Y. Y. Ji. B. H. Xiang, S. S. Fang, PRD 108, 014038 (2023)

η REFERENCES

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ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

- $J/\psi \to \gamma\eta \to 1.1\times10^7\ \eta$
- $J/\psi \to \gamma\eta',\ \eta' \to \pi^+\pi^-\eta \to 2.2\times10^7\ \eta$

- η' constraint to suppress backgrounds from QED and J/ψ decays!
- Help distinguish muons from pions

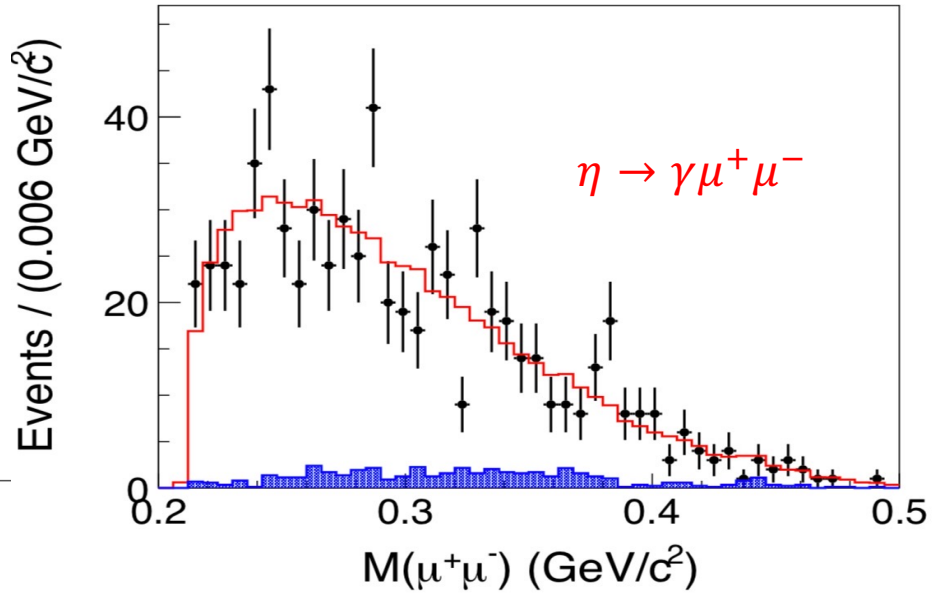
"Few results" on η decays at BESIII

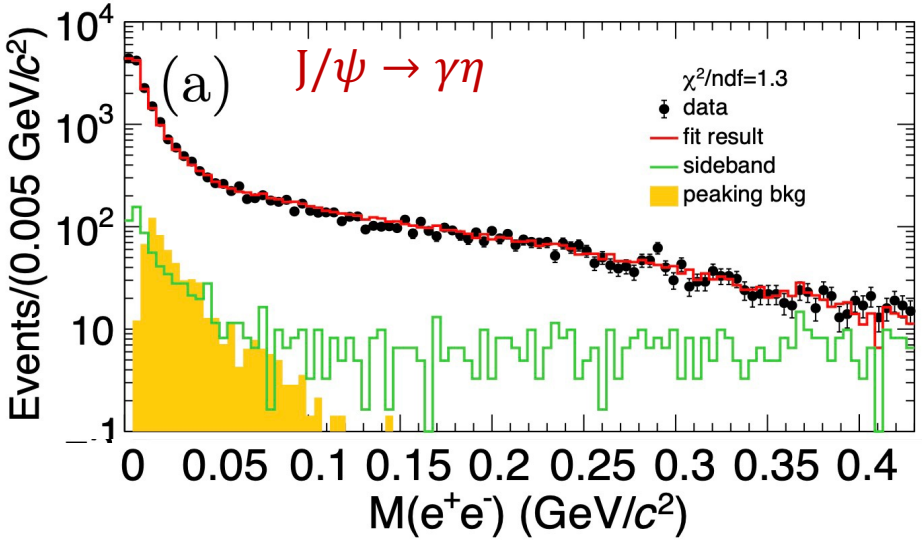
New approach to investigate η decays with $\eta' \to \pi^+\pi^-\eta$

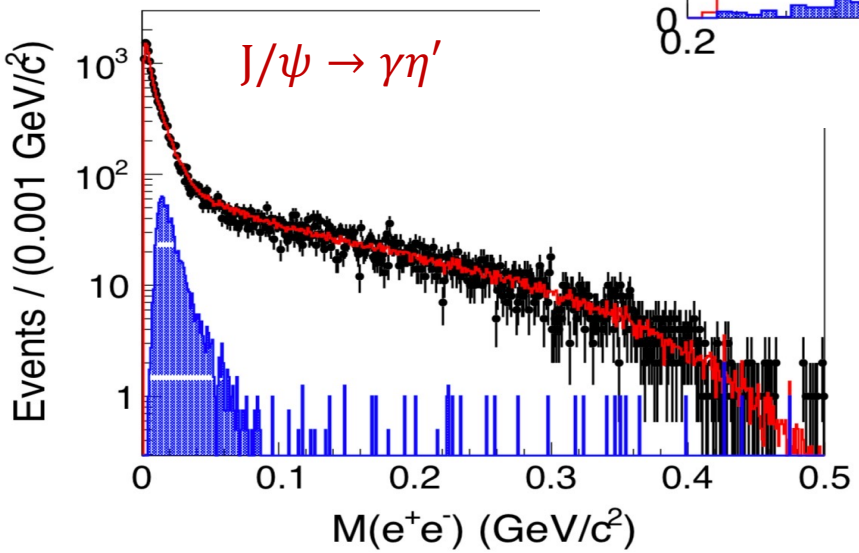
X. L. Kang, Y. Y. Ji. B. H. Xiang, S. S. Fang, PRD 108, 014038 (2023)

Feasibility study of $J/\psi \to \gamma\eta', \eta' \to \pi^+\pi^-\eta$

- ✓ CP violation decays $\eta \to \pi^+\pi^-,\ \pi^0\pi^0$
- ✓ Rare decays $\eta \to e^+e^-,\ \mu^+\mu^-,\ \pi^0e^+e^-,\ \pi^0\mu^+\mu^-$
- ✓ TFF with $\eta \to \gamma e^+e^-,\ \gamma\mu^+\mu^-$





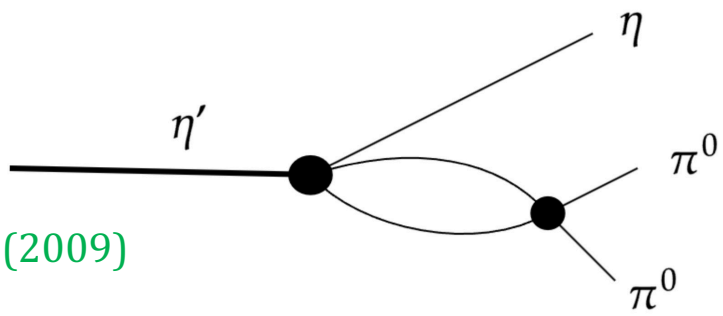


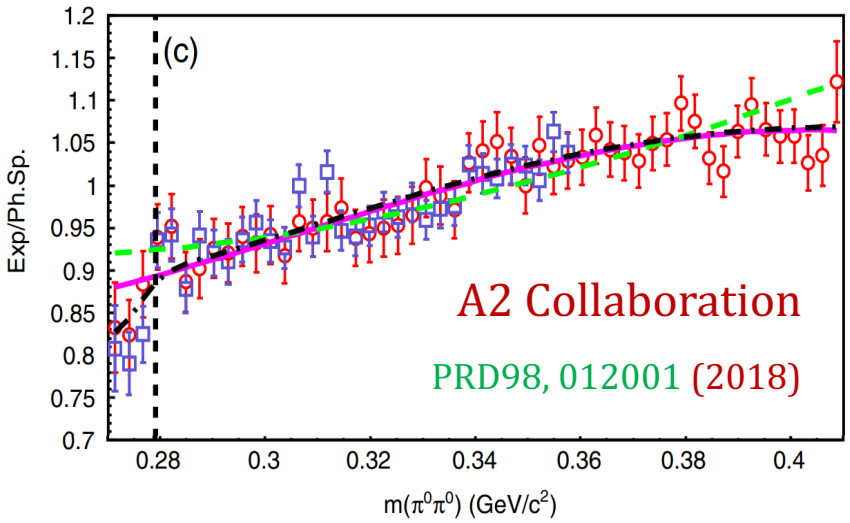
First evidence of cusp effect in $\eta' \to \pi^0\pi^0\eta$

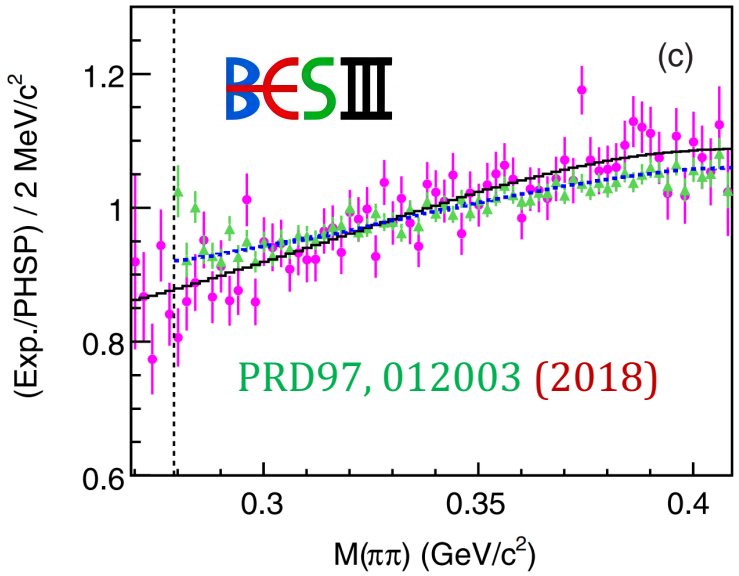
BESIII: PRL130, 081901(2023)

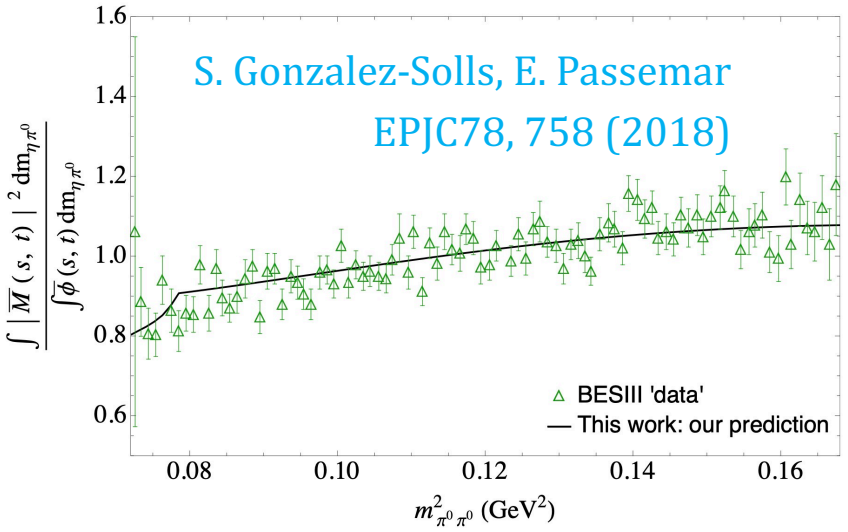
- Charge-exchange rescattering: $\pi^+\pi^- \to \pi^0\pi^0$
- The size of cusp effect is predicted to be about 6% in $\eta' \to \pi^0\pi^0\eta$ within NREFT

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

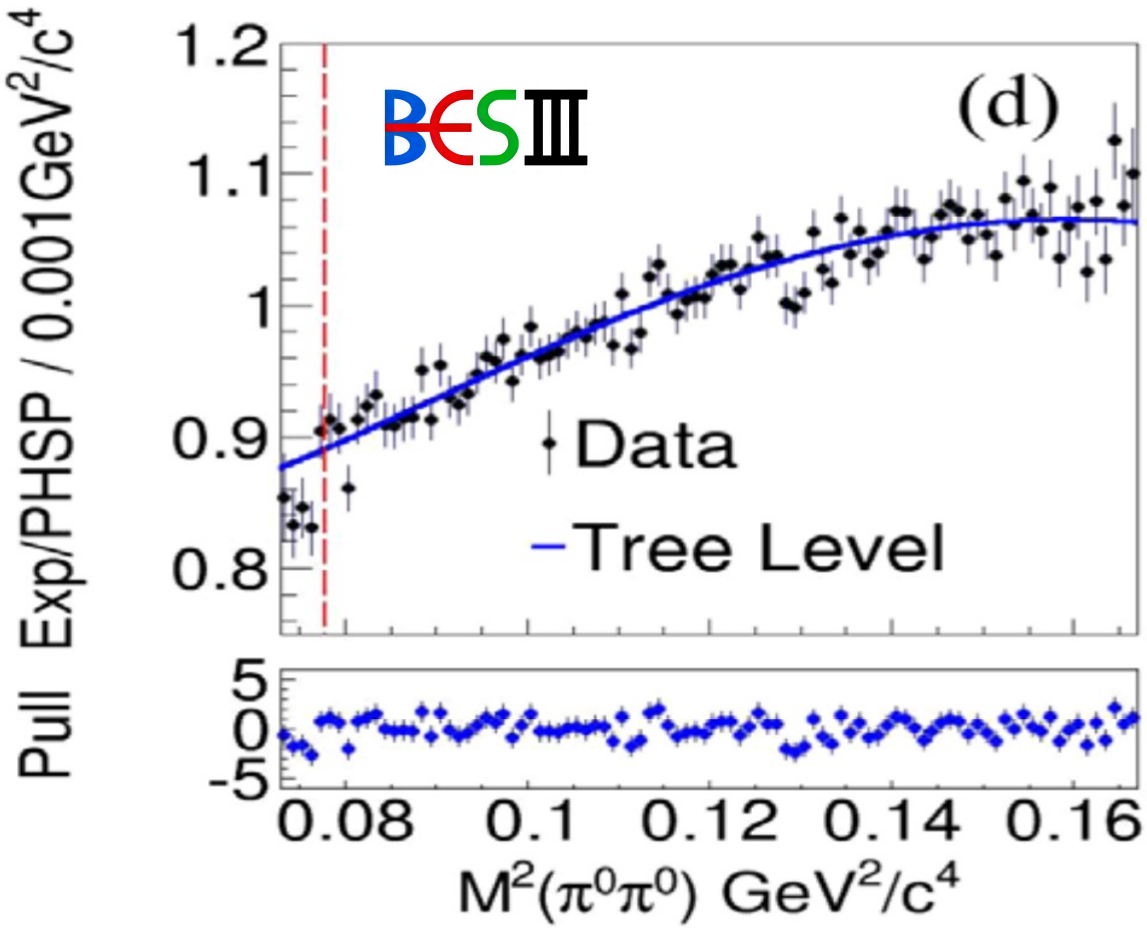








BESIII: PRL130, 081901(2023)



BESIII: PRL130, 081901(2023)

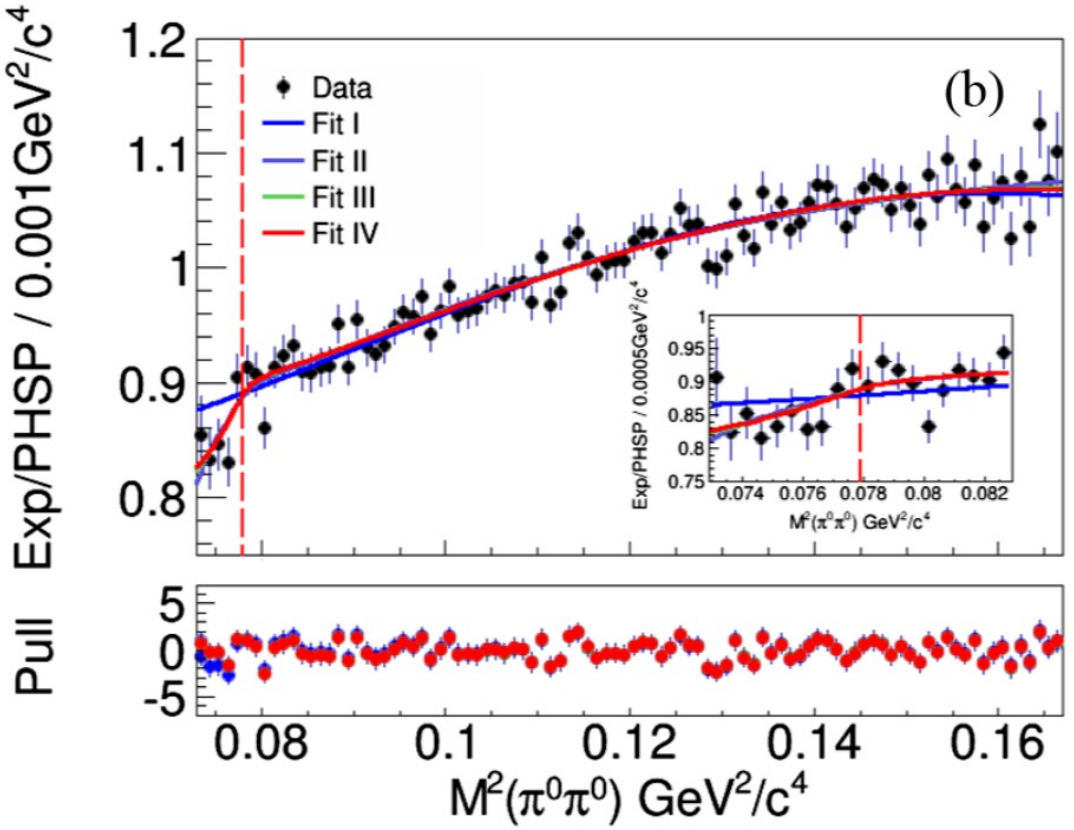
- One and two-loop level contributions based on NREFT are introduced

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

  Cusp effect with ~3.5 σ!

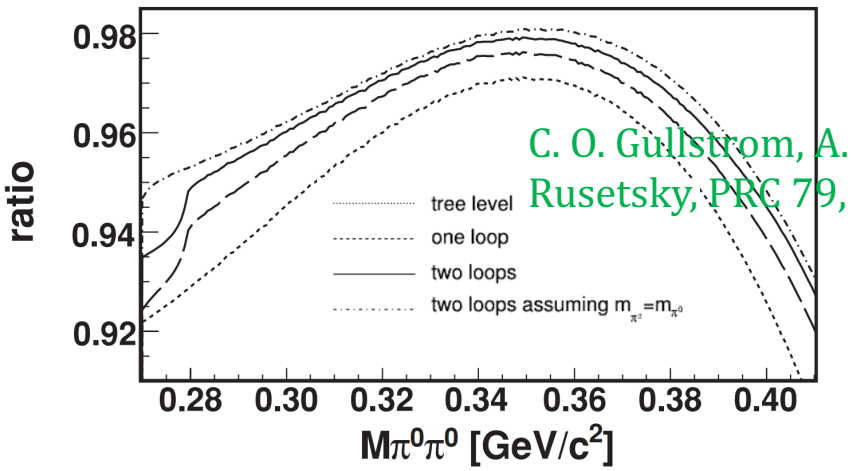
- $\pi-\pi$ scattering parameters:

  $a_0 - a_2 = 0.226 \pm 0.060 \pm 0.013$

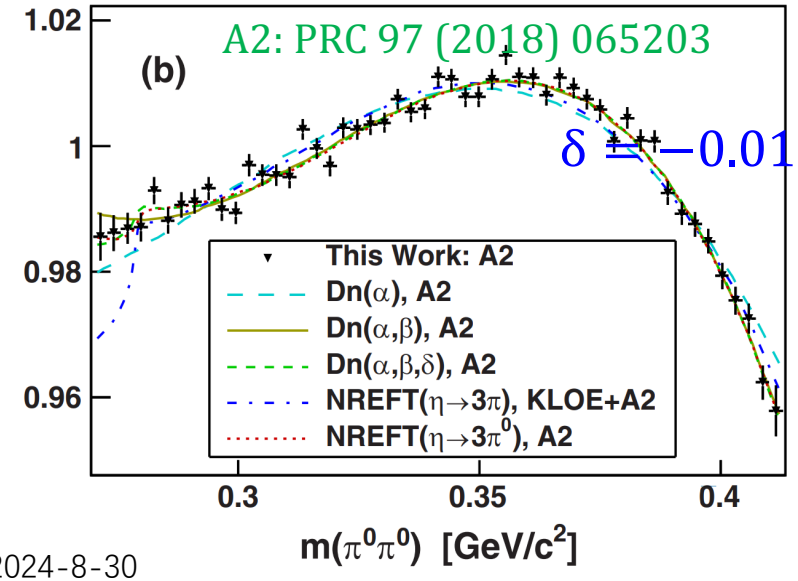


- Amplitude analysis of $\eta' \to \pi^+\pi^-\eta$ within NREFT is forthcoming, sizeble contribution from final state interactions

Cusp structure in $\eta \to \pi^0\pi^0\pi^0$



C. O. Gullstrom, A. Kupsc, A. Rusetsky, PRC 79, 028201 (2009)

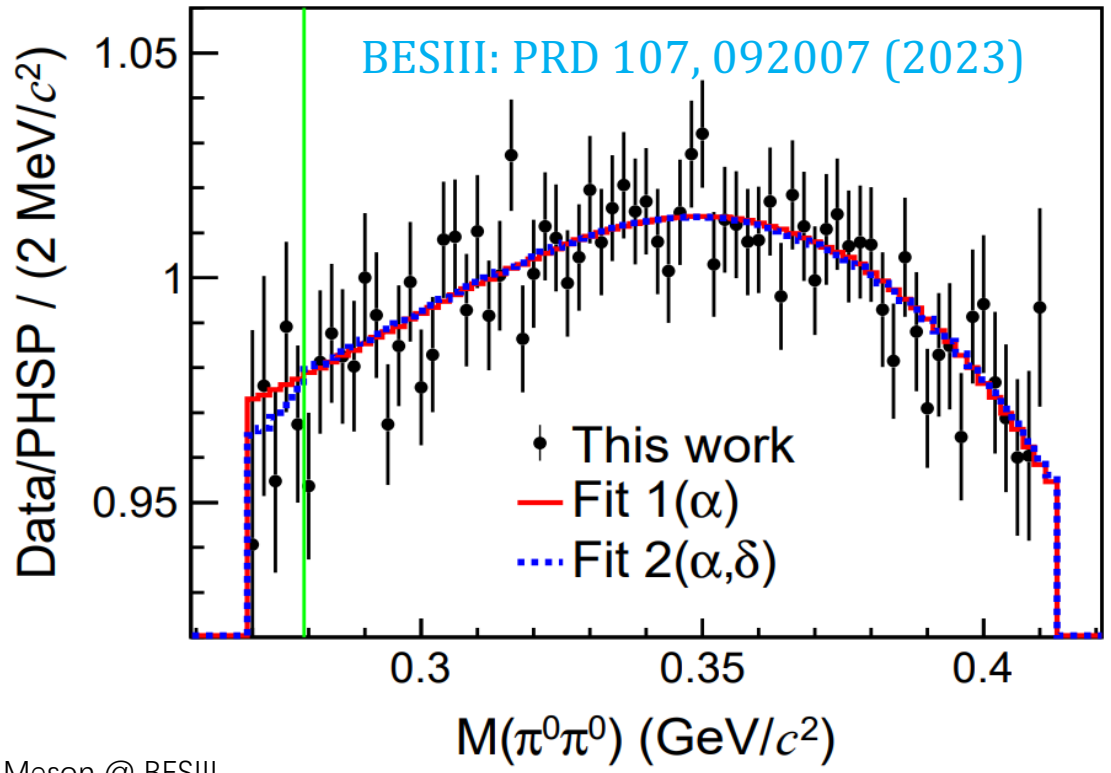


A2: PRC 97 (2018) 065203

$\delta = -0.0169 \pm 0.0067$

$$|A(X,Y)|^2 \propto 1 + 2\alpha Z + 2\delta \sum_{i=1}^{3} \Re\sqrt{1 - s_i/4m^2_{\pi^\pm}}$$

$\delta = -0.018 \pm 0.022_{stat.}$



Dalitz plot of $\eta \to \pi^0\pi^0\pi^0$

BESIII: PRD 107, 092007 (2023)
https://www.hepdata.net/record/141642

$$Z = X^2 + Y^2 = \frac{2}{3}\sum_{i=1}^{3}(\frac{3T_i}{Q} - 1)^2$$

$$|A(X,Y)|^2 \propto 1 + 2\alpha Z + 2\beta(3X^2Y - Y^3) + 2\gamma Z^2 + \cdots$$

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

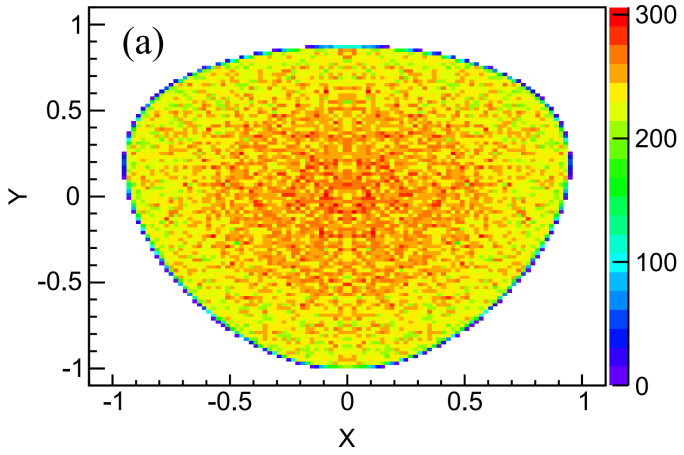
$$\beta = 0.0038 \pm 0.0033_{stat.}$$

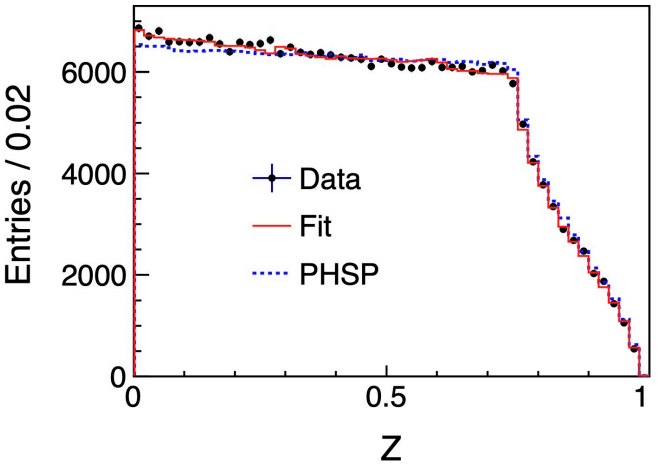
$$\gamma = -0.018 \pm 0.014_{stat.}$$

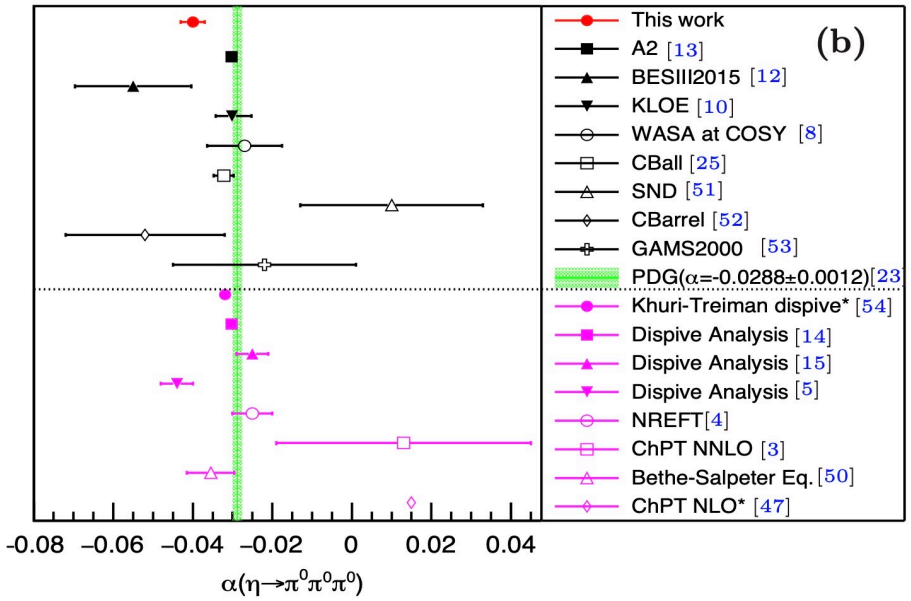
α is consistent with A2 result ($-0.0302 \pm 0.0008_{stat.}$) in 2.8σ

$$\beta(A_2) = -0.0070 \pm 0.0010_{stat.}$$

$$\gamma(A_2) = -0.0023 \pm 0.0040_{stat.}$$



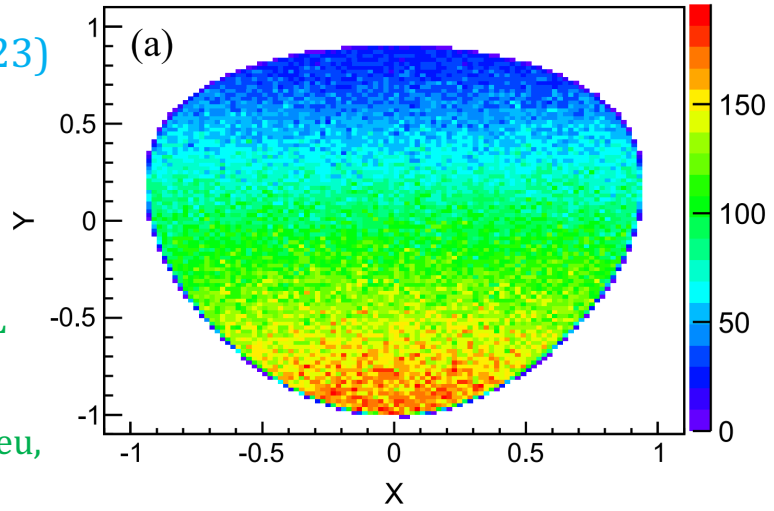




Dalitz plot of $\eta \to \pi^+\pi^-\pi^0$

BESIII: PRD 107, 092007 (2023)

https://www.hepdata.net/record/141642



➢SM: C conserved, isospin broken, EM effects suppressed

⇒ ideal process to extract $m_u - m_d$

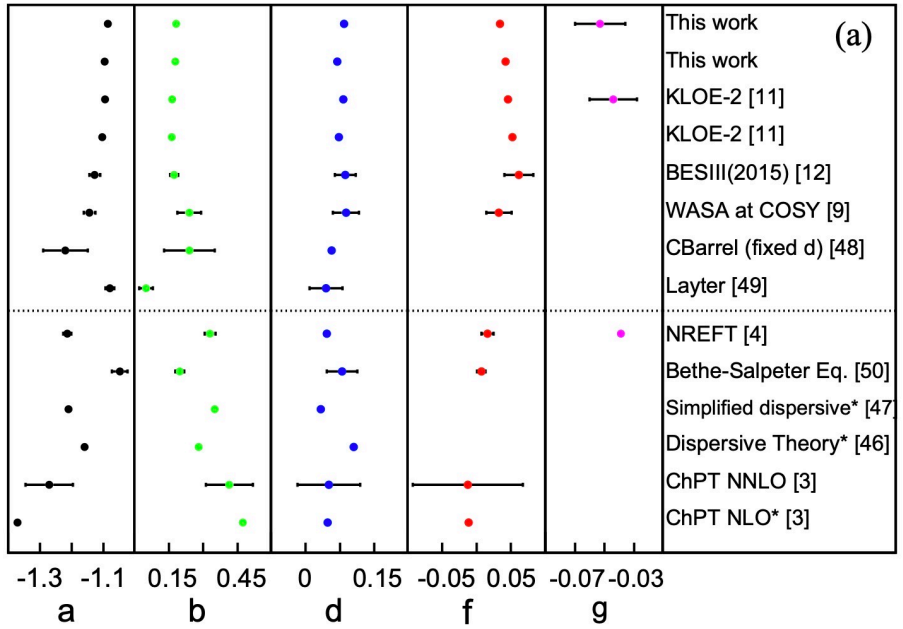
G. Colangelo, S. Lanz, H. Leutwyler, E. Passemar, PRL 118, 022001 (2017)

P. Guo, I. V. Danilkin, C. Fernández-Ramírez, V. Mathieu, A. P. Szczepaniak, PLB 771, 497 (2017)

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

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

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



$c = (-0.086 \pm 2.986)\times10^{-3}$, $e = -0.001 \pm 0.007$ ⇒ no C symmetry breaking

Dalitz plot Asymmetries in $\eta \to \pi^+\pi^-\pi^0$

BESIII: PRD 107, 092007 (2023)

⇒ B. Kubis's talk

- BSM: C broken, isospin either conserved or broken

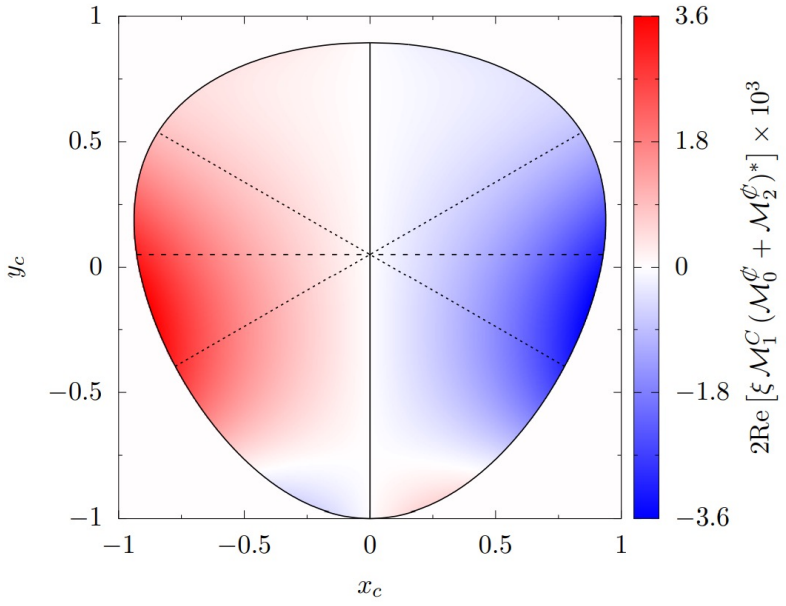
$$\mathcal{M}(s,t,u) = \mathcal{M}_1^C(s,t,u) + \mathcal{M}_0^{\not C}(s,t,u) + \mathcal{M}_2^{\not C}(s,t,u)$$

S. Gardner, J. Shi, PRD 101 (2020) 115038

H. Akdag, T. Isken, B. Kubis, JHEP 02 (2022)137

J. Shi, J. Liang, S. Gardner arXiv:2407.08766

- The interferences give rise to mirror symmetry breaking (permille level) in the Dalitz plot

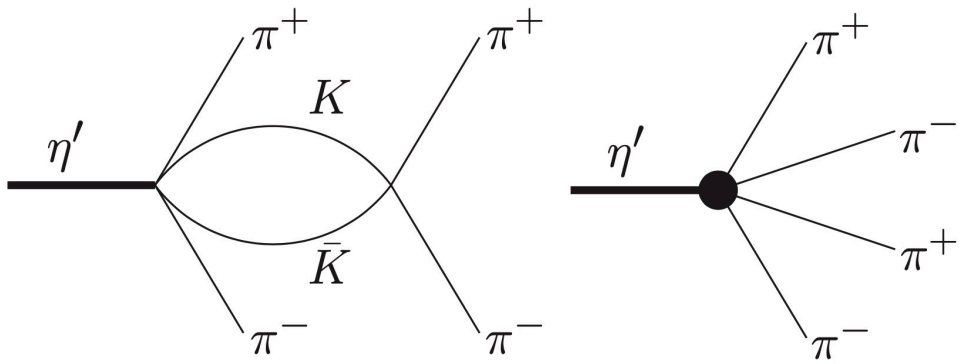


overall C/CP-violation | ΔI = 2 | ΔI = 0

Experiment	$A_{LR}(\%)$	$A_Q(\%)$	$A_S(\%)$
This work	$0.114 \pm 0.131 \pm 0.001$	$-0.035 \pm 0.131 \pm 0.011$	$-0.070 \pm 0.131 \pm 0.009$
KLOE-2 [11]	$-0.050 \pm 0.045^{+0.050}_{-0.110}$	$0.018 \pm 0.045^{+0.048}_{-0.023}$	$0.004 \pm 0.045^{+0.031}_{-0.035}$
Jane [40]	0.28 ± 0.26	-0.30 ± 0.25	0.20 ± 0.25
Layter [24]	-0.05 ± 0.22	-0.07 ± 0.22	0.10 ± 0.22
Gormley [41]	1.5 ± 0.5	-	0.5 ± 0.5

Amplitude analysis for $\eta' \to 4\pi$

BESIII: PRD 109, 032006 (2024)



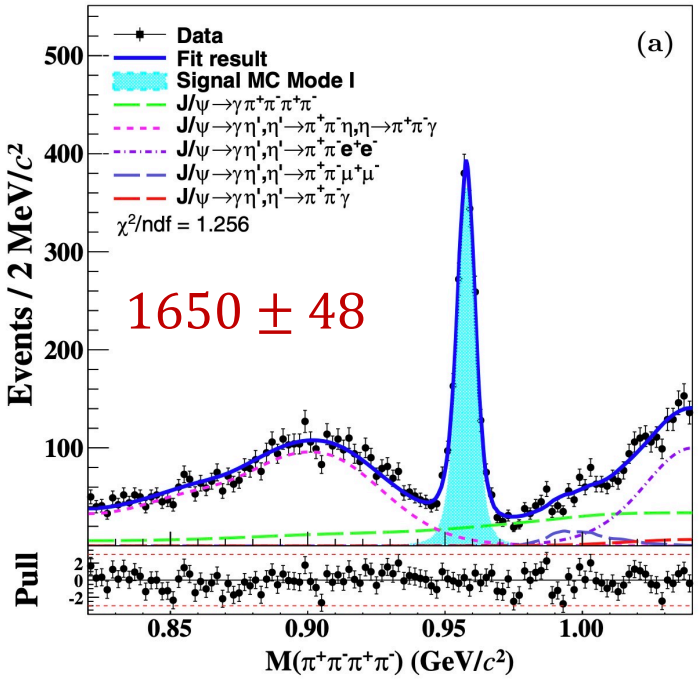
Loop and counter term at O(p^6)

F. K. Guo, B. Kubis, A. Wirzba, PRD 85,014014 (2012)

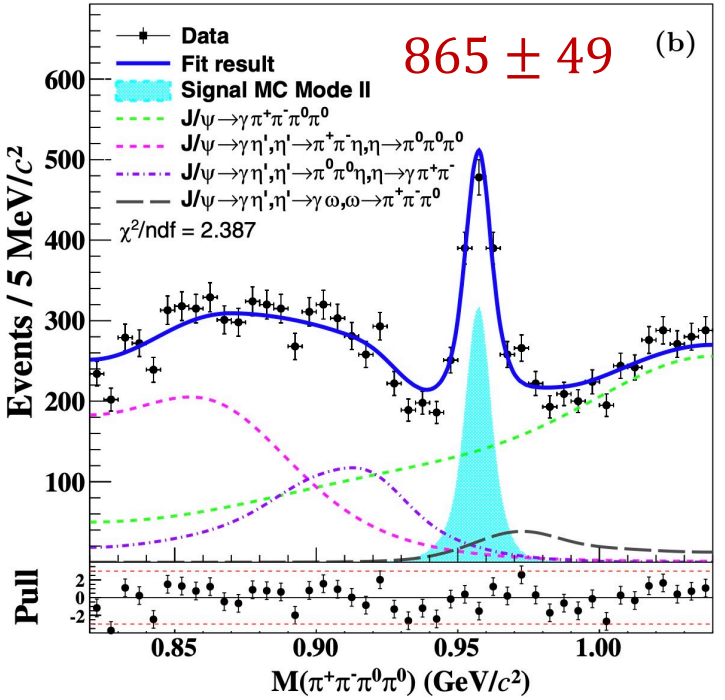
$Br(\eta' \to 2(\pi^+\pi^-)) = (1.0 \pm 0.3)\times10^{-4}$

$Br(\eta' \to \pi^+\pi^-2\pi^0) = (2.4 \pm 0.7)\times10^{-4}$

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



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



$Br(\eta' \to \pi^+\pi^-\pi^+\pi^-) = (8.56 \pm 0.25 \pm 0.23)\times10^{-5}$

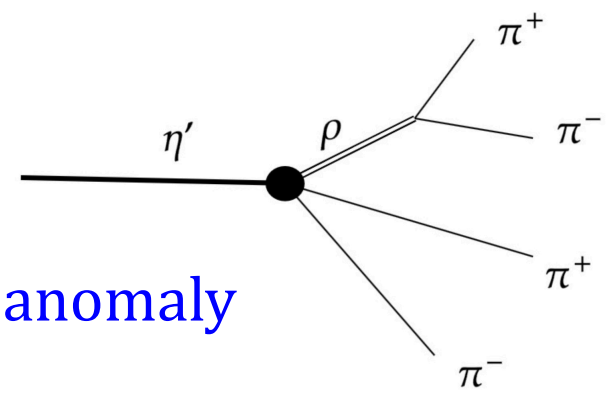
$Br(\eta' \to \pi^+\pi^-\pi^0\pi^0) = (2.12 \pm 0.12 \pm 0.10)\times10^{-4}$

Amplitude analysis for $\eta' \to 2(\pi^+\pi^-)$

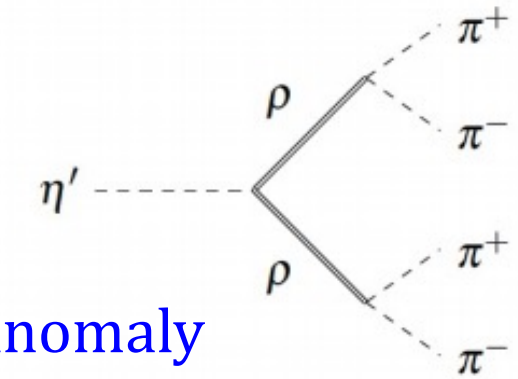
BESIII: PRD 109, 032006 (2024)

Combination of ChPT and VMD model: PRD85, 014014 (2012)

$$\mathcal{A}(\eta' \to \pi^+\pi^-\pi^+\pi^-) = \epsilon_{\mu\nu\alpha\beta} p_1^\mu p_2^\nu p_3^\alpha p_4^\beta \times \left\{ \left[\frac{s_{12}}{D_\rho(s_{12})} + \frac{s_{34}}{D_\rho(s_{34})} - \frac{s_{14}}{D_\rho(s_{14})} - \frac{s_{23}}{D_\rho(s_{23})} \right] + \alpha \left[\frac{M_\rho^2(s_{12}+s_{34})}{D_\rho(s_{12})D_\rho(s_{34})} - \frac{M_\rho^2(s_{14}+s_{23})}{D_\rho(s_{14})D_\rho(s_{23})} \right] \right\},$$



Box anomaly



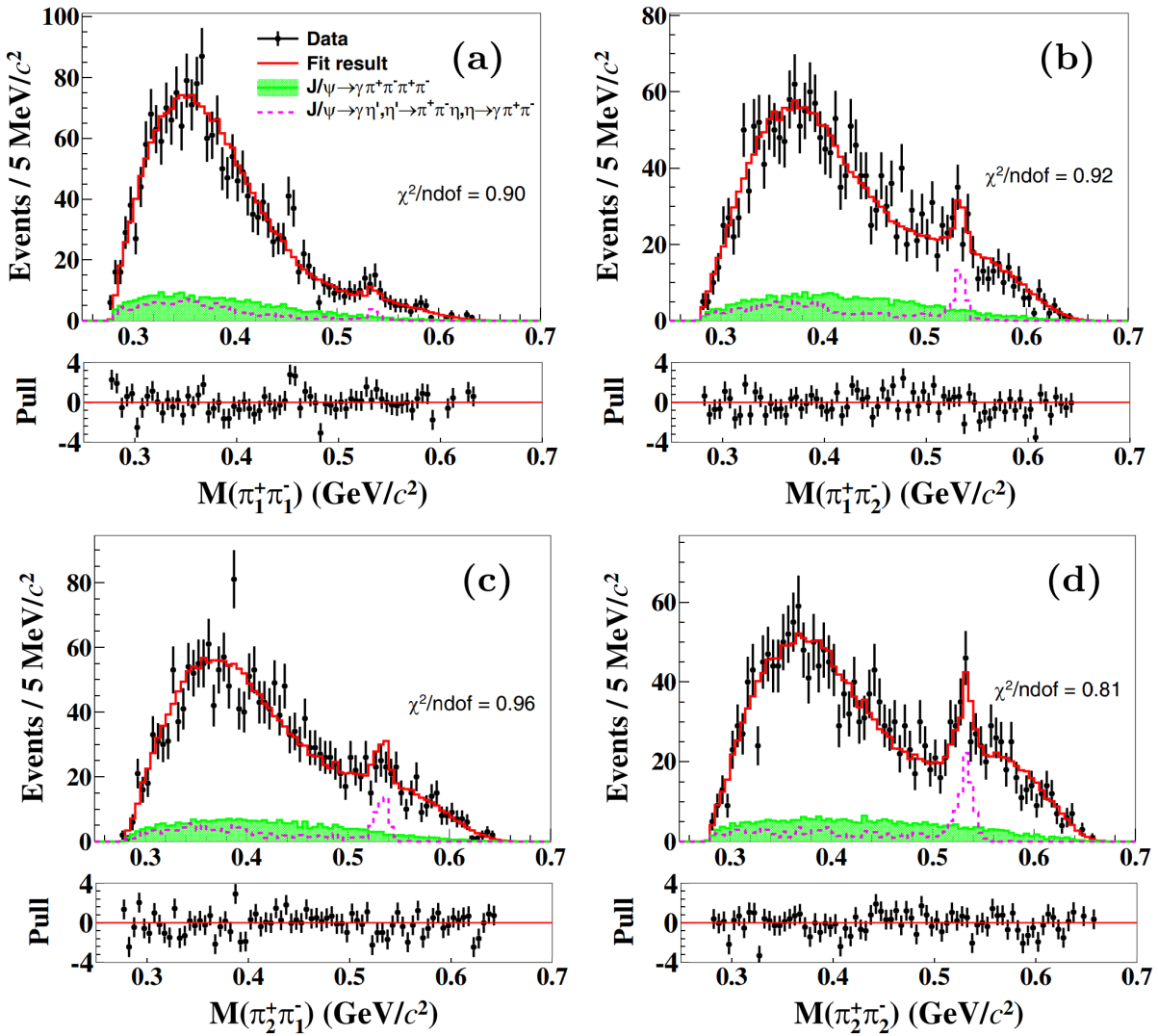
Triangle anomaly

Amplitude analysis results for $\eta' \to 2(\pi^+\pi^-)$ BESIII: PRD 109, 032006 (2024)

- First measurement of the doubly virtual isovector form factor

$$\alpha = \frac{c_3}{c_1 - c_2} = 1.22 \pm 0.33 \pm 0.04$$

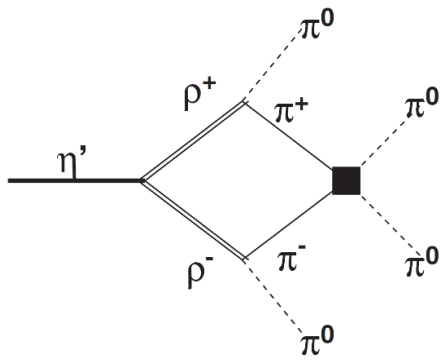
If $\alpha \simeq 1$, triangle anomaly would be dominated



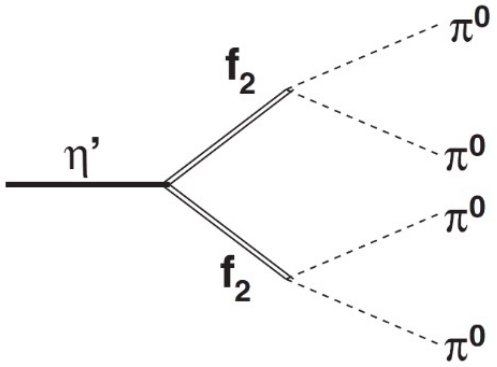
Search for rare decay $\eta' \to \pi^0\pi^0\pi^0\pi^0$

BESIII: PRD 109, 032006 (2024)

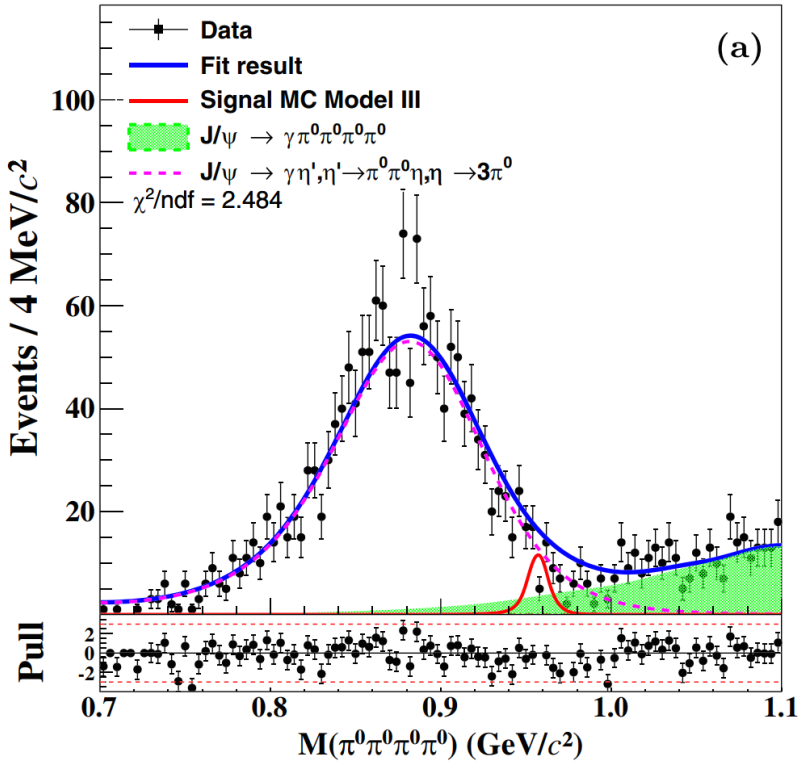
- CP-violation S-wave, induced by the QCD Lagrangian θ-term ⇒ Br~10^{-23}
- CP-conserving higher order ⇒ Br~10^{-8} F. K. Guo, B. Kubis, A. Wirzba, PRD 85,014014 (2012)



D-wave pion loop

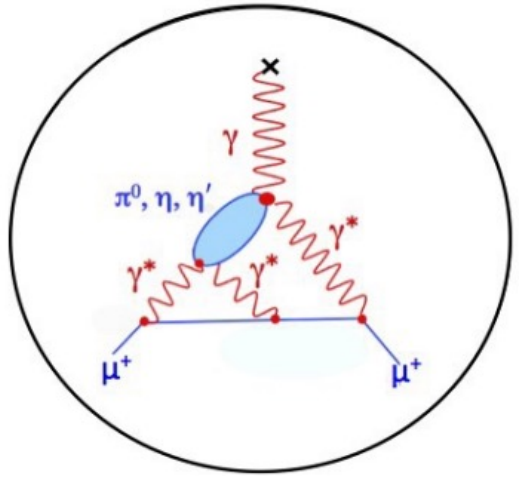


Small contribution from two f_2 tensor mesons



- With 10 billion J/ψ, the UL at 90% CL is set as 1.24×10^{-5}

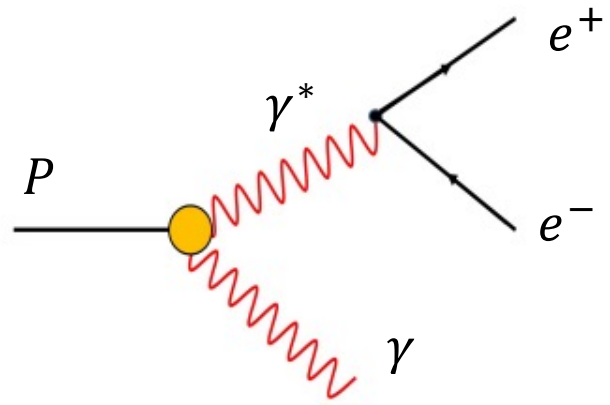
Transition form factor at BESIII



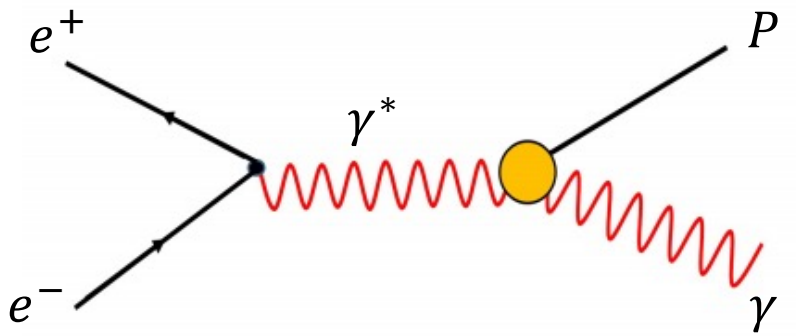
- Important input for HLbL contributions

⇒ H. Wittig, G. Colangelo, S. Holz's talk

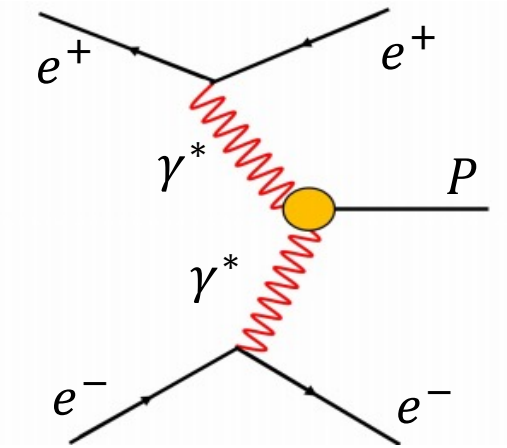
Pseudoscalar TFFs are experimentally accessible in three different processes



Dalitz decays $0<q^2<M^2$



Annihilation process $q^2>M^2$



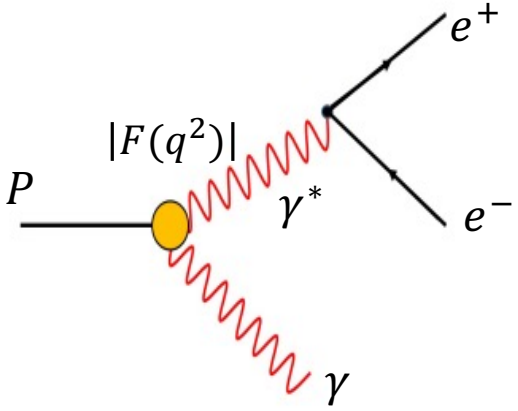
Two photon process

Transition form factor of $\eta/\eta' \to \gamma e^+ e^-$

BESIII: PRD 109, 072001 (2024)

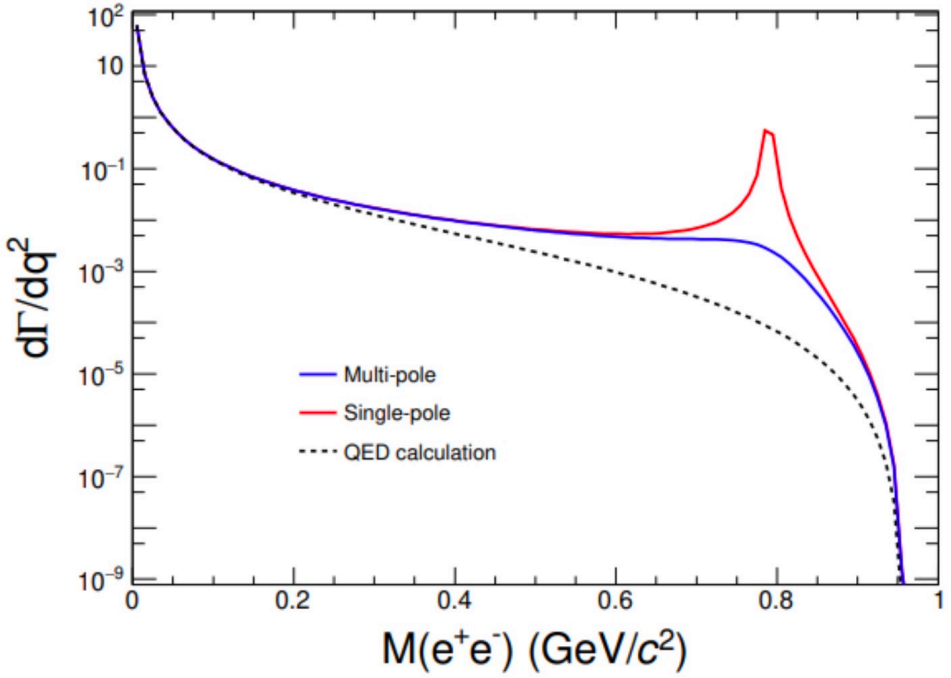
$$\frac{d\Gamma(P \to \gamma l^+ l^-)}{dq^2 \Gamma_{\gamma\gamma}} = \frac{2\alpha}{3\pi}\frac{1}{q^2}\sqrt{1-\frac{4m_l^2}{q^2}}\left(1+\frac{2m_l^2}{q^2}\right)\left(1-\frac{q^2}{M_P^2}\right)^3 |F_P(q^2,0)|^2$$

$$= QED(q^2) \times |F_P(q^2,0)|^2$$



❖ **Single-pole model:** $F(q^2) = \dfrac{1}{1 - q^2/\Lambda^2}$

❖ **Multi-pole model:** $|F(q^2)|^2 = \dfrac{\Lambda^2(\Lambda^2+\gamma^2)}{(\Lambda^2-q^2)^2+\Lambda^2\gamma^2}$



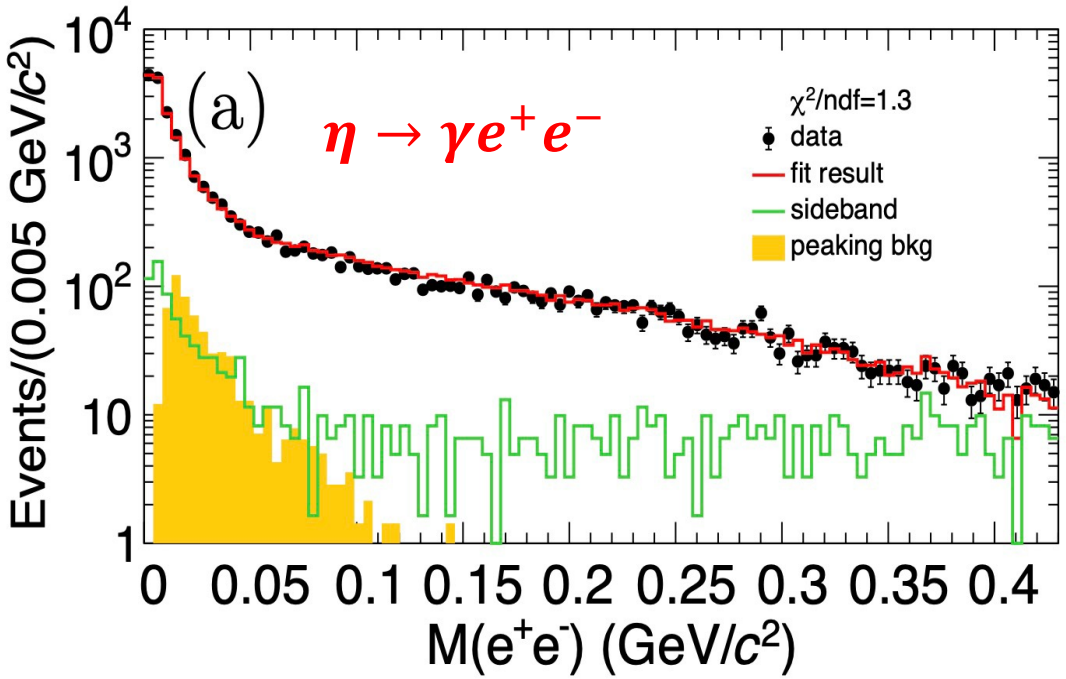
Transition form factor of $\eta/\eta' \to \gamma e^+ e^-$

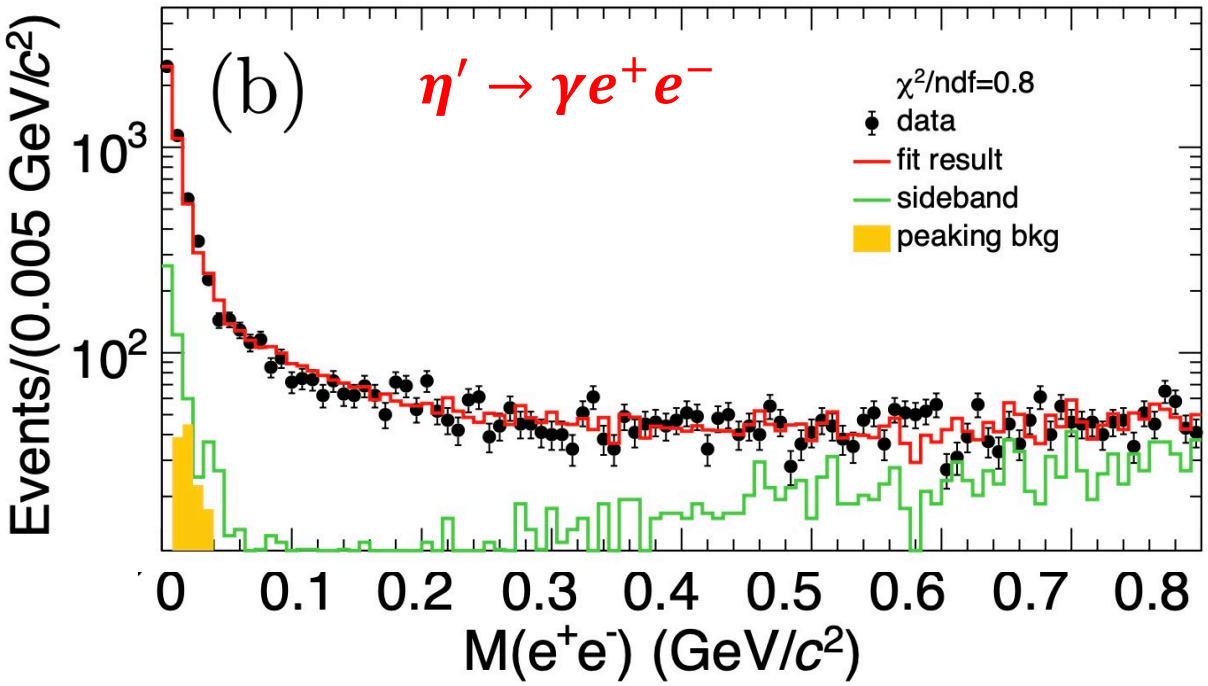
BESIII: PRD 109, 072001 (2024)

$\Lambda_\eta = (0.749 \pm 0.026 \pm 0.008)\ GeV/c^2$

$\Lambda_{\eta'} = (0.749 \pm 0.026 \pm 0.008)\ GeV/c^2$

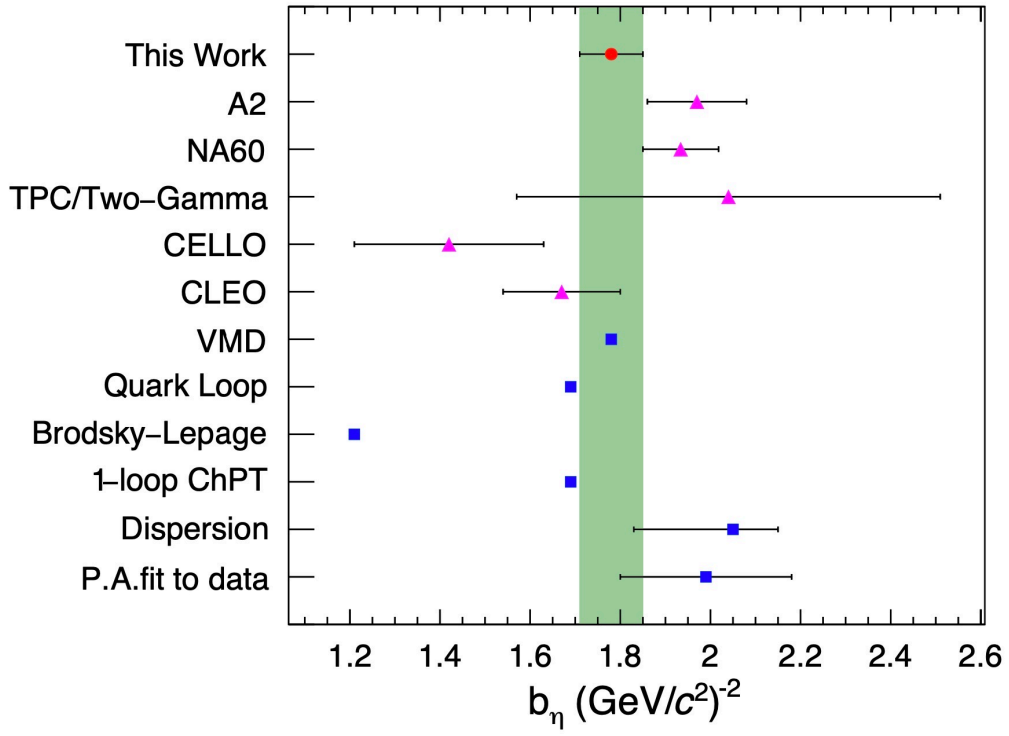
$\gamma_{\eta'} = (0.113 \pm 0.009 \pm 0.002)\ GeV/c^2$

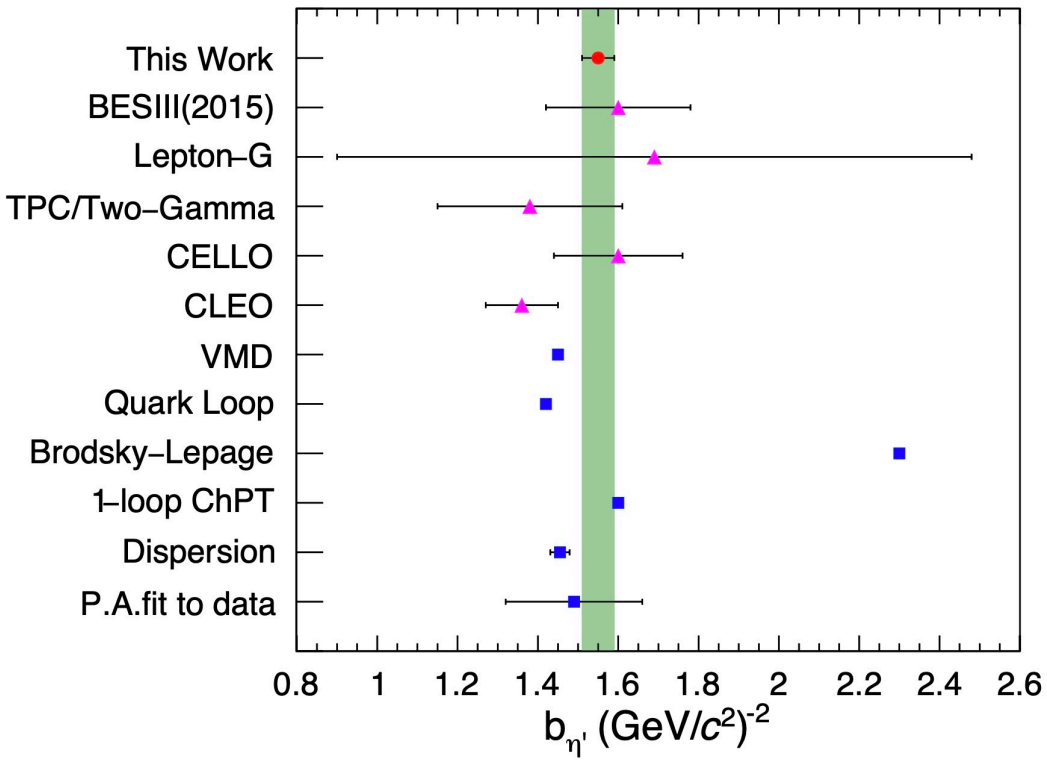




Slope parameter: $b_{\eta/\eta'} = \frac{d|F(q^2)|}{dq^2}\Big|_{q^2=0}$

BESIII: PRD 109, 072001 (2024)



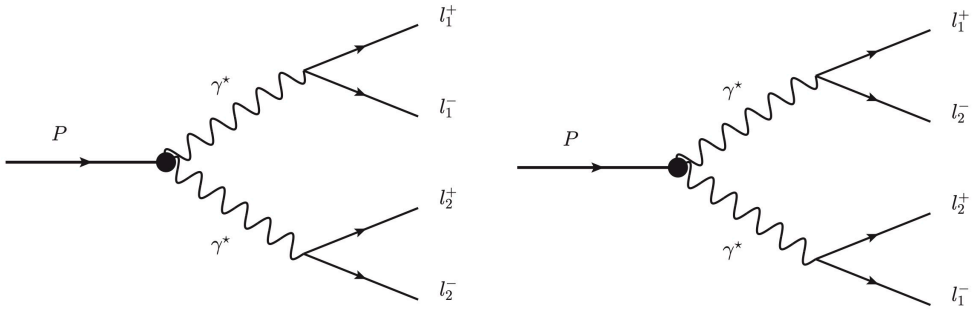


$b_\eta = 1.781 \pm 0.123 \pm 0.033\ (\mathrm{GeV/c^2})^{-2}$

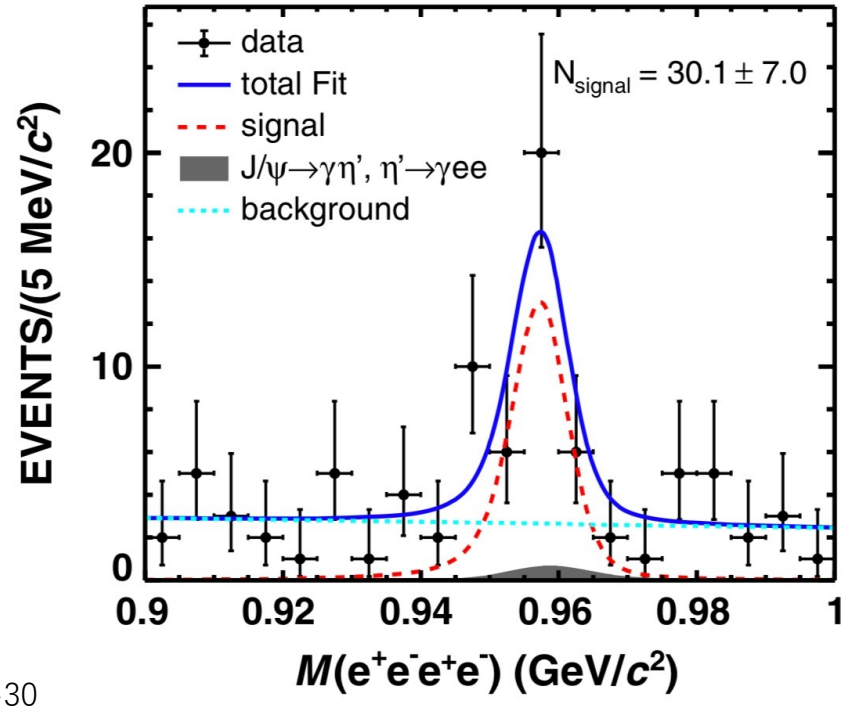
$b_{\eta'} = 1.574 \pm 0.048 \pm 0.016\ (\mathrm{GeV/c^2})^{-2}$

Double Dalitz decays $\eta' \to e^+e^-e^+e^-$

BESIII: PRD105,112010(2022)



Thimo Petri, arXiv: 1010.2378



R. Escribano, S. Gonzalez-Solıs, CPC 42 (2018) 023109

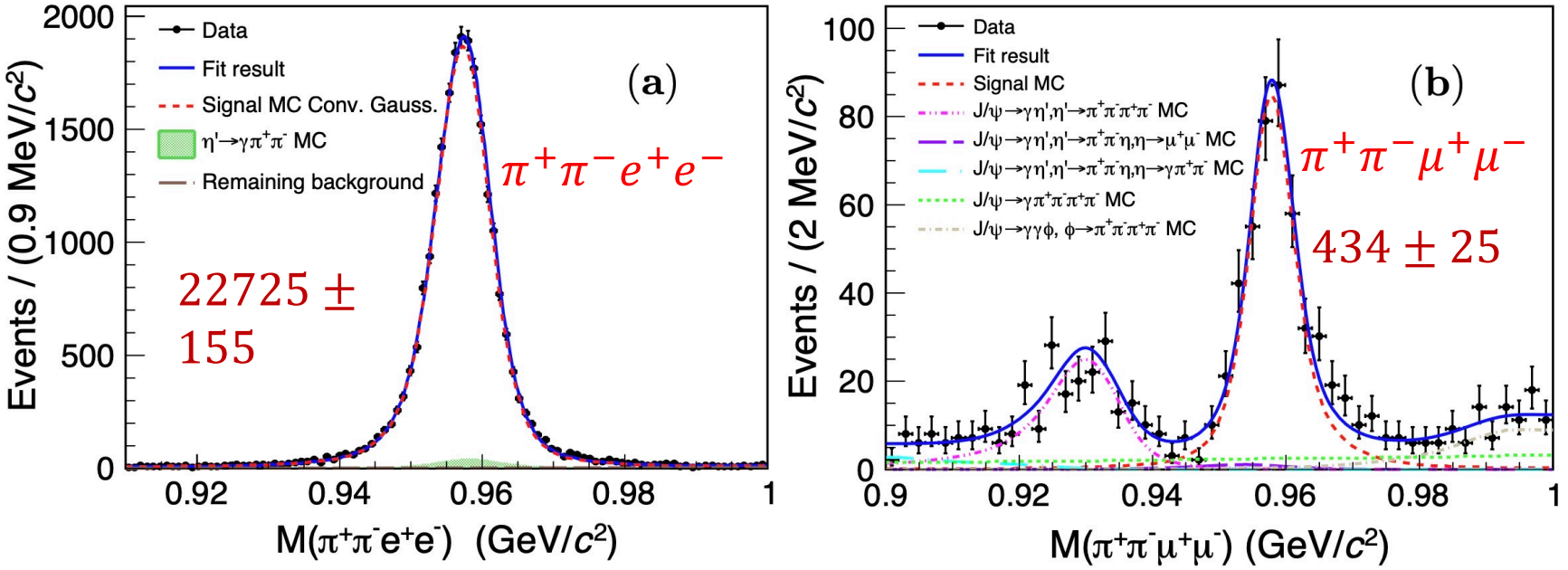
decay	this work	experimental value
$\eta' \to e^+e^-e^+e^-$	$2.10(45)\times10^{-6}$	not seen
$\eta' \to \mu^+\mu^-\mu^+\mu^-$	$1.69(36)\times10^{-8}$	not seen
$\eta' \to e^+e^-\mu^+\mu^-$	$6.39(91)\times10^{-7}$	not seen

$$\mathcal{B}(\eta' \to e^+e^-e^+e^-) = \left(4.5 \pm 1.0_{stat.} \pm 0.5_{sys.}\right)\times10^{-6}$$

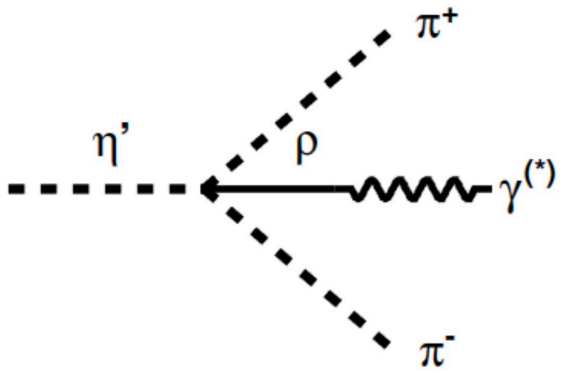
- Statistical significance 5.7σ
- Insufficient statistics for extraction of TFF

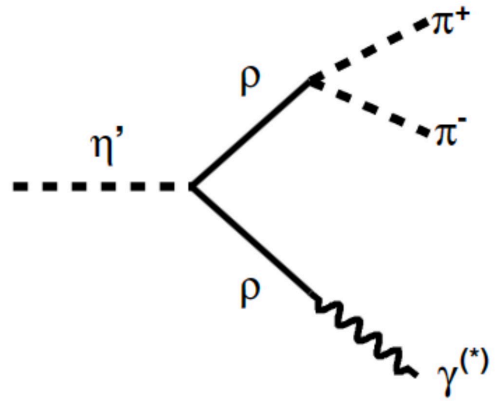
Precision study of $\eta' \to \pi^+\pi^- l^+ l^-$

BESIII: JHEP 07, 135 (2024)



VMD Contribution





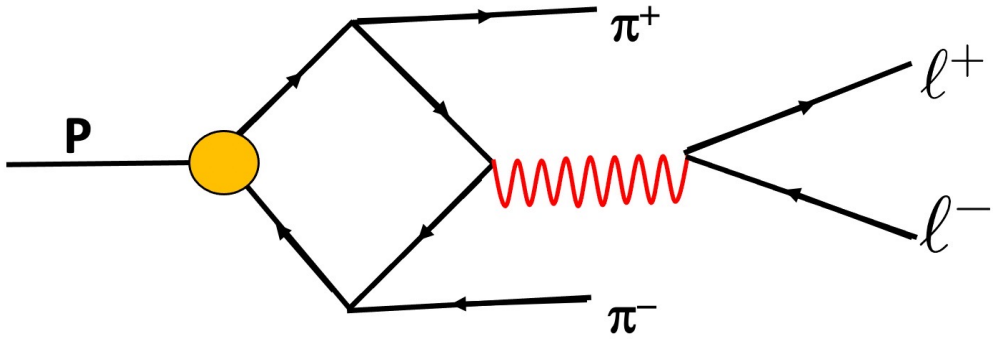
BESIII 2024

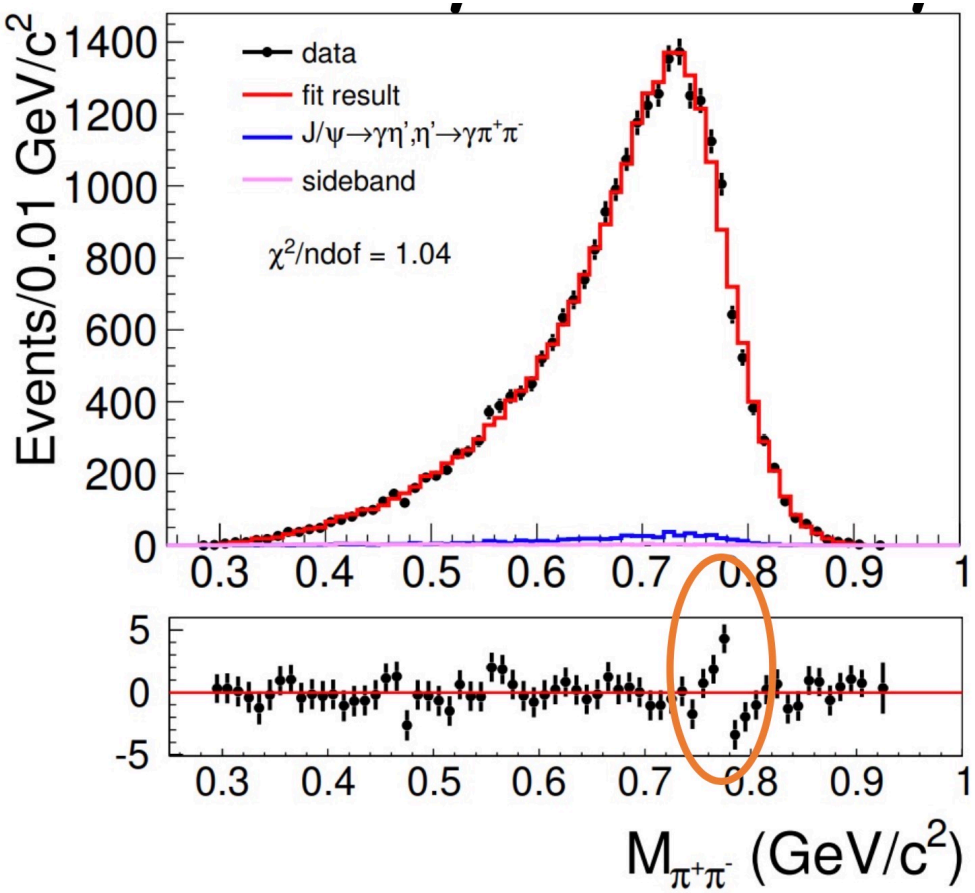
$2.45 \pm 0.02 \pm 0.08$ $\quad$ $2.16 \pm 0.12 \pm 0.06$

	$\mathcal{B}(\eta' \to \pi^+\pi^- e^+ e^-)$ (10^{-3})	$\mathcal{B}(\eta' \to \pi^+\pi^- \mu^+ \mu^-)$ (10^{-5})
Hidden gauge*	2.17 ± 0.21	2.20 ± 0.30
Unitary χPT*	$2.13^{+0.17}_{-0.31}$	$1.57^{+0.96}_{-0.75}$
VMD*	2.27 ± 0.13	2.41 ± 0.25
BESIII (2013)$^\diamond$	$2.11 \pm 0.12 \pm 0.15$	< 2.9
BESIII (2021)$^\diamond$	$2.42 \pm 0.05 \pm 0.08$	$1.97 \pm 0.33 \pm 0.19$
CLEO$^\diamond$	$2.50^{+1.2}_{-0.9} \pm 0.5$	< 24

Precision study of $\eta' \to \pi^+\pi^- l^+ l^-$

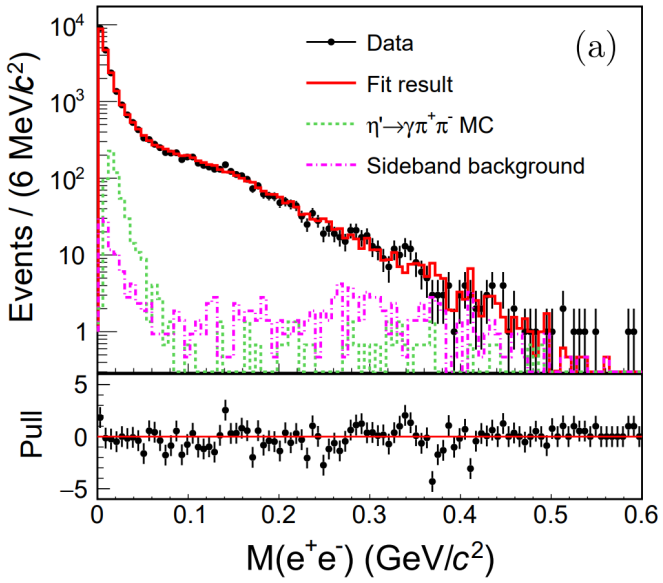
BESIII: JHEP 07, 135 (2024)

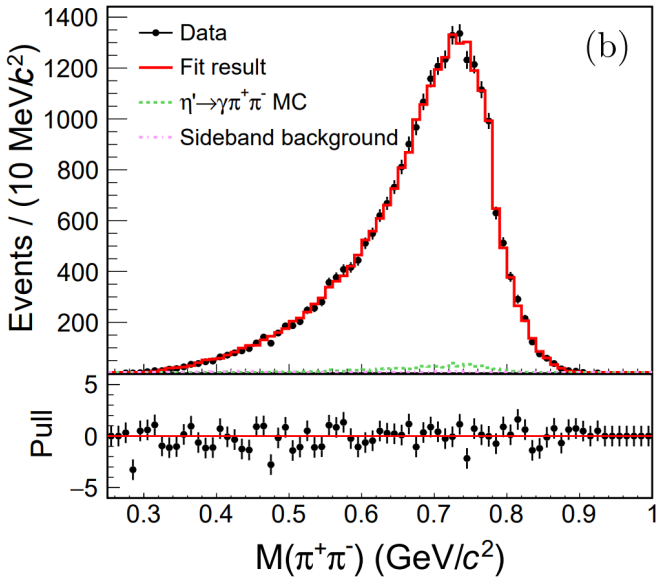


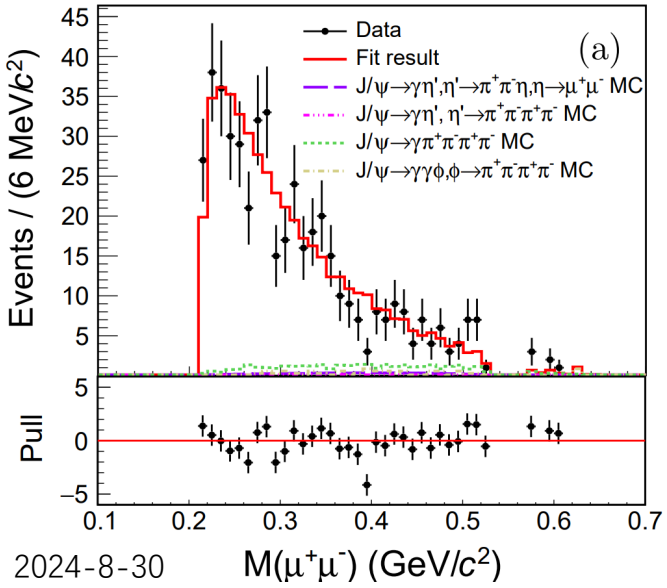


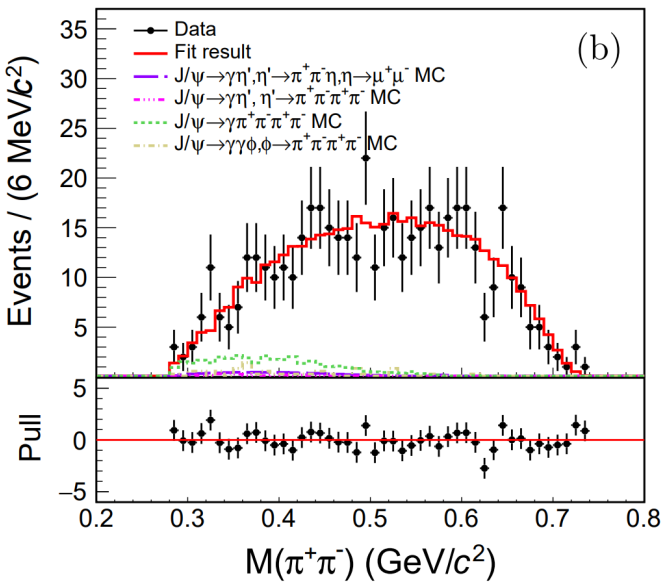
- **Box-anomaly** is needed to describe data
  - ✓ Similar structure as $\eta' \to \gamma\pi^+\pi^-$, replacing the γ with an off-shell one
- $\omega \to \pi^+\pi^-$ is also necessary

Amplitude analysis result of $\eta' \to \pi^+\pi^- l^+ l^-$ BESIII: JHEP 07, 135 (2024)



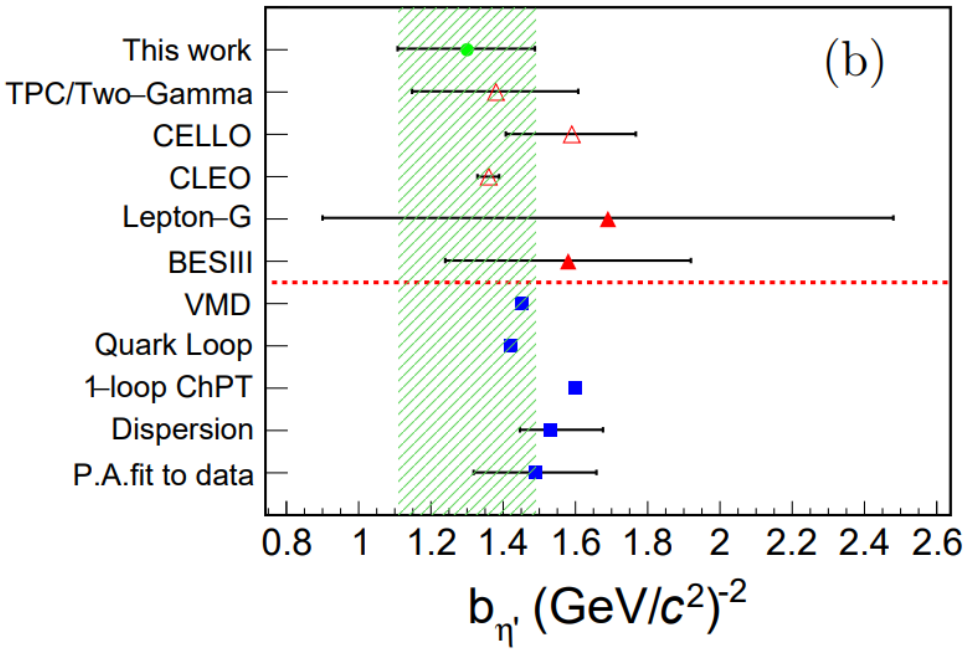






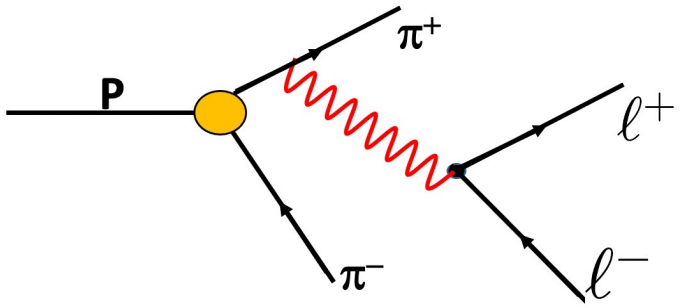
- ✓ First time to assess the form factors with $\eta' \to \pi^+\pi^- l^+ l^-$

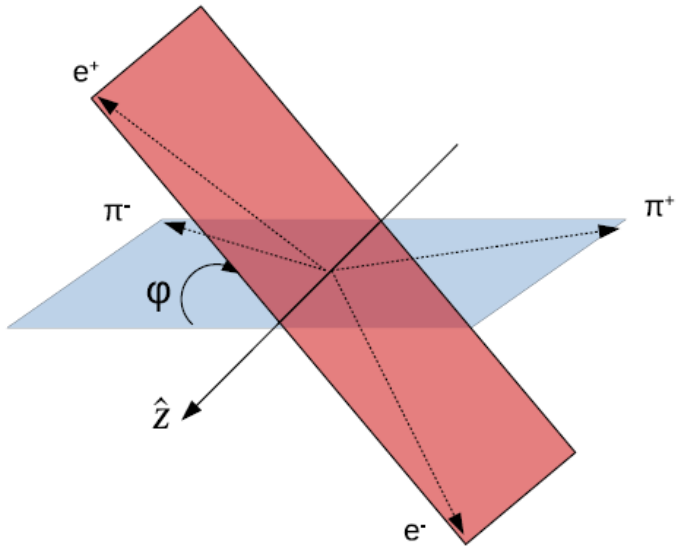
$$b_{\eta'} = 1.30 \pm 0.19 \left(\mathrm{GeV/c^2}\right)^{-2}$$



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

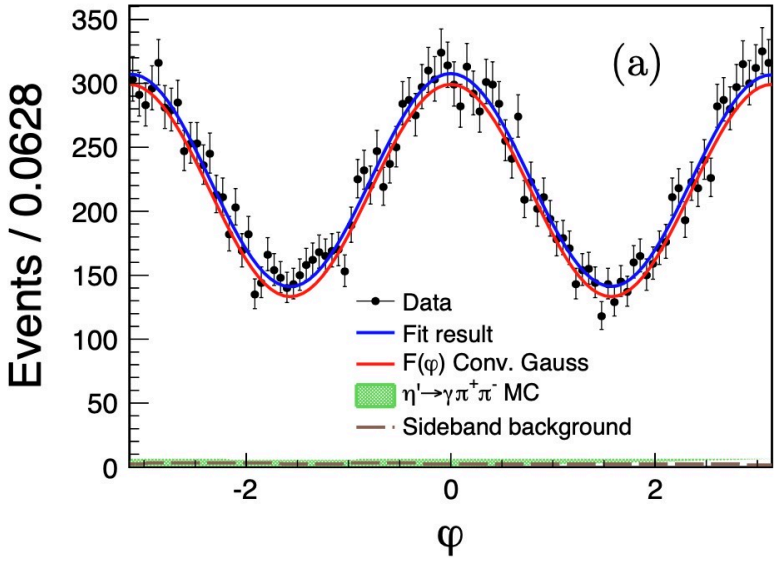
BESIII: JHEP 07, 135 (2024)





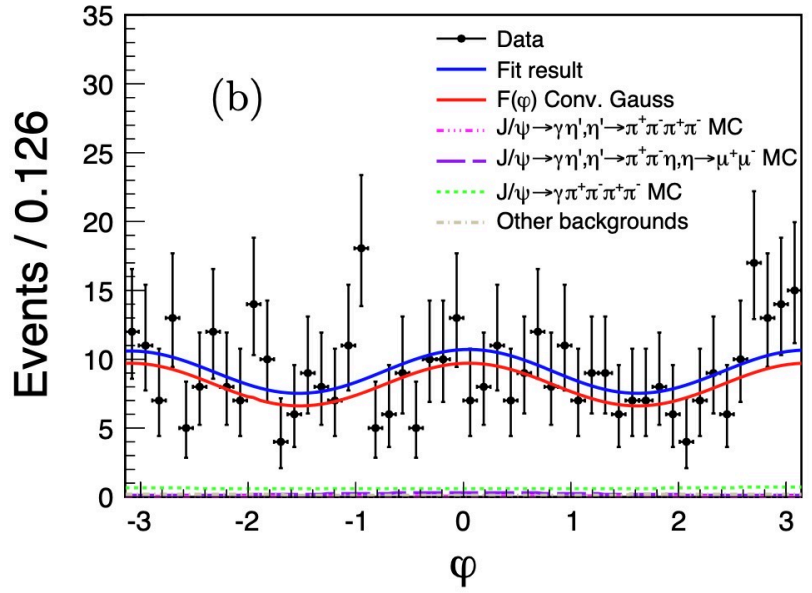
D. N. Gao, Mod Phys Lett A17 (2002) 1583
M. Zillinger, B. Kubis, P. Sánchez-Puertas, JHEP 12 (2022) 001

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



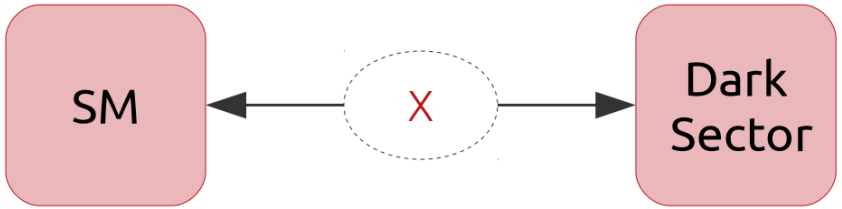
$A_{CP} = (-0.21 \pm 0.73 \pm 0.01)\%$

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



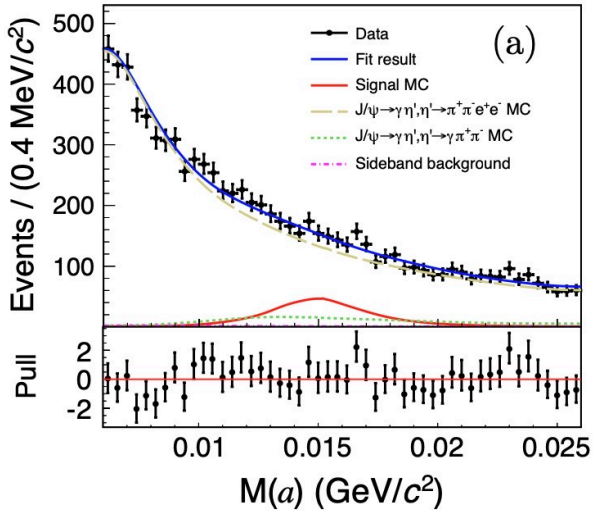
$A_{CP} = (0.62 \pm 4.71 \pm 0.08)\%$

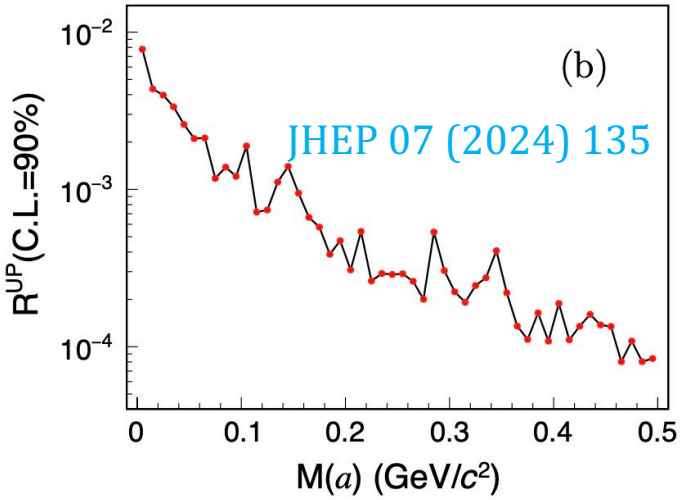
BSM Physics in Dark Sector



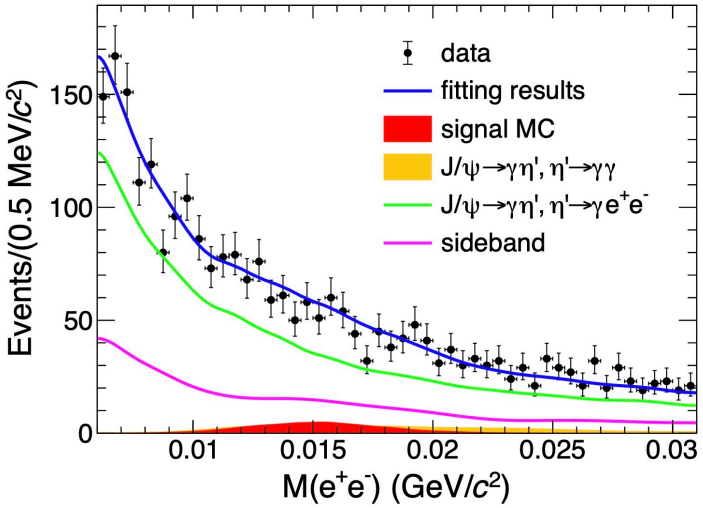
- ALPs in $\eta' \to \pi^+\pi^- a,\ a \to e^+e^-$
- Dark photon in $\eta/\eta' \to \gamma A', A' \to e^+e^-$

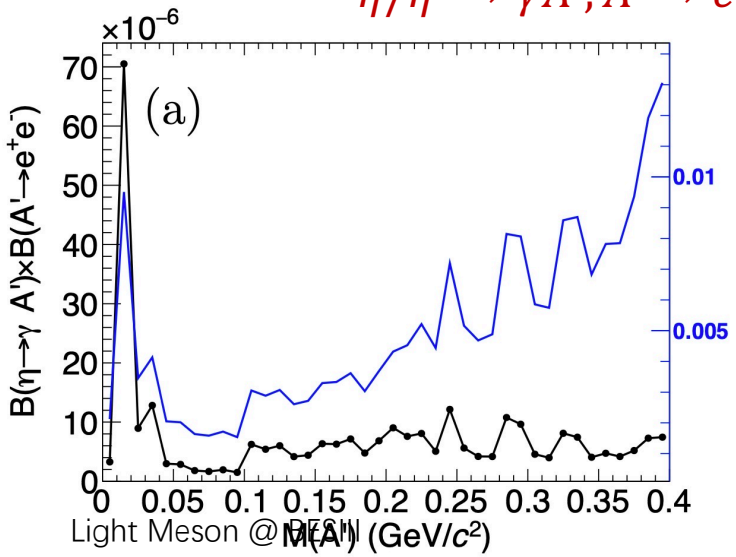
$\eta' \to \pi^+\pi^- a, a \to e^+e^-$

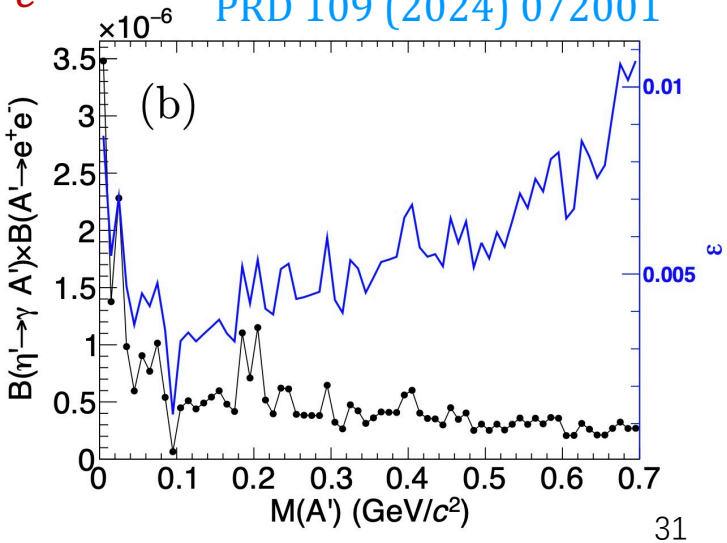




$\eta/\eta' \to \gamma A', A' \to e^+e^-$ PRD 109 (2024) 072001







Summary

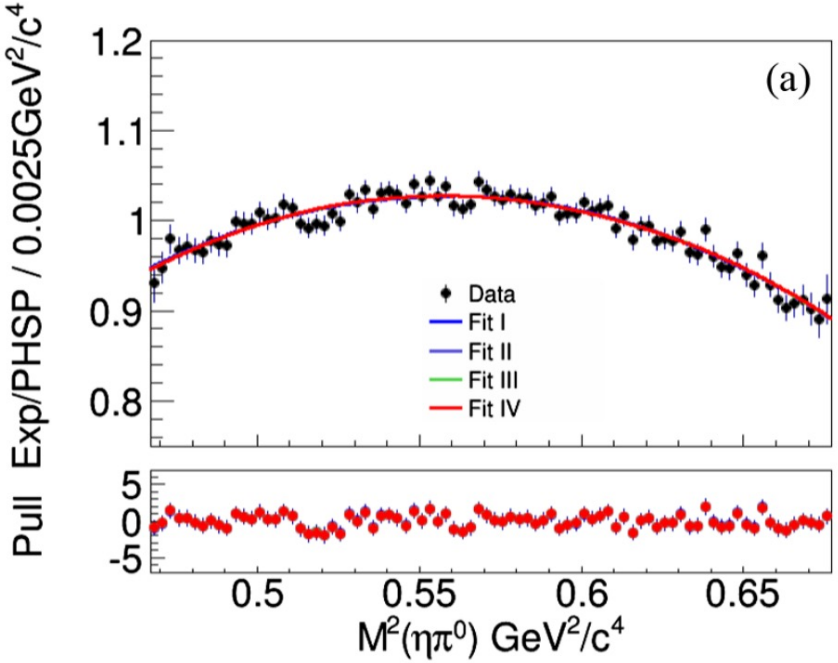
- **10 Billion J/ψ events at BESIII:**
  - ✓ A worldwide unique laboratory to study light mesons with unprecedented statistics
  - ✓ Significant progresses achieved on η/η' decays
    - ✓ Decay mechanisms, TFFs, ……
- **More results are coming soon**
  - ✓ Precision measurement of $\eta' \to \eta\pi^+\pi^-$, $\eta' \to \pi^+\pi^-\pi^0$ …
  - ✓ Rare or forbidden decays of η
  - ✓ ……
- **Together with other Exps, the light meson physics will be into a precision era**

Thanks for your attention!!!

Back up

First evidence of cusp effect in $\eta' \to \pi^0\pi^0\eta$

BESIII: PRL130, 081901(2023)



Cusp effect with ~3.5 σ!

With cusp effect

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

Decay Amplitude of $\eta' \to \pi^+\pi^- l^+ l^-$

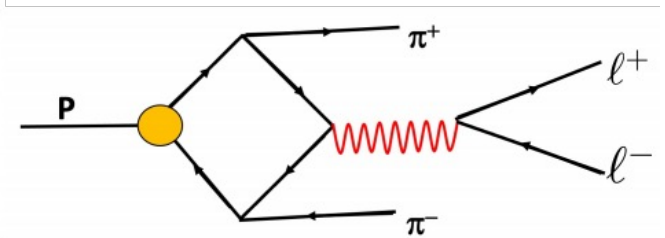
$$\overline{\left|\mathcal{A}_{\eta'\to\pi^+\pi^- l^+ l^-}\right|}^2(s_{\pi\pi}, s_{ll}, \theta_\pi, \theta_1, \phi) = \frac{e^2}{8k^2}|M(s_{\pi\pi}, s_{ll})|^2 \times \lambda\left(m_{\eta'}^2, s_{\pi\pi}, s_{ll}\right) \times \left[1 - \beta_1^2 \sin^2\theta_1 \sin^2\phi\right] s_{\pi\pi}\beta_\pi^2 \sin^2\theta_\pi$$

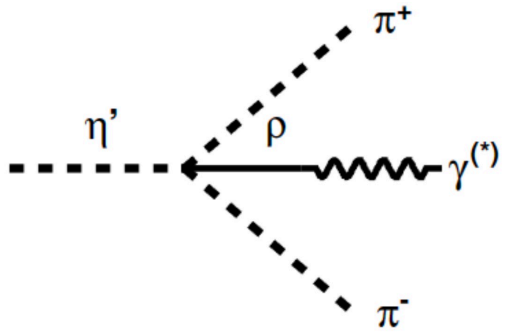
A. Faessler, C. Fuchs, M. I. Krivoruchenko, PRC 61, 035206 (2000)
B. Borasoy, R. Nissler, EPJA 33, 95 (2007)
T. Petri, arXiv:1010.2378

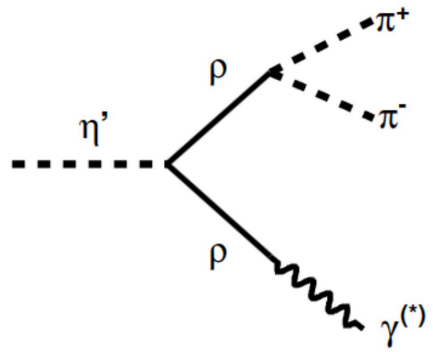
$$M(s_{\pi\pi}, s_{ll}) = M_{mix} \times VMD(s_{\pi\pi}, s_{ll})$$

contains the information of the decaying particle and the form factor

$$VMD(s_{\pi\pi}, s_{ll}) = \underbrace{1 - \frac{3}{4}(c_1 - c_2 + c_3)}_{\text{Box anomaly}} + \underbrace{\frac{3}{4}(c_1 - c_2 - c_3)\frac{m_V^2}{m_V^2 - s_{ll} - i m_V \Gamma(s_{ll})}}_{\text{VMD contribution}} + \underbrace{\frac{3}{2}c_3 \frac{m_V^2}{m_V^2 - s_{ll} - i m_V \Gamma(s_{ll})} \frac{m_{V,\pi}^2}{m_{V,\pi}^2 - s_{\pi\pi} - i m_{V,\pi}\Gamma(s_{\pi\pi})}}_{\text{VMD contribution}}$$







Various VMD models can be switch by adjusting the $c_{1,2,3}$ values

Amplitude analysis result of $\eta' \to \pi^+\pi^- l^+ l^-$

BESIII: JHEP 07, 135 (2024)

	Hidden gauge	Full VMD	Modified VMD
$\eta' \to \pi^+\pi^- e^+ e^-$	Model I	Model II	Model III
	$c_1 - c_2 = c_3 = 1$	$c_1 - c_2 = 1/3, c_3 = 1$	$c_1 - c_2 \neq c_3$
$m_V(\mathrm{MeV}/c^2)$	$954.3 \pm 87.8 \pm 36.4$	857.4 ± 76.5	787.5 ± 173.9
$m_{V,\pi}(\mathrm{MeV}/c^2)$	$765.3 \pm 1.2 \pm 20.2$	765.4 ± 1.2	764.8 ± 1.3
$m_\omega(\mathrm{MeV}/c^2)$	$778.7 \pm 1.3 \pm 17.3$	778.7 ± 1.3	778.7 ± 1.4
$\beta(10^{-3})$	$8.5 \pm 1.4 \pm 0.7$	8.5 ± 1.4	8.1 ± 1.5
θ	$1.4 \pm 0.3 \pm 0.1$	1.4 ± 0.3	1.4 ± 0.3
$c_1 - c_2$	1	1/3	-0.03 ± 1.09
c_3	1	1	1.03 ± 0.03
$\chi^2/ndof(e^+e^-, \pi^+\pi^-)$	77.9/82.0, 47.8/65.0	78.7/82.0, 47.6/65.0	79.4/82.0, 45.1/65.0
$b_{\eta'}(\mathrm{GeV}/c^2)^{-2}$	$1.10 \pm 0.20 \pm 0.07$	1.36 ± 0.24	1.61 ± 0.71

	Hidden gauge	Full VMD	Modified VMD
$\eta' \to \pi^+\pi^- \mu^+ \mu^-$	Model I	Model II	Model III
	$c_1 - c_2 = c_3 = 1$	$c_1 - c_2 = 1/3, c_3 = 1$	$c_1 - c_2 \neq c_3$
$m_V(\mathrm{MeV}/c^2)$	$649.4 \pm 55.9 \pm 35.6$	601.6 ± 25.7	589.6 ± 25.9
$m_{V,\pi}(\mathrm{MeV}/c^2)$	$757.3 \pm 24.1 \pm 18.0$	765.4 ± 18.8	774.4 ± 43.5
$c_1 - c_2$	1	1/3	0.01 ± 0.45
c_3	1	1	0.98 ± 0.40
$\chi^2/ndof(\mu^+\mu^-, \pi^+\pi^-)$	48.1/34.0, 32.9/46.0	48.3/34.0, 32.9/46.0	49.7/35.0, 32.4/46.0
$b_{\eta'}(\mathrm{GeV}/c^2)^{-2}$	$2.37 \pm 0.41 \pm 0.27$	2.76 ± 0.24	2.88 ± 0.25