Light meson decays at BESIII

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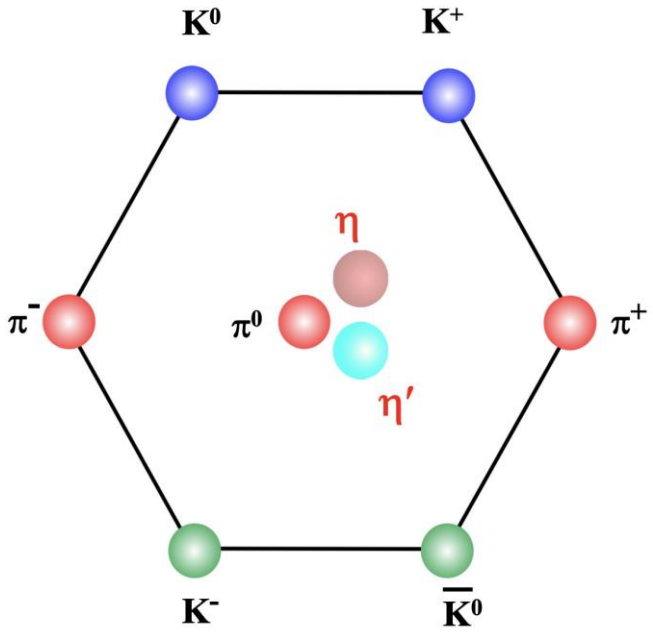
Outline

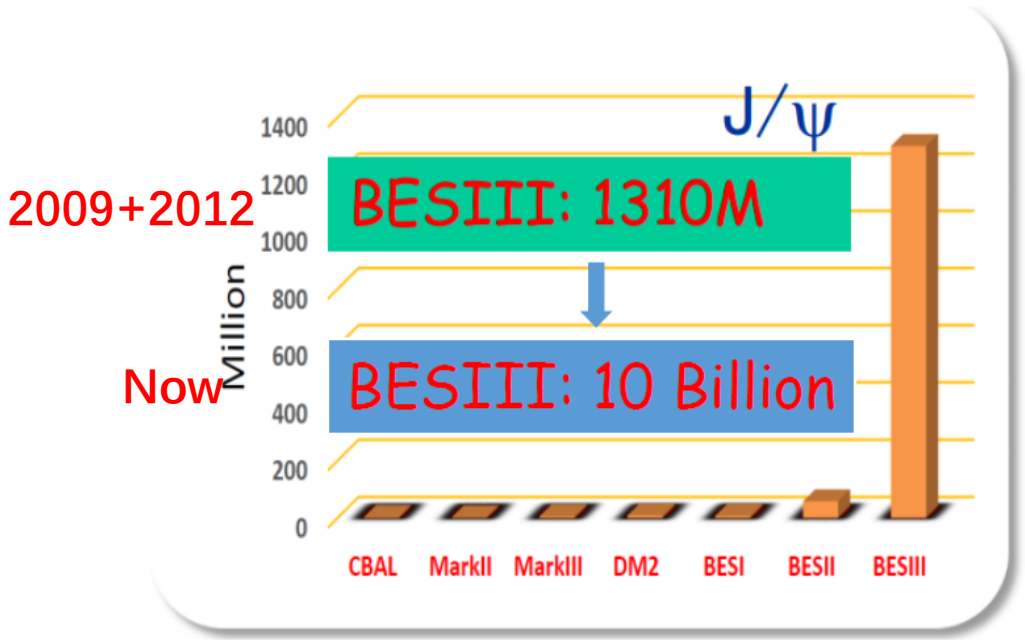
- Light meson Physics
- BESIII: a light meson factory
- Recent highlights
- Conclusion

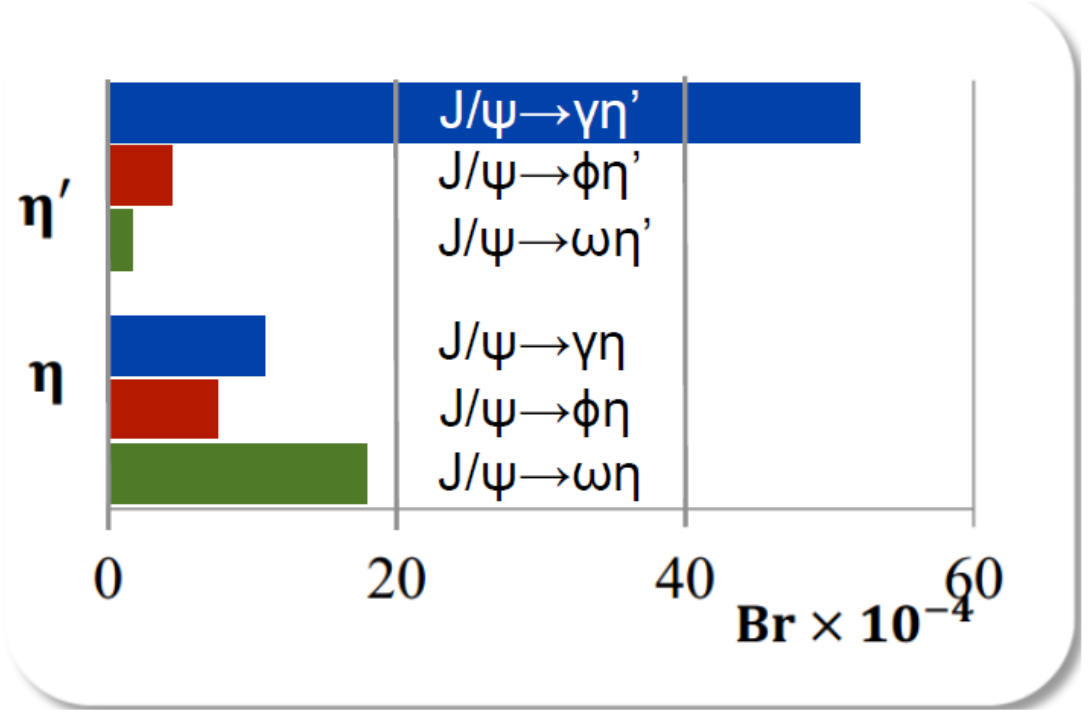
Light meson Physics

- Light mesons
  - ✓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



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

η REFERENCES

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HAYRAPETY...	23A	PRL 131 091903	A. Hayrapetyan *et al.*	(CMS Collab.)
ABLIKIM	21AM	PR D104 092004	M. Ablikim *et al.*	(BESIII Collab.)
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ZHEVLAKOV	19	PR D99 031703	A.S. Zhevlakov *et al.*	(TMSK, MAINZ, TUBIN+)
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PRAKHOV	18	PR C97 065203	S. Prakhov *et al.*	(A2 Collab. at MAMI)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
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ARNALDI	16	PL B757 437	R. Arnaldi *et al.*	(NA60 Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim *et al.*	(BESIII Collab.)
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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.)
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GOSLAWSKI	12	PR D85 112011	P. Goslawski *et al.*	(COSY-ANKE Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

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η′(958) REFERENCES

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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+)
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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.)
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ABLIKIM	13	PR D87 012009	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
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ABLIKIM	11	PR D83 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

AI识图

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

Xiao-lin Kang, Yuyao Ji et al, PRD 108, 014038 (2023)

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η REFERENCES

ABLIKIM	23AN	PR D107 092007	M. Ablikim *et al.*	(BESIII Collab.)
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- Production rate lower than η'
- Background from QED and J/ψ decays
- Help distinguish muons from pions

➢ $J/\psi \to \gamma\eta \implies 1 \times 10^7\ \eta$

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

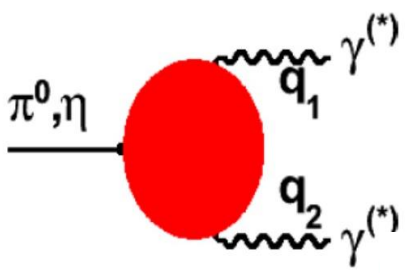
One more η' constraint to suppress the background events !

Allow us to access the rare η decays!

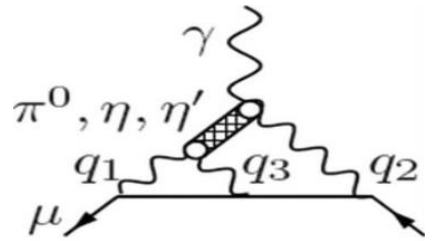
Recent highlights

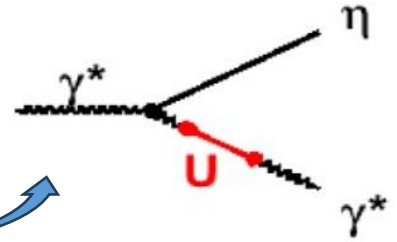
- ✓ **Transition Form Factor**
- ✓ **Double Dalitz Decays**
- ✓ **Charge Lepton Flavor Violation Decays**

Meson transition form factors

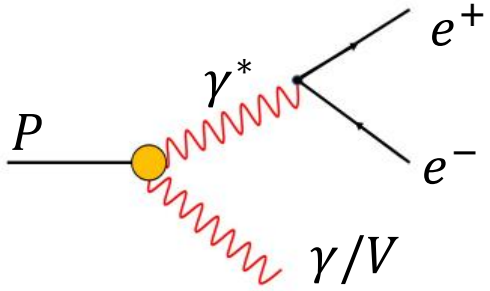


- Low energy QCD:
  - Enters in th. description of QCD processes
  - Evolution with Q^2 predicted by pQCD: models can be tested using data on Q^2 dependance
- Light-by-light contribution to a_μ
- Search for light dark force mediator

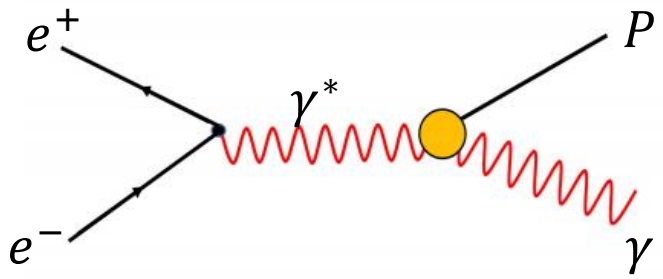




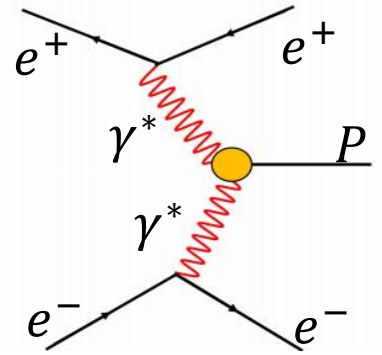
Experimentally



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

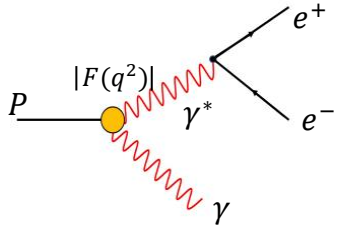


Annihilation process $q^2>M^2$

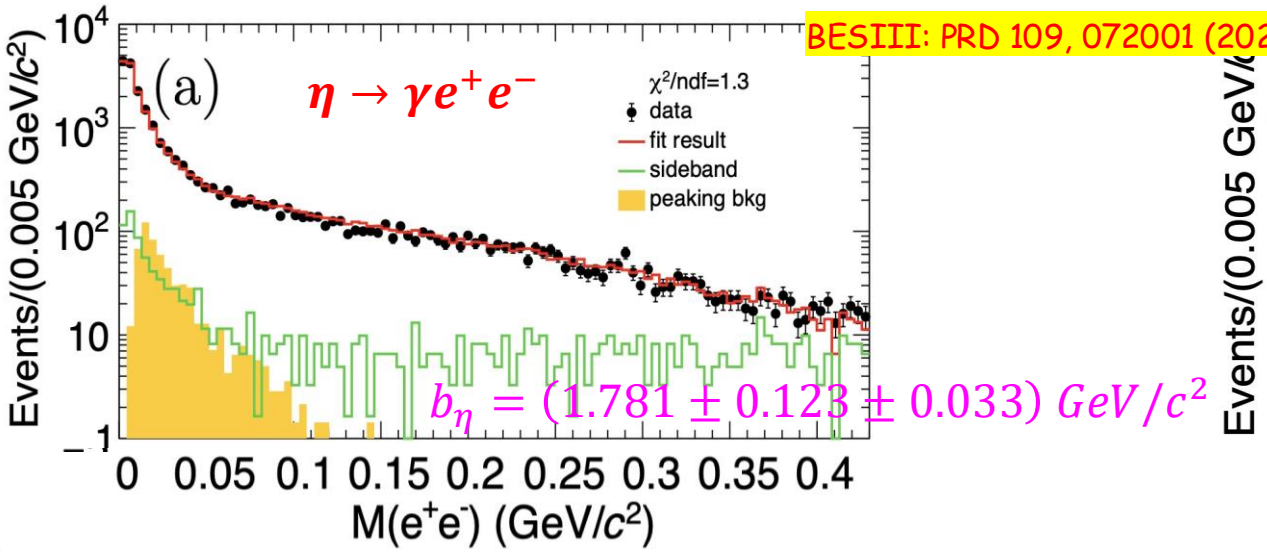


Two photon process $q^2<0$

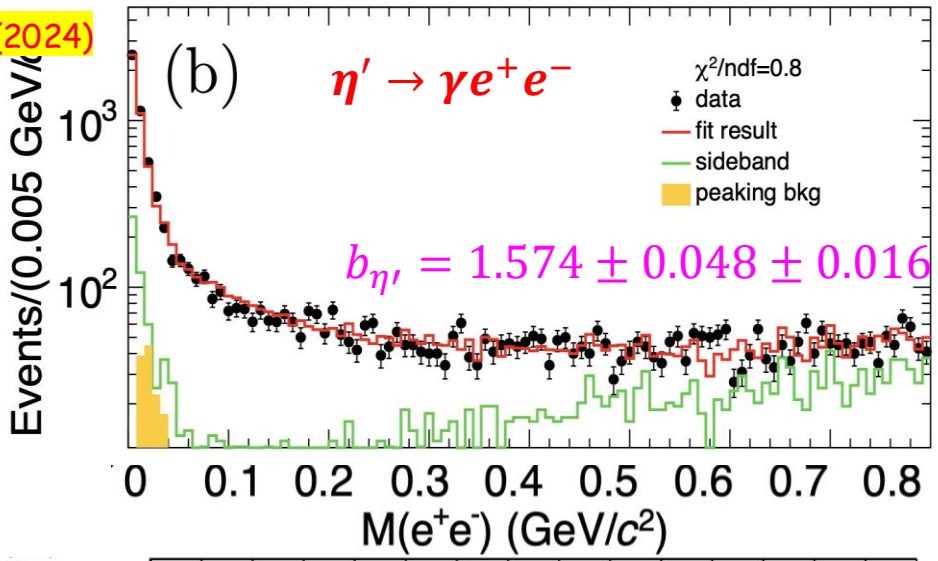
TFF of $\eta/\eta' \to \gamma e^+e^-$



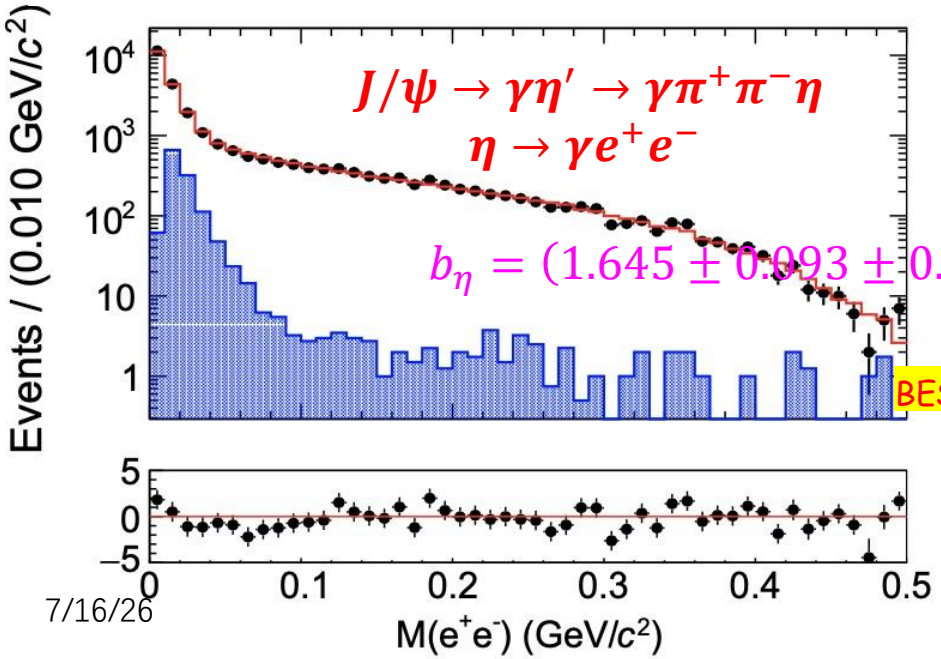
BESIII: PRD 109, 072001 (2024)



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

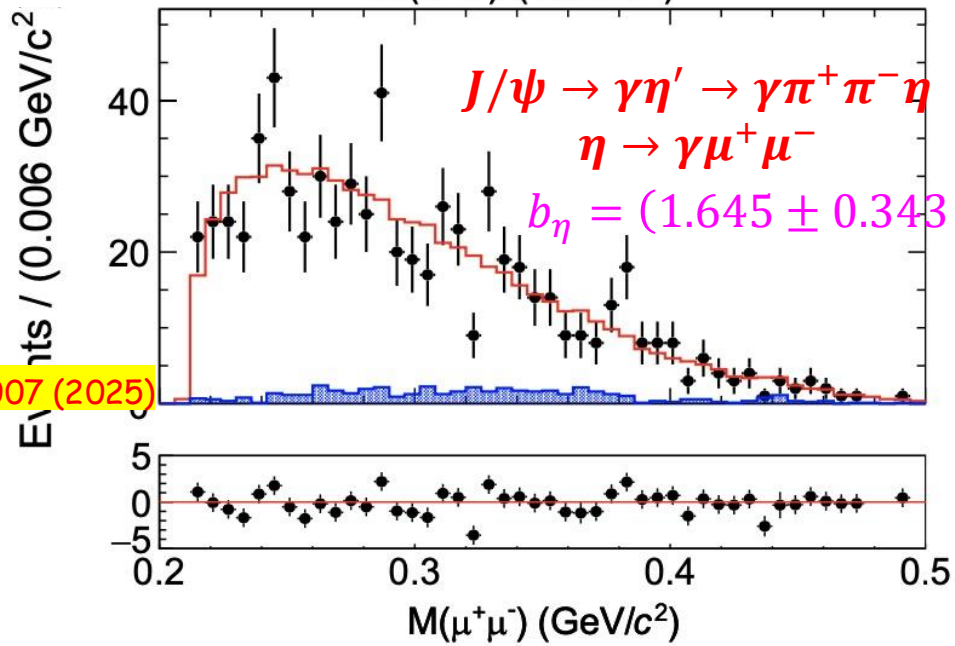


$b_{\eta'} = 1.574 \pm 0.048 \pm 0.016\ (\mathrm{GeV}/c^2)^{-2}$



$b_\eta = (1.645 \pm 0.093 \pm 0.024)\ GeV/c^2$

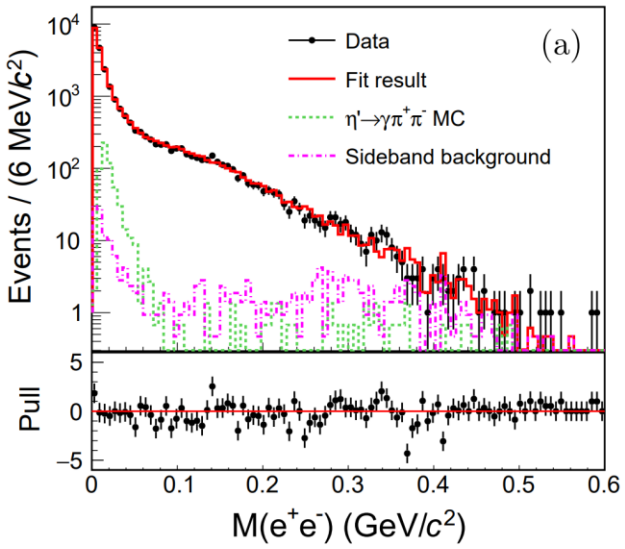
BESIII: PRD112, 052007 (2025)

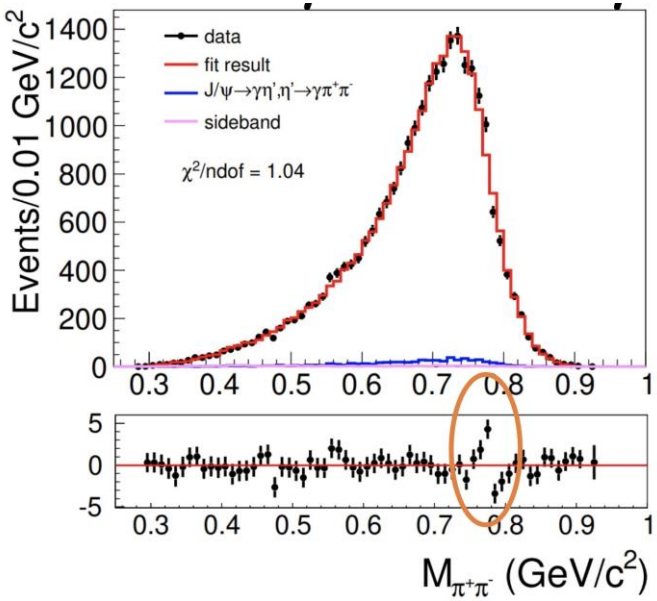


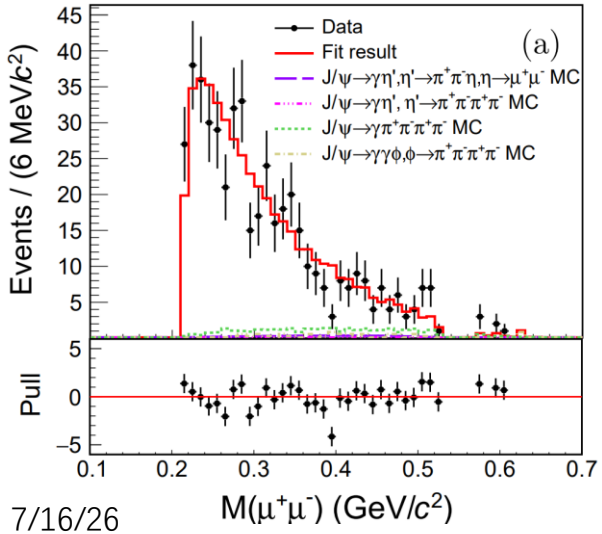
$b_\eta = (1.645 \pm 0.343 \pm 0.017)\ GeV/c^2$

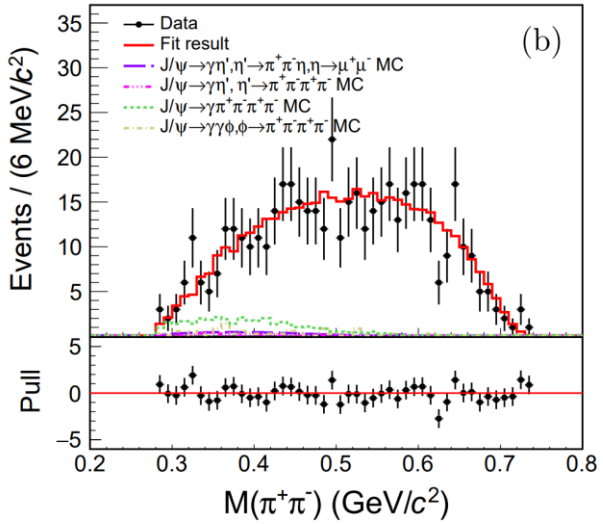
TFF of $\eta' \to \pi^+\pi^- l^+ l^-$

BESIII: JHEP 07, 135 (2024)



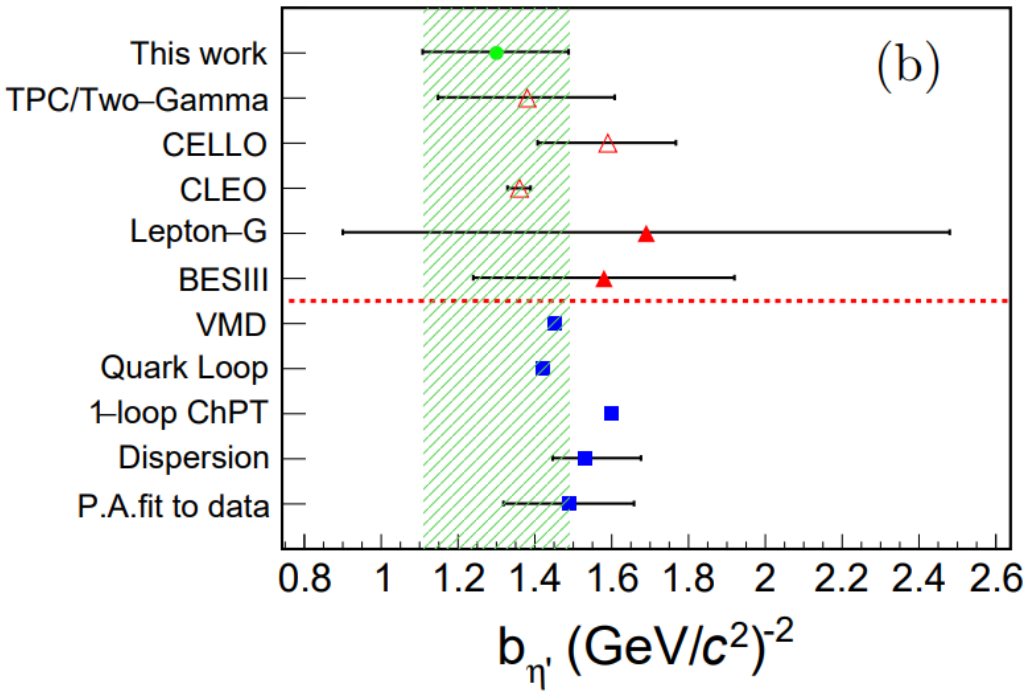




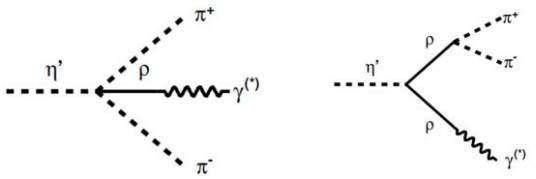


- 10 billion J/ψ allows to access the dynamic
- **Box-anomaly** is needed to describe data
- **$\omega \to \pi^+\pi^-$ is also necessary**
- First time to assess the form factors with $\eta' \to \pi^+\pi^- l^+ l^-$ within VMD

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

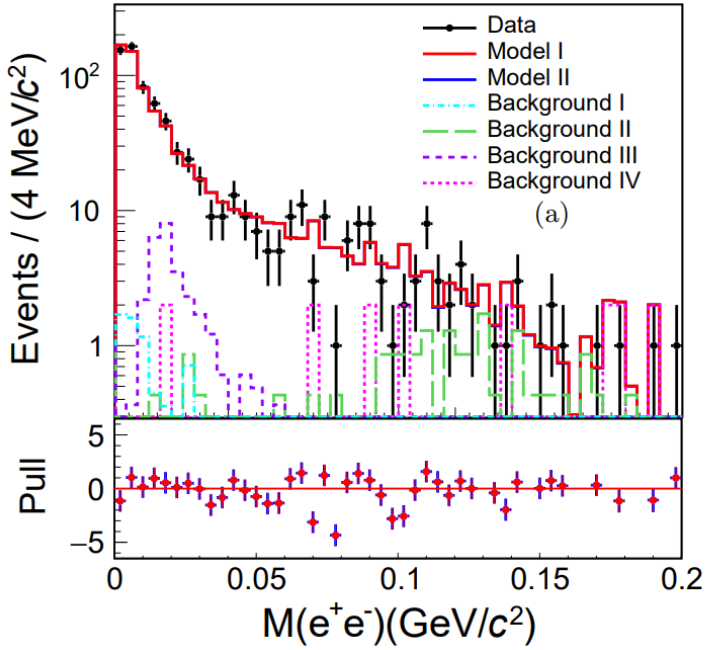


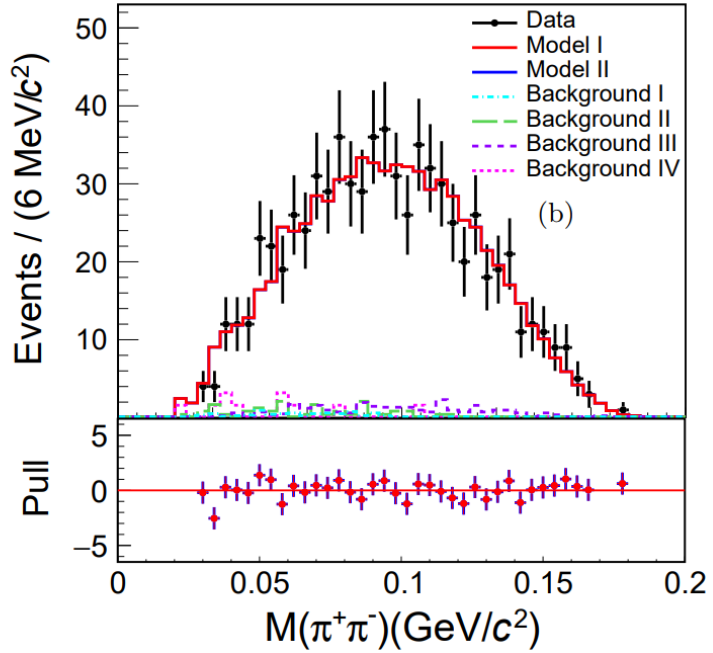
Study of $\eta \to \pi^+\pi^- l^+ l^-$



BESIII: PRD 111 (2025) 072008 (arXiv:2501.10130)

- BESIII: 10 billion J/ψ radiative decays $Br(\eta \to \pi^+\pi^- e^+ e^-) = (3.07 \pm 0.12 \pm 0.19) \times 10^{-4}$
- Allow to access dynamic but with limited statistics $m_V = (749 \pm 54 \pm 14)\ MeV/c$
- No event left for $\eta \to \pi^+\pi^-\mu^+\mu^-$ hypothesis $Br(\eta \to \pi^+\pi^-\mu^+\mu^-) < 4.0 \times 10^{-4}$ at 90% CL.





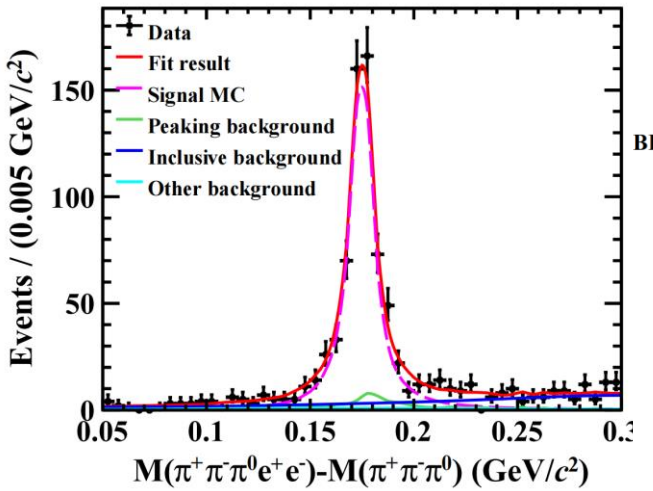
	$\mathcal{B}(\eta \to \pi^+\pi^- e^+ e^-)$ (10^{-4})	$\mathcal{B}(\eta \to \pi^+\pi^-\mu^+\mu^-)$ (10^{-9})
Unitary χPT [1]	$2.99^{+0.06}_{-0.09}$	$7.50^{+1.80}_{-0.70}$
Hidden gauge [2]	3.14 ± 0.17	8.65 ± 0.39
VMD [2]	3.02 ± 0.12	8.64 ± 0.25
CMD-2 [4]	$3.7^{+2.5}_{-1.8} \pm 3.0$	...
WASA [5]	$4.3^{+0.2}_{-1.6} \pm 0.4$	$< 3.6 \times 10^5$
KLOE [6]	$2.68 \pm 0.09 \pm 0.07$	...

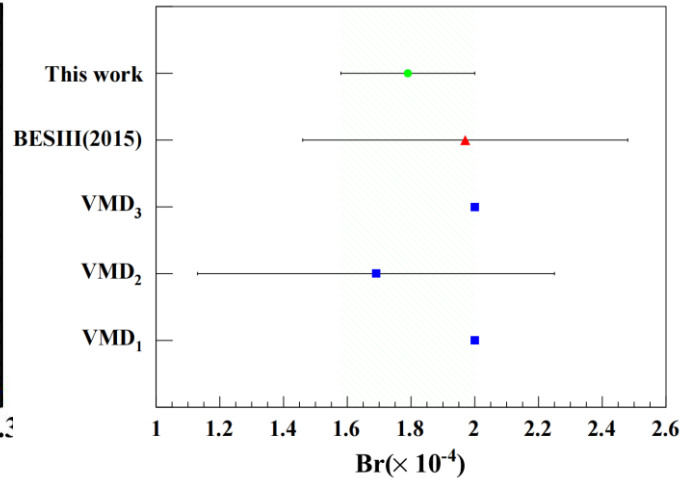
TFF of $\eta' \to \omega e^+e^-$

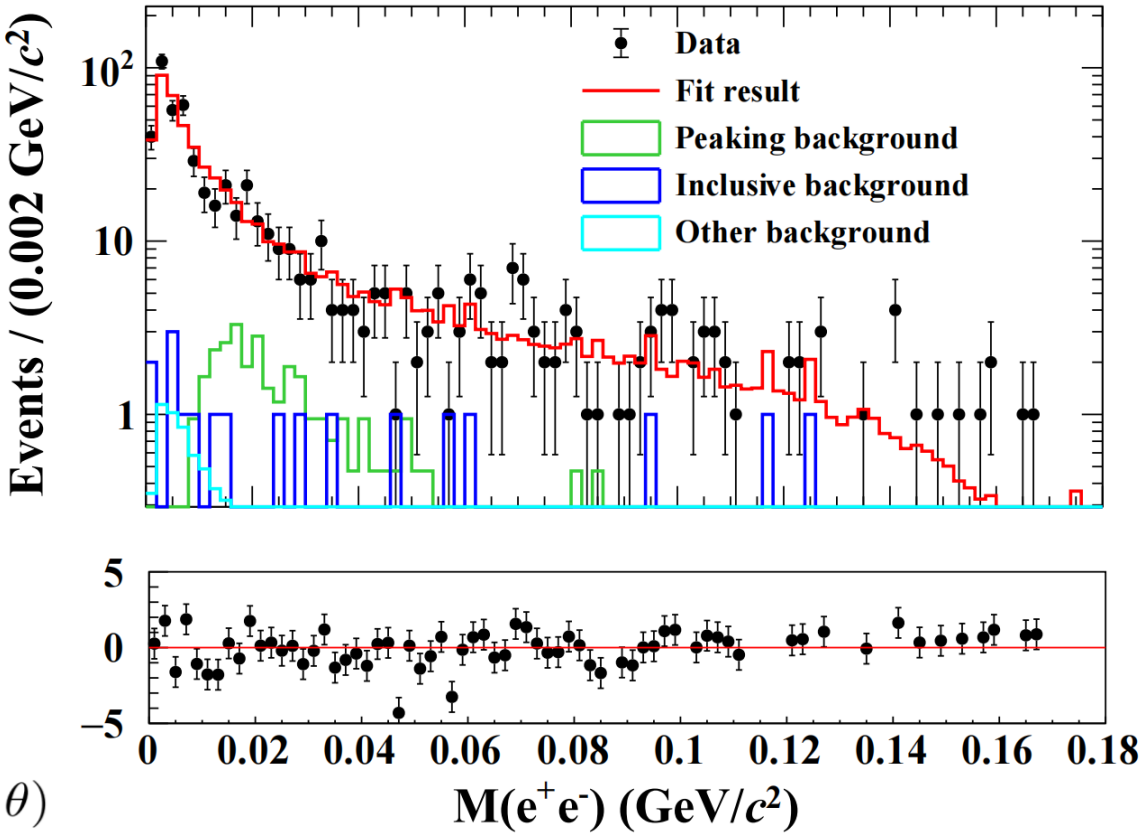
BESIII arXiv:2603.08120

- With 10 billion J/ψ events, 609.1 ± 27.7 $\eta' \to \omega e^+e^-$ signal events are observed

$$\mathrm{Br}(\eta' \to \omega e^+e^-) = (1.79 \pm 0.09 + 0.12) \times 10^{-4}$$





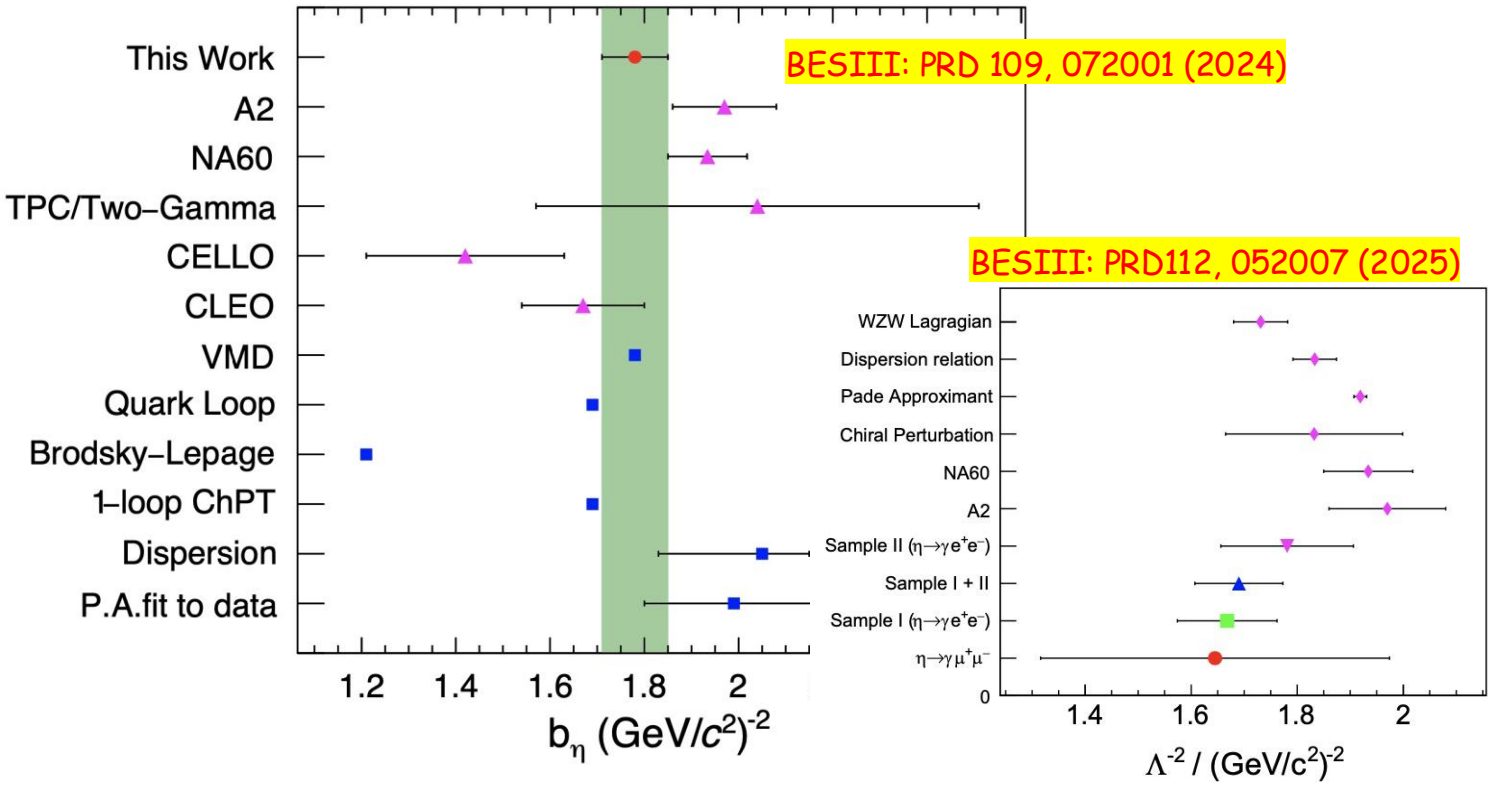


$$|\mathcal{A}_{\eta' \to e^+e^-\omega}|^2 = \frac{2^6\pi^2 M_{\eta'}^3 \alpha \Gamma_{\eta' \to \gamma\omega}}{(M_{\eta'}^2 - M_\omega^2)^3} |F(q^2)|^2 \cdot \frac{(M_{\eta'}^2 - q^2 - M_\omega^2)^2 - 4M_\omega^2 q^2}{q^2} (2 - \beta^2 \sin^2\theta)$$

$$\text{slope} \equiv \left.\frac{dF}{dq^2}\right|_{q^2=0} = \frac{1}{\Lambda^2}$$

TFF is measured for the first time: $\Lambda^{-1} = (2.92 \pm 0.83 \pm 0.15)\ GeV^{-1}$

Summary of the TFF for η/η'



BESIII: PRD 109, 072001 (2024)

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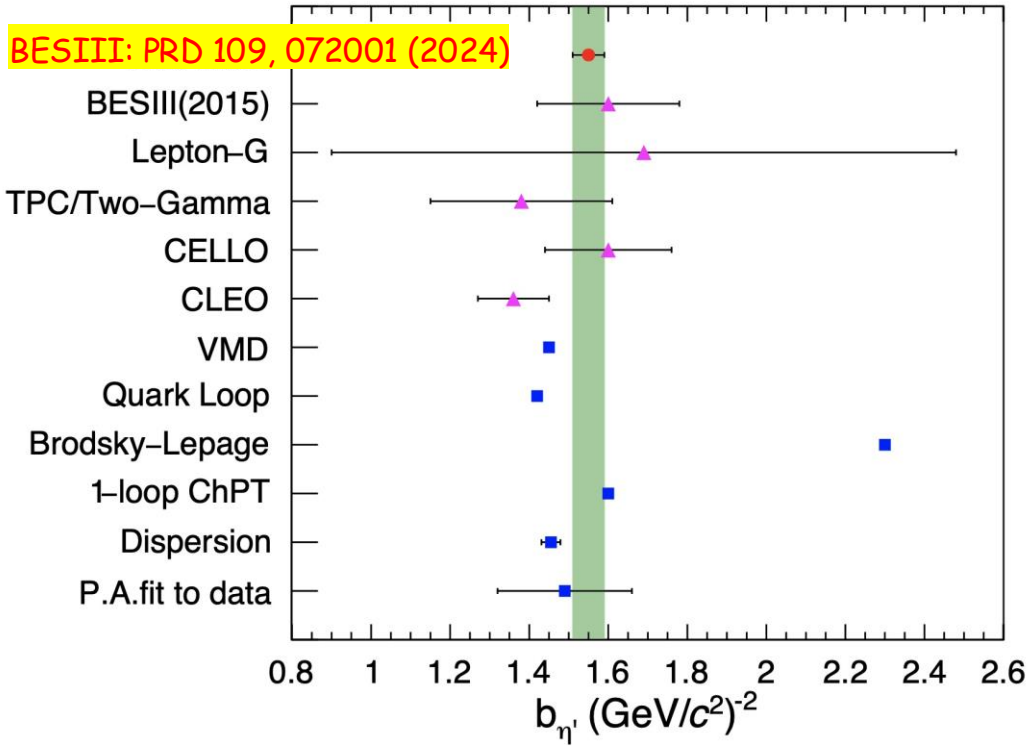


Combined the two $\eta \to \gamma e^+e^-$ samples:

$$b_\eta = (1.707 \pm 0.076 \pm 0.029)\ GeV/c^2$$

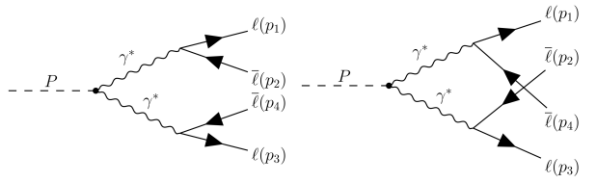
$\boldsymbol{\eta \to \gamma\mu^+\mu^-}$: $b_\eta = (1.645 \pm 0.343 \pm 0.017)\ GeV/c^2$

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

$\eta' \to \pi^+\pi^-e^+e^-$: $b_{\eta'} = 1.30 \pm 0.19\ (\mathrm{GeV/c^2})^{-2}$

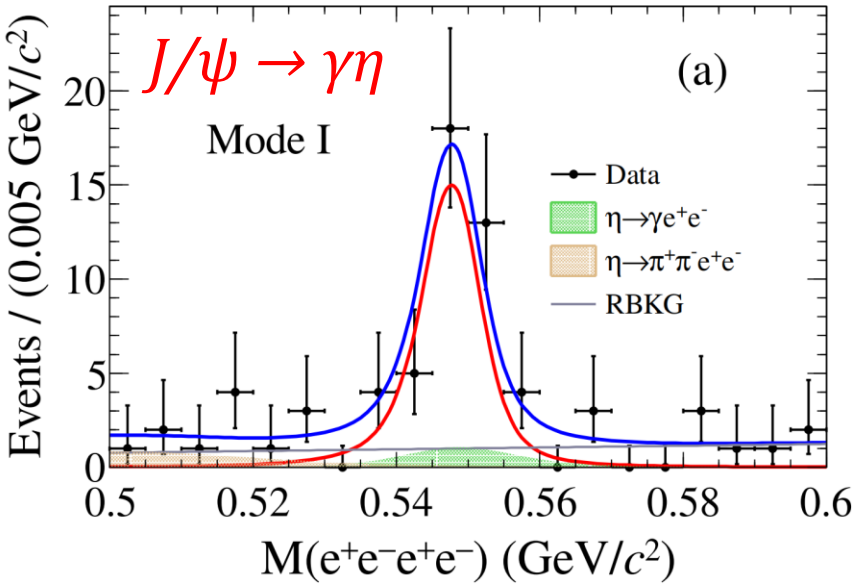
$\eta' \to \omega e^+e^-$: $\Lambda^{-1} = (2.92 \pm 0.83 \pm 0.15)\ GeV^{-1}$

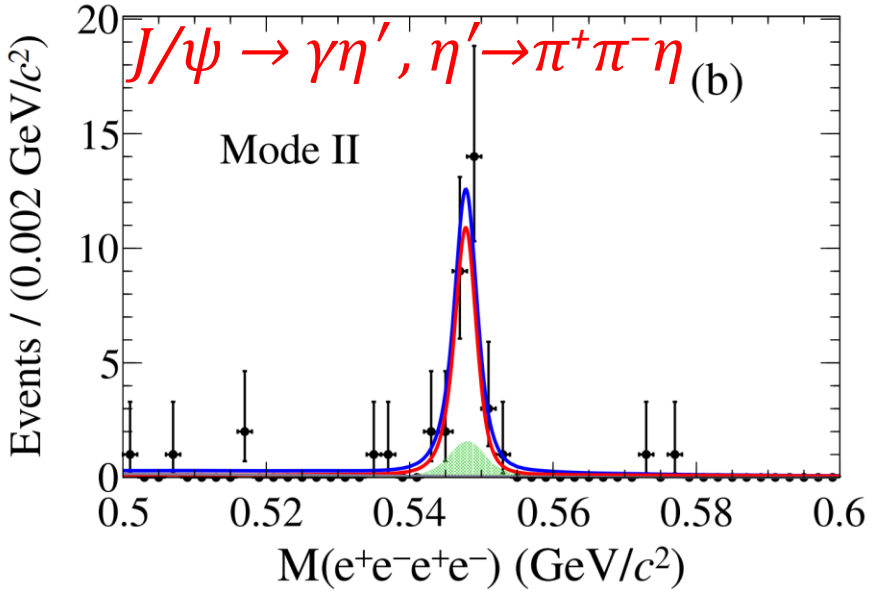
Double Dalitz decays $\eta \to e^+e^-e^+e^-$

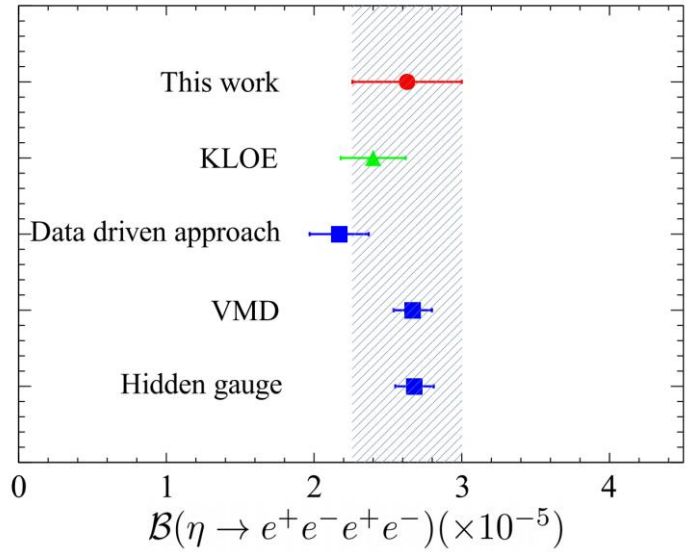


- Expected to proceed through two virtual photons, TFF

BESIII: arXiv:2605.04898v1







Mode	$N^{\rm obs}$	ϵ (%)	$\mathcal{B}$ $(\times 10^{-5})$
I	35.9 ± 6.7	13.1	2.51 ± 0.47
II	29.5 ± 6.1	4.7	2.80 ± 0.58

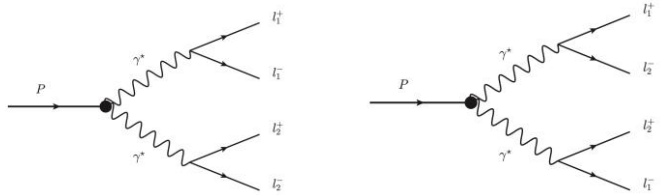
The combined branching fraction is determined to be $(2.63 \pm 0.34 \pm 0.16) \times 10^{-5}$

Source	$\eta \to e^+e^-e^+e^-$ $(\times 10^{-5})$	$\eta' \to e^+e^-e^+e^-$ $(\times 10^{-6})$
Hidden gauge [11]	2.68 ± 0.13	2.38 ± 0.40
Modified VMD [11]	2.67 ± 0.13	2.32 ± 0.40
Data driven approach [12]	2.17 ± 0.20	2.10 ± 0.45
KLOE [13]	2.40 ± 0.22	...
BESIII [14]	...	4.50 ± 0.12

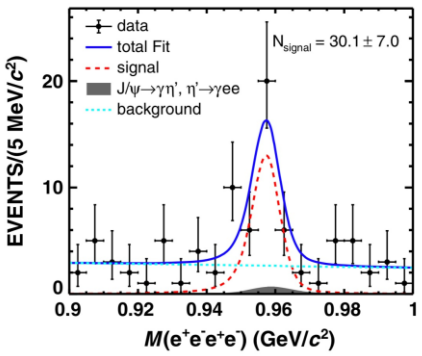
T. Petri, arXiv:1010.237

CPC 42 (2018) 023109

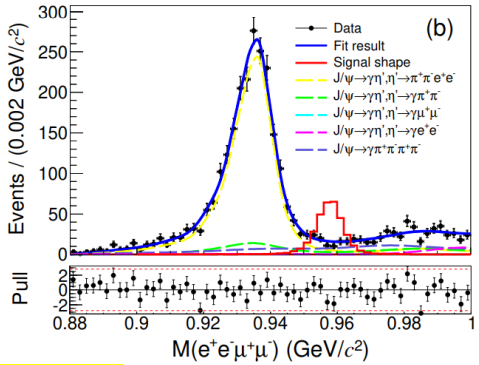
Double Dalitz decays $\eta/\eta' \to l^+l^-l^+l^-$



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

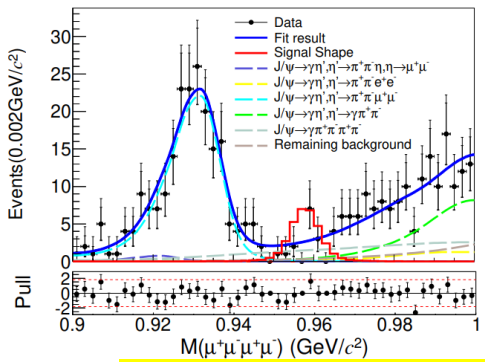


$\eta' \to e^+e^-\mu^+\mu^-$

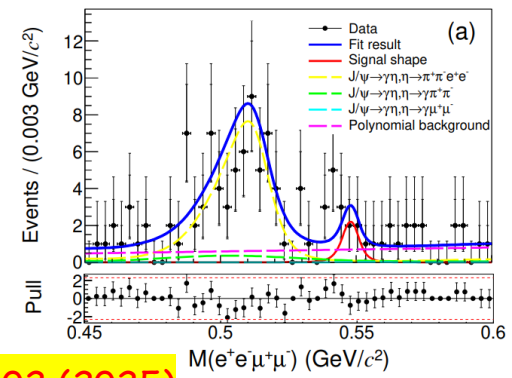


BESIII: PRD105,112010 (2022)

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

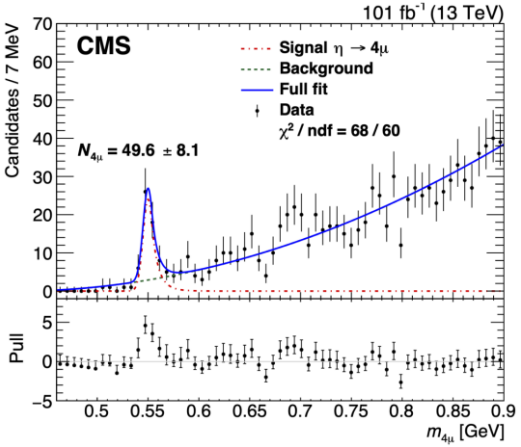


$\eta \to e^+e^-\mu^+\mu^-$



BESIII: PRD111,052002 (2025)

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



CMS: PRL 131 (2023) 091903

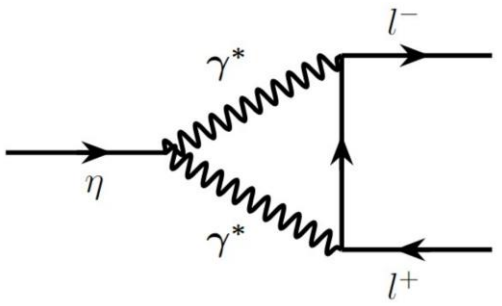
- Very limited Statistics!

Decay	Hidden gauge [9]	Modified VMD [9]	Data driven approach [10]	Experimental result
$\eta \to e^+e^-e^+e^-$	$2.680(13) \times 10^{-5}$	$2.668(13) \times 10^{-5}$	$2.17(2) \times 10^{-5}$	$2.40(22) \times 10^{-5}$ [11]
$\eta' \to e^+e^-e^+e^-$	$2.384(4) \times 10^{-6}$	$2.317(4) \times 10^{-6}$	$2.10(45) \times 10^{-6}$	$4.5(1) \times 10^{-6}$ [12]
$\eta \to \mu^+\mu^-\mu^+\mu^-$	$3.992(27) \times 10^{-9}$	$3.797(26) \times 10^{-9}$	$3.98(15) \times 10^{-9}$	$5.0(8) \times 10^{-9}$ [13]
$\eta' \to \mu^+\mu^-\mu^+\mu^-$	$2.360(12) \times 10^{-8}$	$2.185(10) \times 10^{-8}$	$1.69(36) \times 10^{-8}$	$< 5.28 \times 10^{-7}$
$\eta \to e^+e^-\mu^+\mu^-$	$2.213(26) \times 10^{-6}$	$2.154(22) \times 10^{-6}$	$2.39(7) \times 10^{-6}$	$< 6.88 \times 10^{-6}$
$\eta' \to e^+e^-\mu^+\mu^-$	$8.626(33) \times 10^{-7}$	$7.968(31) \times 10^{-7}$	$6.39(91) \times 10^{-7}$	$< 1.75 \times 10^{-6}$

Quite close to the SM predictions

Study of $\eta \to e^+e^-$ and $\mu^+\mu^-$

➢SM: $\eta \to l^+l^-$ proceeds via fourth-order electromagnetic transition, dominated by a two-photon intermediate state



➢$\eta \to e^+e^-$: Suppressed, helicity factor is proportional to m_e^2

$Br(\eta \to e^+e^-) = (5.31^{+0.14}_{-0.04}) \times 10^{-9}$
$Br(\eta \to \mu^+\mu^-) = \left(4.72^{+0.05}_{-0.21}\right) \times 10^{-6}$

P. Masjuan and P. Sanchez-Puertas, JHEP 2016 (8), 108.

➢Based on dispersive representation for the η transition form factors:

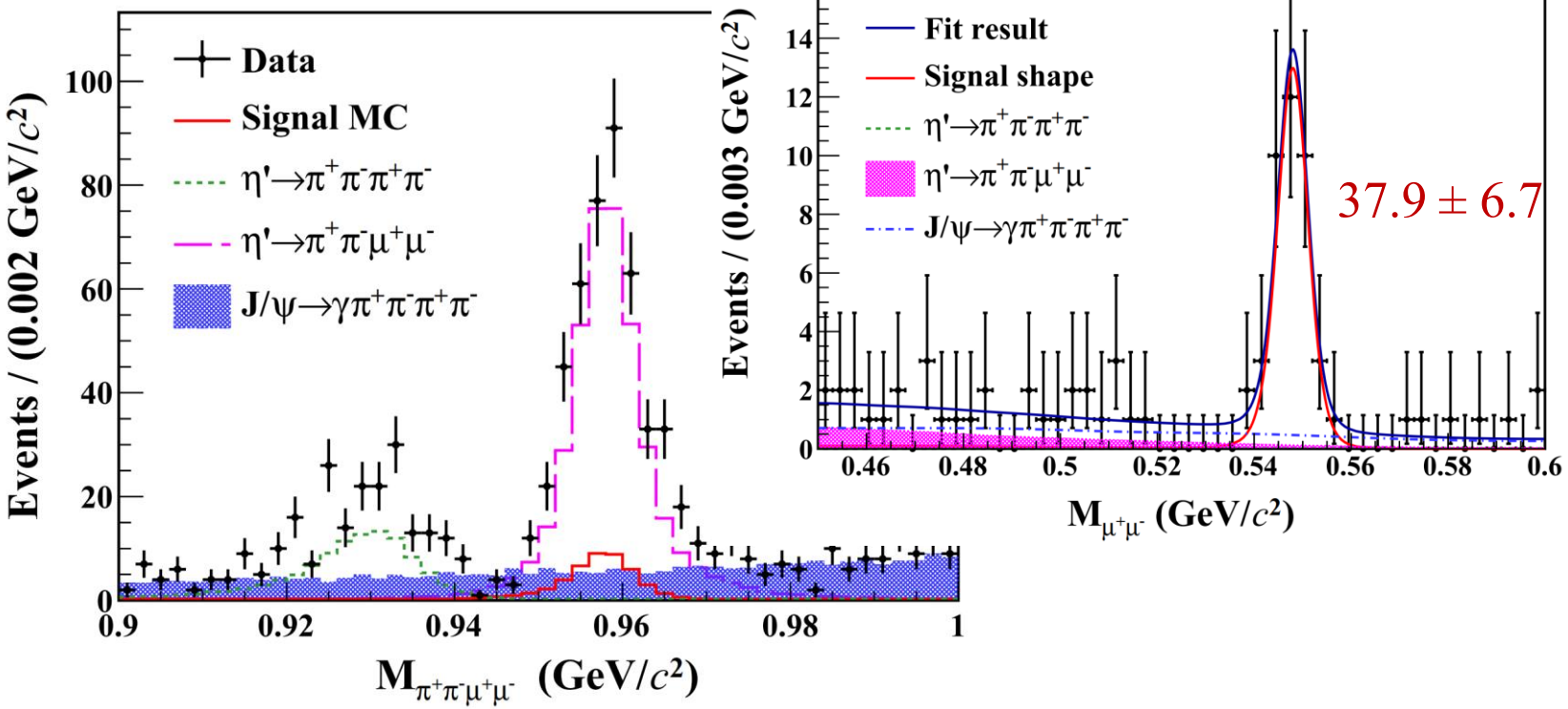
$Br(\eta \to e^+e^-) = (5.37 \pm 0.04 \pm 0.02) \times 10^{-9}$
$Br(\eta \to \mu^+\mu^-) = (4.54 \pm 0.04 \pm 0.02) \times 10^{-6}$

N. Messerli, M. Hoferichter, B.-L. Hoid, S. Holz, and B. Kubis, arXiv:2512.13776

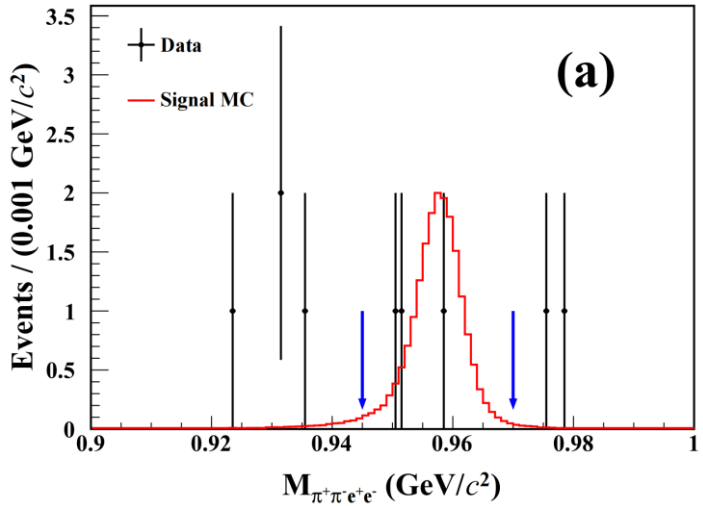
- A stringent UL of $Br(\eta \to e^+e^-) < 7 \times 10^{-7}$ at 90% CL obtained from $e^+e^- \to \eta$
- The world average of $Br(\eta \to \mu^+\mu^-) = (5.7 \pm 0.8) \times 10^{-6}$, combining the results from SATURNEII and Lepton-G more than thirty years ago

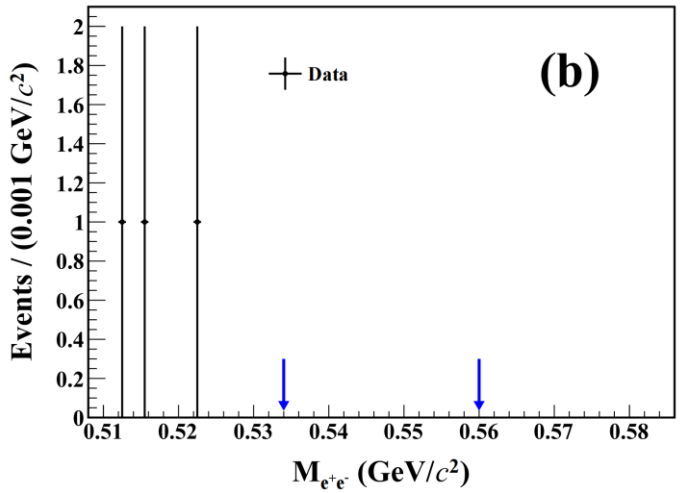
- With η sample from $J/\psi \to \gamma\eta', \eta' \to \pi^+\pi^-\eta, J/\psi \to \gamma l^+ l^-$ background is highly reduced compared with $J/\psi \to \gamma\eta$

BESIII: arXiv:2512.07144v2



$$Br(\eta \to \mu^+\mu^-) = (5.8 \pm 1.0 \pm 0.2) \times 10^{-6}$$

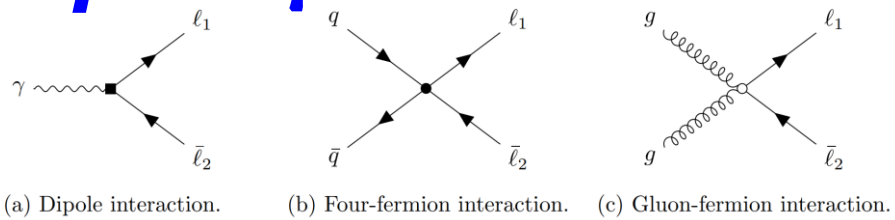




$$Br(\eta \to e^+e^-) < 2.2 \times 10^{-7}\ at\ 90\%\ CL$$

PDG: $Br(\eta \to \mu^+\mu^-) = (5.7 \pm 0.8) \times 10^{-6}$ and $Br(\eta \to e^+e^-) < 7 \times 10^{-7}$ at 90% CL

Search for CLFV process $\eta' \to e\mu$ and $\eta \to e\mu$

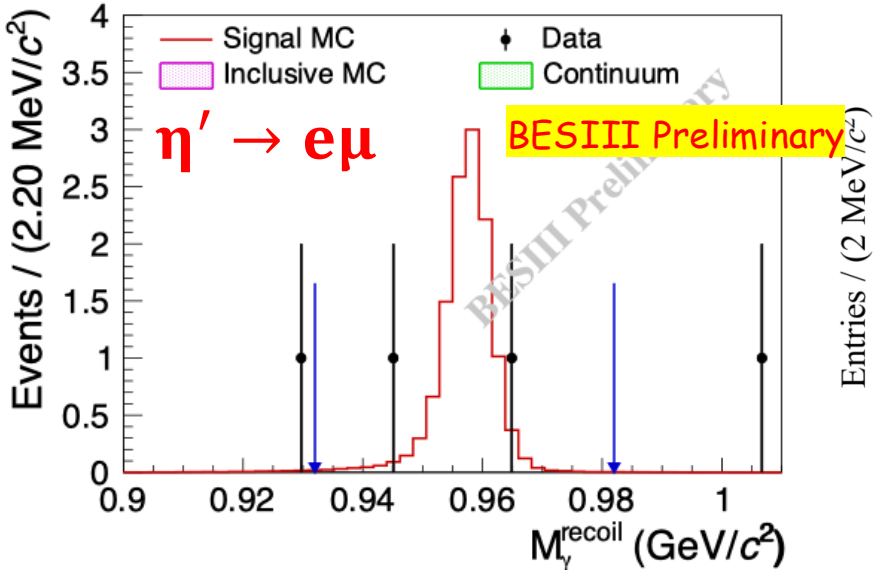


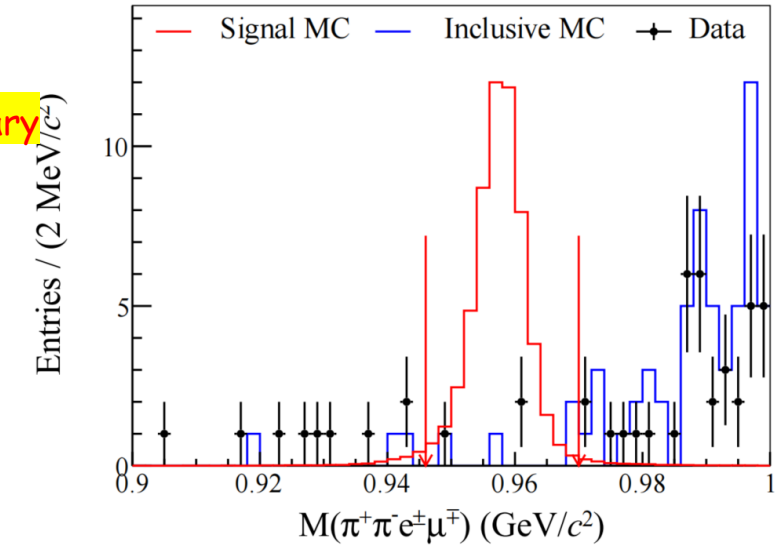
(a) Dipole interaction. (b) Four-fermion interaction. (c) Gluon-fermion interaction.

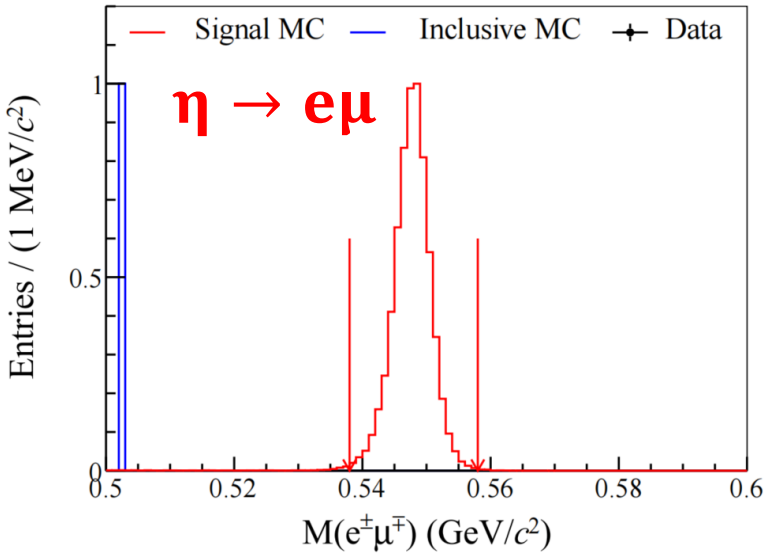
- Highly suppressed in SM $\propto \left(\Delta m_{ij}^2/M_W^2\right)^2 \sim 10^{-50}$
- Many New Physics models introduce Charge Lepton Flavor Violation (CLFV) processes
- Latest result $\mathcal{B}(\eta \to e\mu) < 6.0\times10^{-6}$ from CLEO in 2000 and $\mathcal{B}(\eta' \to e\mu) < 4.7 \times 10^{-4}$ from SPES2 in 1996

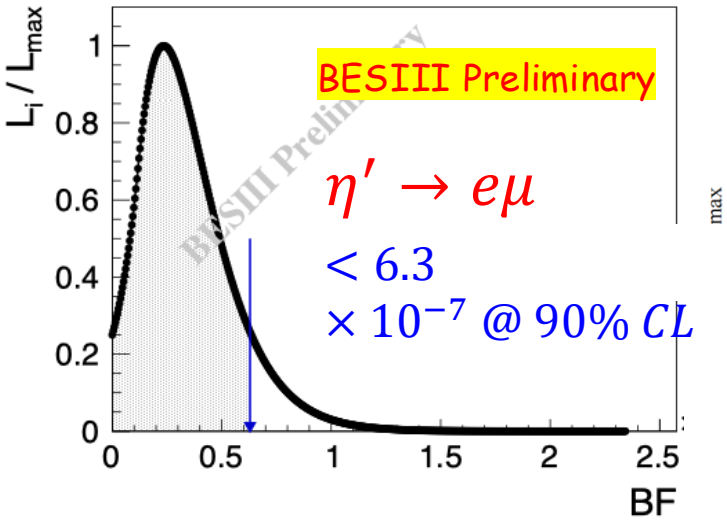
- For $\eta' \to e\mu$ with $J/\psi \to \gamma\eta'$ process is used.
- While for $\eta \to e\mu$, $J/\psi \to \gamma\eta' \to \gamma\pi^+\pi^-\eta$ is used to suppress continuum backgrounds

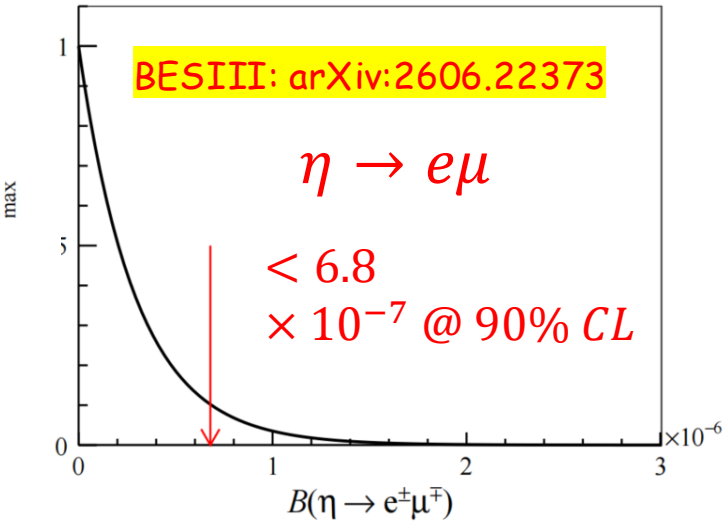
BESIII: arXiv:2606.22373











- $P \to \ell_1 \bar{\ell}_2$ are sensitive to different Wilson coefficients $C_i^{(D)}$ by $|C/\Lambda^2| \propto \sqrt{\mathcal{B}(P \to \ell_1 \bar{\ell}_2)}$
  - ✓ pseudoscalar coefficients in $\mathcal{L}_{\ell q}$: $C_{PL/PR}^{q\ell_1\ell_2}$
  - ✓ axial coefficients in $\mathcal{L}_{\ell q}$ $C_{AL/AR}^{q\ell_1\ell_2}$
  - ✓ gluonic coefficients in $\mathcal{L}_G$ $C_{\tilde{G}L/\tilde{G}R}^{q\ell_1\ell_2}$

L/R specify the chirality of the heavier lepton

$\|C/\Lambda^2\|$ (GeV^{-2})	$\ell_1\ell_2$	PDG $\mathcal{B}(\eta' \to e\mu) < 4.7 \times 10^{-4}$		This analysis $\mathcal{B}(\eta' \to e\mu) < 6.3 \times 10^{-7}$		PDG $\mathcal{B}(\eta \to e\mu) < 6.0 \times 10^{-6}$		This work $\mathcal{B}(\eta \to e\mu) < 6.8 \times 10^{-7}$	
		u,d	s	u,d	s	u,d	s	u,d	s
$\|C_{AL/AR}^{q\ell_1\ell_2}/\Lambda^2\|$	$e\mu$	2.1×10^{-1}	1.9×10^{-1}	7.4×10^{-3}	6.8×10^{-3}	3.0×10^{-3}	2.1×10^{-3}	1.0×10^{-3}	7.0×10^{-4}
$\|C_{PL/PR}^{q\ell_1\ell_2}/\Lambda^2\|$	$e\mu$	3.9×10^{4}	3.6×10^{4}	1.4×10^{3}	1.3×10^{3}	1.7×10^{3}	1.2×10^{3}	5.8×10^{2}	4.0×10^{2}
$\|C_{\tilde{G}L/\tilde{G}R}^{q\ell_1\ell_2}/\Lambda^2\|$	$e\mu$	5.0×10^{3}		1.8×10^{2}		1.6×10^{2}		5.4×10^{1}	

- Improvement of the ULs on the Wilson coefficients of effective operators describing LFV interactions at low energy scales

Conclusions

- BESIII: a light meson factory
- Significant progresses achieved on η/η' decays
  - transition form factors, decay dynamics, rare/forbidden decays …
- $\eta' \to \pi^+\pi^-\eta$ significantly improves the ability to study rare η decays
- More results are expected to come soon !

Thanks for your attention!!!