η and η' physics at BESIII

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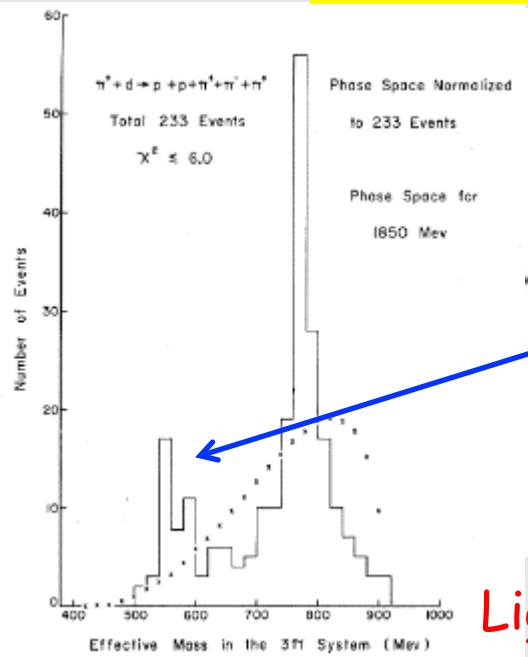
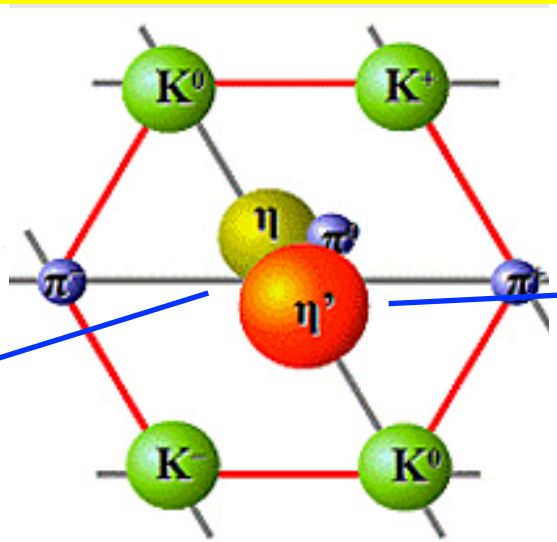
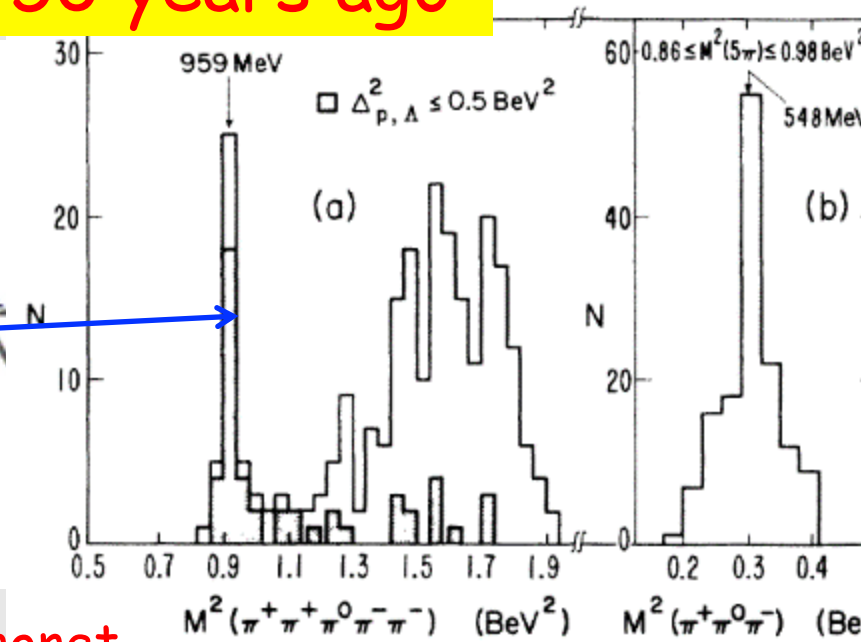
Introduction

Phys. Rev. Lett. 7,421(1961) Phys. Rev. Lett. 12,567(1964)

Discovered about 50 years ago







Lightest pseudoscalar nonet

- Dominant decay modes were observed

$\eta \to 2\gamma$	39.31%	$\eta' \to \pi+\pi-\eta$	44.6%
$\eta \to \pi+\pi-\pi^0$	22.74%	$\eta' \to \gamma\rho(\gamma\pi+\pi-)$	29.4%
$\eta \to \pi^0\pi^0\pi^0$	32.57%	$\eta' \to \pi^0\pi^0\eta$	20.7%
$\eta \to \gamma\pi+\pi-$	4.60%	$\eta' \to 2\gamma$	3.02%
		$\eta' \to \gamma\omega$	2.10%

Introdcution

- Still listed in many facilities' physics program (KLOE, WASA-at-COSY, CB at MAINZ, CLAS, GlueX, BESIII)

- **η/η' : a rich physics field**
  - Unique place to test fundamental symmetries in QCD at low energy
  - Probe physics beyond the Standard Model (SM)

$\eta/\eta' \to 2\gamma$	chiral anomaly
$\eta/\eta' \to \pi^+\pi^-\pi^0$	quark masses
$\eta' \to \gamma\pi^+\pi^-$	box anomaly
$\eta/\eta' \to \pi\pi$	CP violation
$\eta/\eta' \to \mu^+\mu^-\pi^0, e^+e^-\pi^0$	C violation
$\eta/\eta' \to \mu e$	LF violation
……	

η and η' events at BESIII

- 225 million J/ψ events taken in 2009
- ~ 1 billion J/ψ events taken in 2012

- η and η' production in J/ψ decays
  - $B(J/\psi \to \gamma\eta) \sim 1.1\times10^{-3} \to 2.3\times10^{5}$ η events
  - $B(J/\psi \to \gamma\eta') \sim 5.2\times10^{-3} \to 1.2\times10^{6}$ η' events
  - $B(J/\psi \to \phi\eta) \sim 7.5\times10^{-4} \to 1.7\times10^{5}$ η events
  - $B(J/\psi \to \phi\eta') \sim 4.0\times10^{-4} \to 0.9\times10^{5}$ η' events

The results in this talk are based on the data sample of 225M J/ψ events

Recent η and η' results from BESIII

- Matrix element for $\eta' \to \pi^+\pi^-\eta$
- Search for CP violation $\eta/\eta' \to \pi^+\pi^-, \pi^0\pi^0$
- BF measurement of $\eta' \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$
- BF measurement of $\eta' \to \pi^+\pi^-e^+e^-, \pi^+\pi^-\mu^+\mu^-$
- Search for η/η' invisible decays
- Search for η/η' weak decays

Matrix Element for the Decay $\eta' \to \pi^+\pi^-\eta$

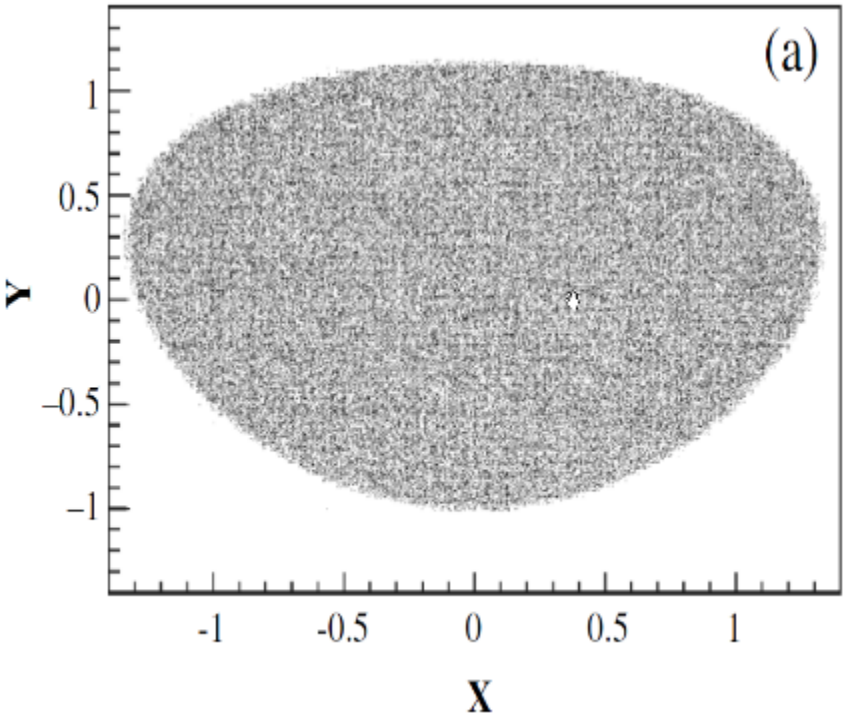
Phys. Rev. D83,012003(2011)

- Impact of gluon component on the dynamics of η' decays
- Comparison to the theoretical calculations with the effective ChPT
- Previous measurements on the dalitz plot of $\eta' \to \pi\pi\eta$ are from VES, GAMS and CLEO

$$X = \frac{\sqrt{3}}{Q}(T_{\pi^+} - T_{\pi^-}), \qquad Y = \frac{m_\eta + 2m_\pi}{m_\pi}\frac{T_\eta}{Q} - 1$$

$T_{\pi,\eta}$ denote the kinetic energies of mesons in the η' rest frame

$$Q = T_\eta + T_{\pi^+} + T_{\pi^-} = m_{\eta'} - m_\eta - 2m_\pi$$

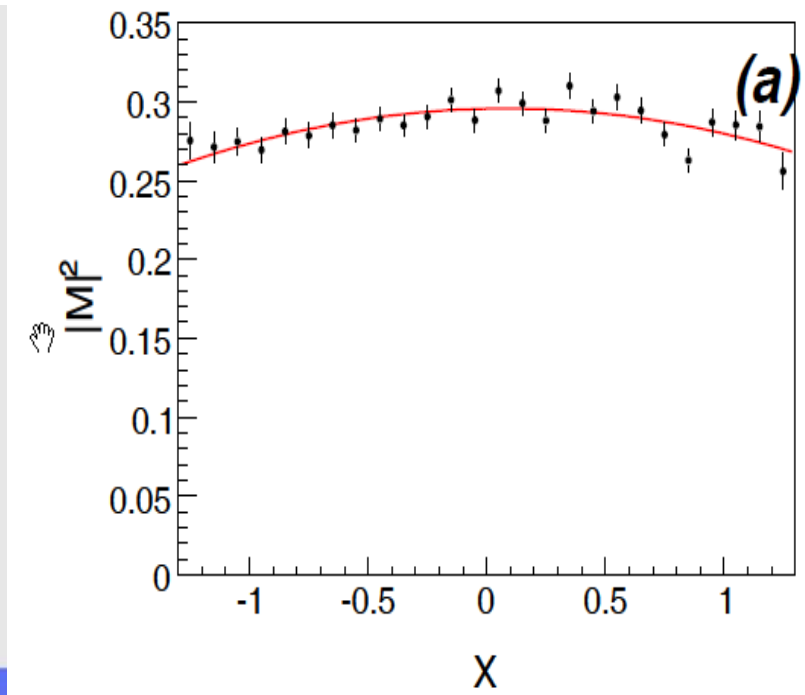


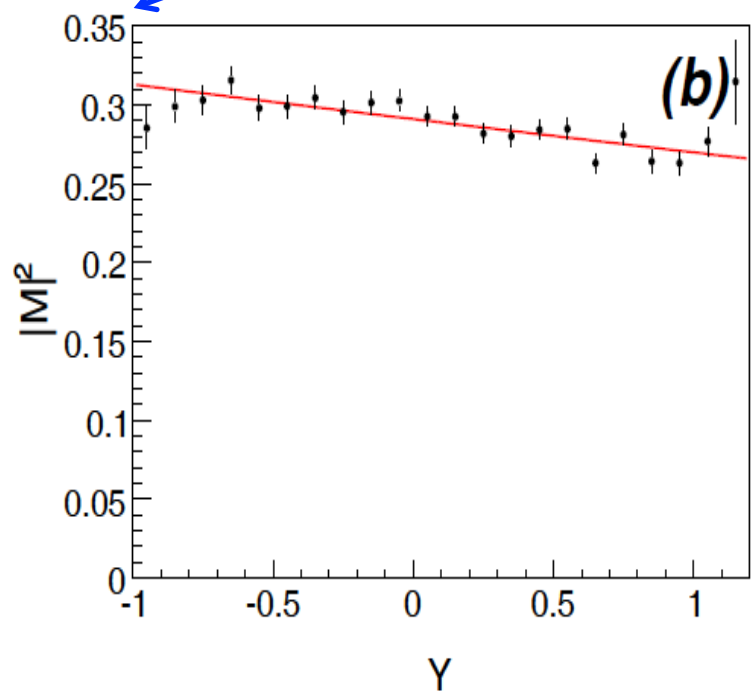
Flat, seems no dynamics is involved

Two representations used

$$M^2 = A(1 + aY + bY^2 + cX + dX^2)$$

$$M^2 = A(|1 + \alpha Y|^2 + cX + dX^2)$$





Results from the fit with two different representations

Parameter	VES [9] (Phys. Lett.B651,22(2007))	Theory [26] (Eur. Phys.J.A26,383(2005))	This work
a	-0.127 ± 0.018	-0.116 ± 0.011	-0.047 ± 0.012
b	-0.106 ± 0.032	-0.042 ± 0.034	-0.069 ± 0.021
c	$+0.015 \pm 0.018$	$\cdots$	$+0.019 \pm 0.012$
d	-0.082 ± 0.019	$+0.010 \pm 0.019$	-0.073 ± 0.013

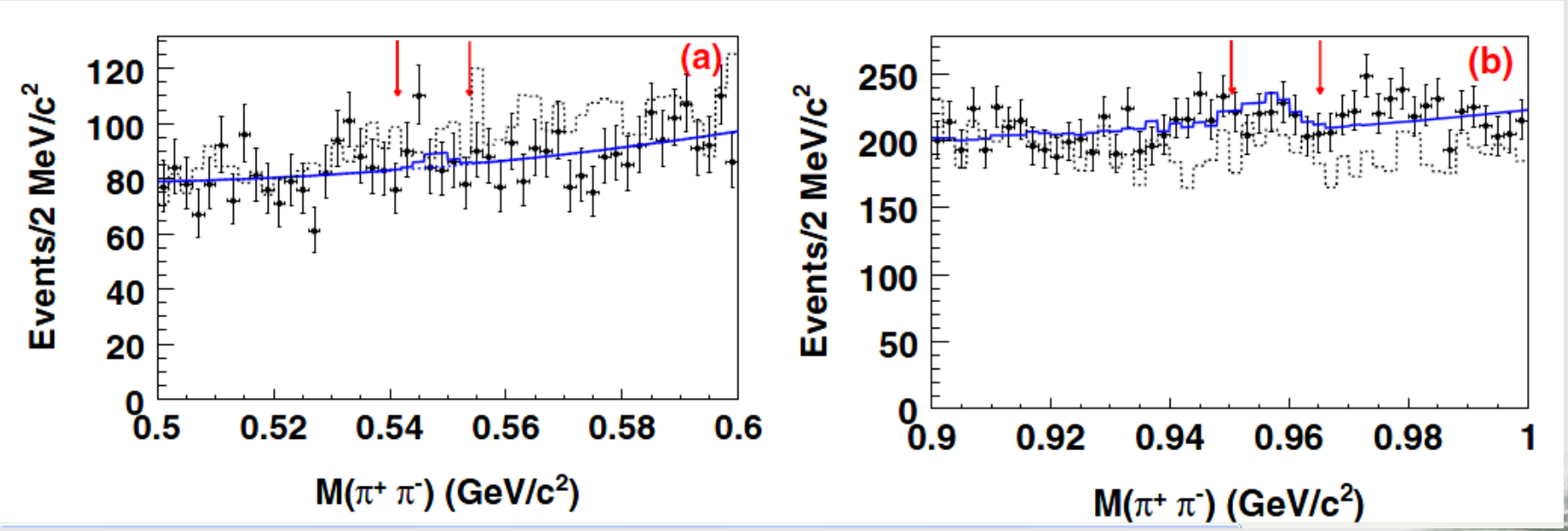
Parameter	CLEO [11] (Phys. Rev,Lett.84,26(2000))	VES [27] (Phys.At.Nucl.68,372(2005))	This work
$\mathrm{Re}(\alpha)$	-0.021 ± 0.025	-0.072 ± 0.014	-0.033 ± 0.006
$\mathrm{Im}(\alpha)$	0.000 (fixed)	0.000 ± 0.100	0.000 ± 0.050
c	0.000 (fixed)	$+0.020 \pm 0.019$	$+0.018 \pm 0.010$
d	0.000 (fixed)	-0.066 ± 0.034	-0.059 ± 0.013

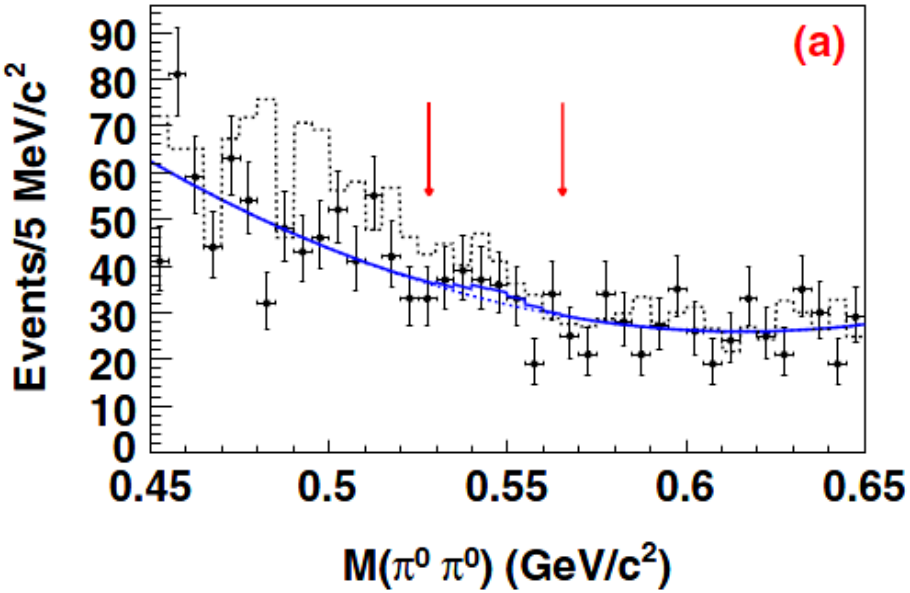
- Part of parameters are not consistent with previous work
- "c" , defined for C parity violation, is consistent with zero within 2 standard deviations

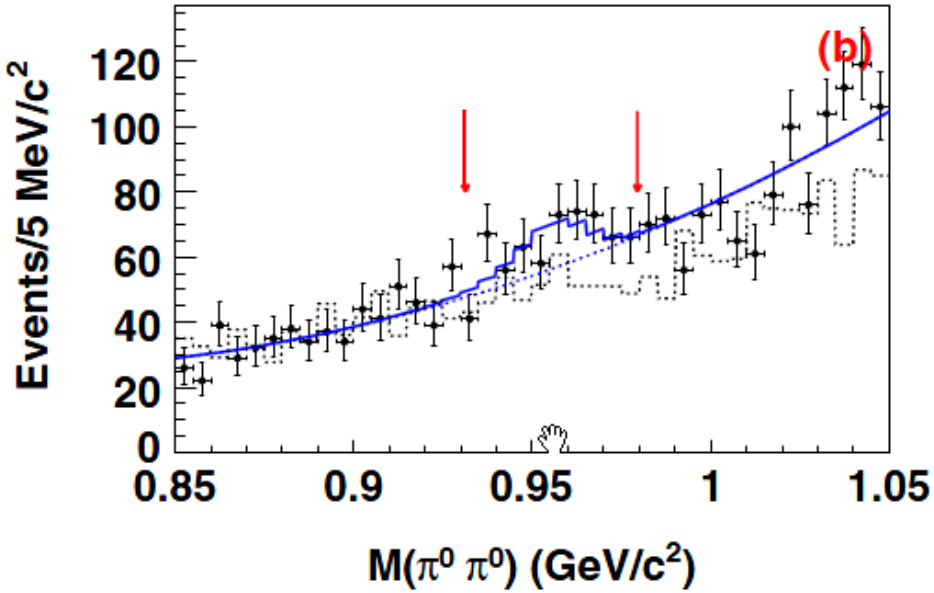
Search for CP violation in η/η′ →ππ

Phys. Rev. D84,032006(2011)

- Offer an excellent laboratory for testing P and CP invariance
- Theoretically proceed via the weak interaction at a level of 10^{-15}~10^{-27}





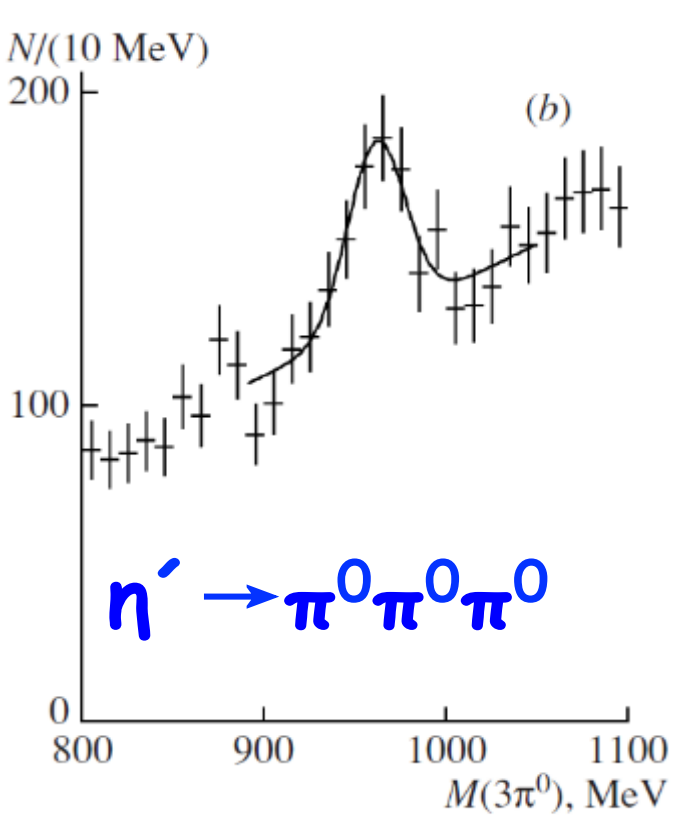


Process	$\mathcal{B}^{UP}$	$\mathcal{B}^{UP}_{PDG}$
$\eta \to \pi^+\pi^-$	3.9×10^{-4}	1.3×10^{-5}
$\eta' \to \pi^+\pi^-$	5.5×10^{-5}	2.9×10^{-3}
$\eta \to \pi^0\pi^0$	6.9×10^{-4}	3.5×10^{-4}
$\eta' \to \pi^0\pi^0$	4.5×10^{-4}	9×10^{-4}

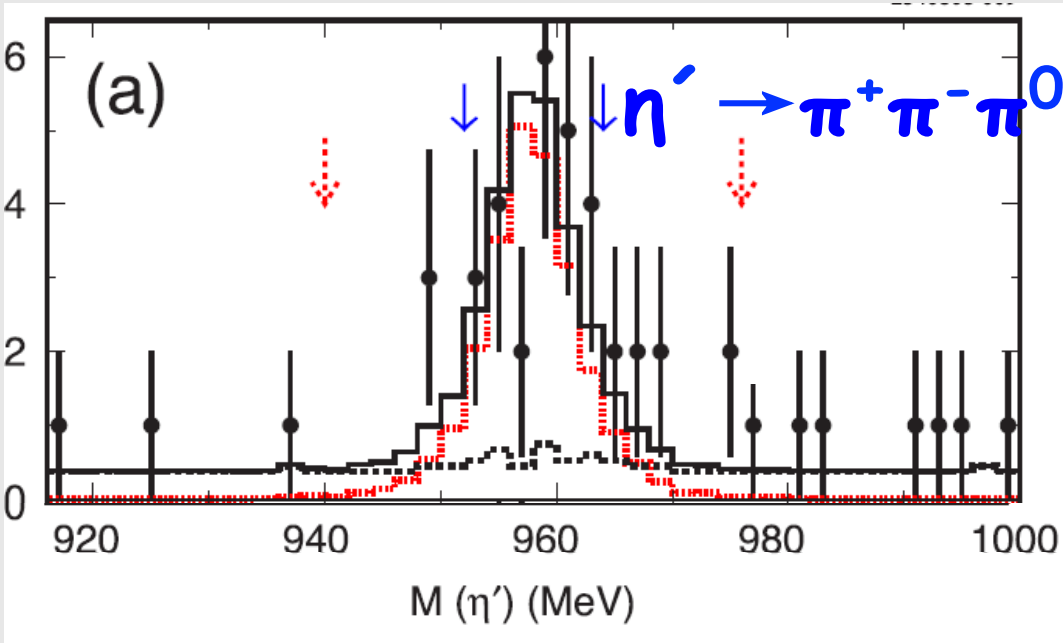
@90% C.L.

BF measurement of $\eta' \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$

- Isospin violating decay modes, related with the mass of light quarks
- Previous measurements are from GAM(S) and CLEOc



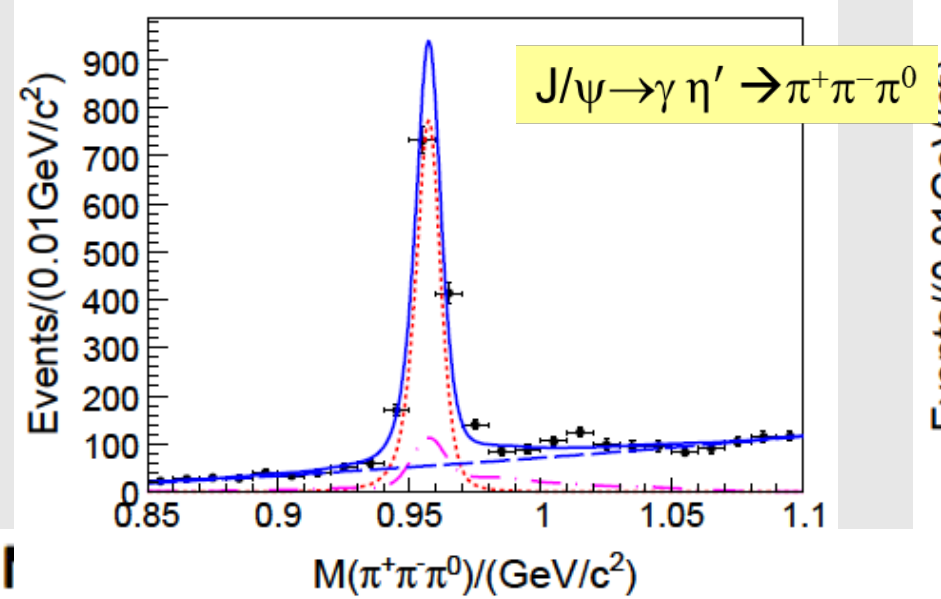
Phys. At.Nucl.71,2124(2008)

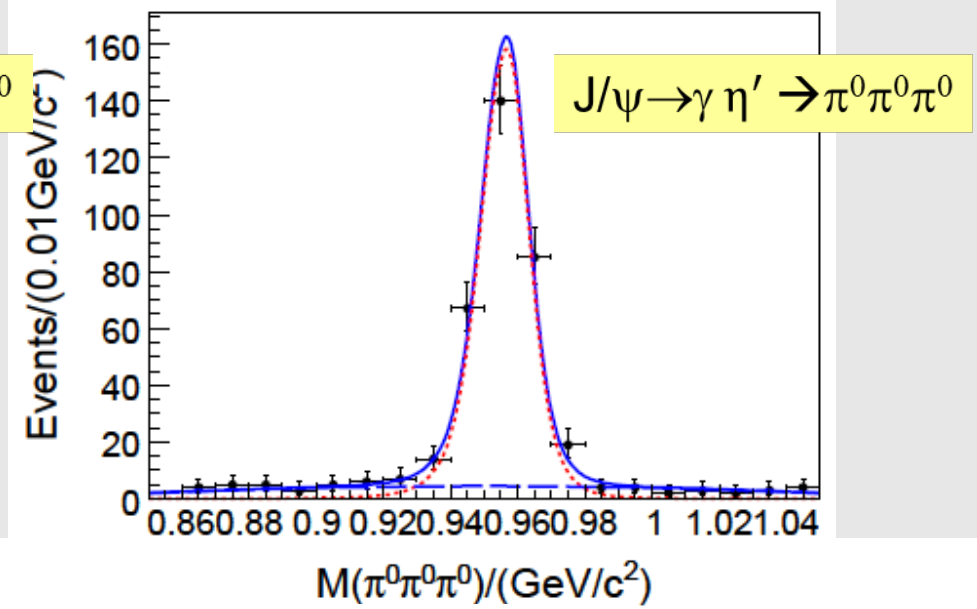


Phys. Rev.Lett.102,061801(2009)

BF measurement of $\eta' \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$

PRL 108, 182001 (2012)





$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$ PDG12: $(3.6^{+1.1}_{-0.9}) \times 10^{-3})$

$Br(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$ PDG12: $(1.68 \pm 0.22) \times 10^{-3})$

For the decay $\eta' \to \pi^0\pi^0\pi^0$, it is two times larger than the world average value.

Comparison: Isospin violations in $\eta' \to \pi\pi\pi$:

$$\frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} \approx 0.9\%, \quad \frac{BR(\eta' \to \pi^0\pi^0\pi^0)}{BR(\eta' \to \pi^0\pi^0\eta)} \approx 1.6\%$$

BF measurement of $\eta' \to \pi^+\pi^-e^+e^-, \pi^+\pi^-\mu^+\mu^-$

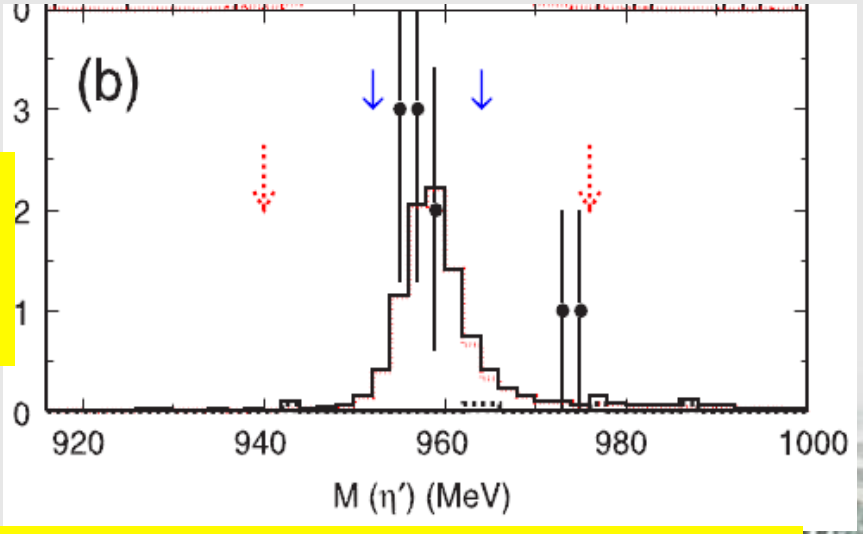
- **Theoretical predictions**

Decay	Effective meson theory PRC 61,0305206(2000)	Chiral Unitary EPJA33,95(2007)
$B(\eta' \to \pi^+\pi^-e^+e^-)$	1.8×10^{-3}	$(2.13^{+0.19}_{-0.32}) \times10^{-3}$
$B(\eta' \to \pi^+\pi^-\mu^+\mu^-)$	2.0×10^{-5}	$(1.57^{+0.96}_{-0.75}) \times10^{-5}$

- **$\eta' \to \pi^+\pi^-e^+e^-$ was first observed by CLEOc**

$B(\eta' \to \pi^+\pi^-e^+e^-)=(2.5^{+1.2}_{-0.9} \pm0.5) \times10^{-3}$

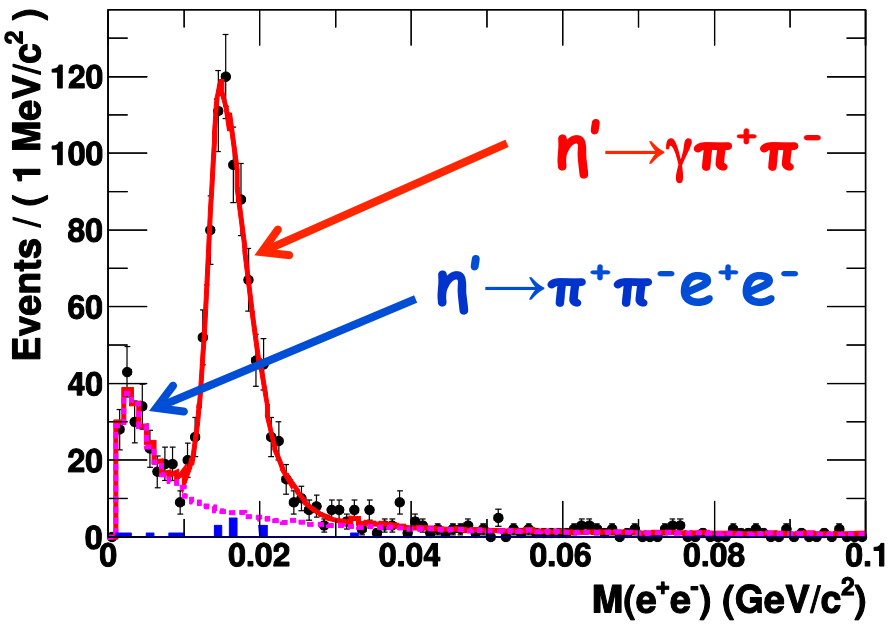
$B(\eta' \to \pi^+\pi^-\mu^+\mu^-)< 2.4\times10^{-4}$ @90%C.L.

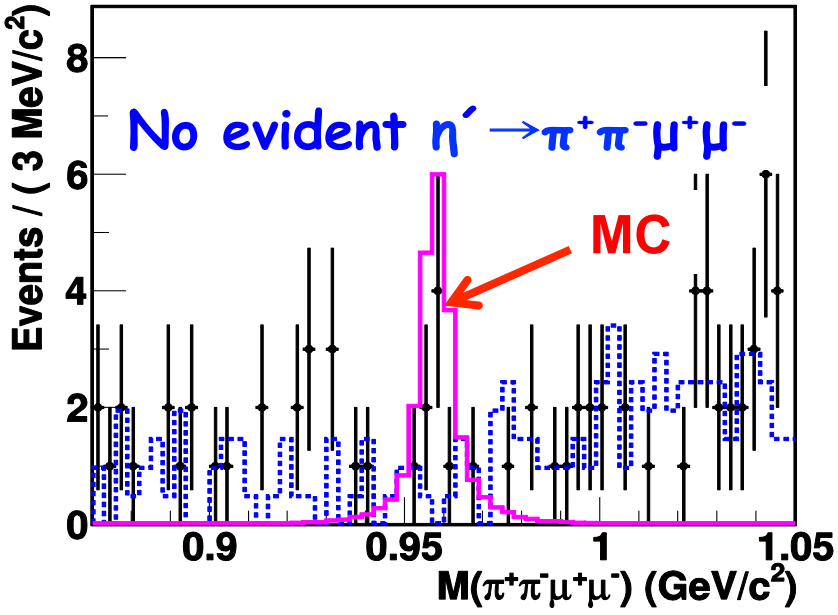


Phys. Rev.Lett.102,061801(2009)

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

Phys. Rev. D87, 092011 (2013)





$B(\eta' \to \pi^+\pi^- e^+ e^-) = (2.11 \pm 0.12 \pm 0.15) \times 10^{-3}$

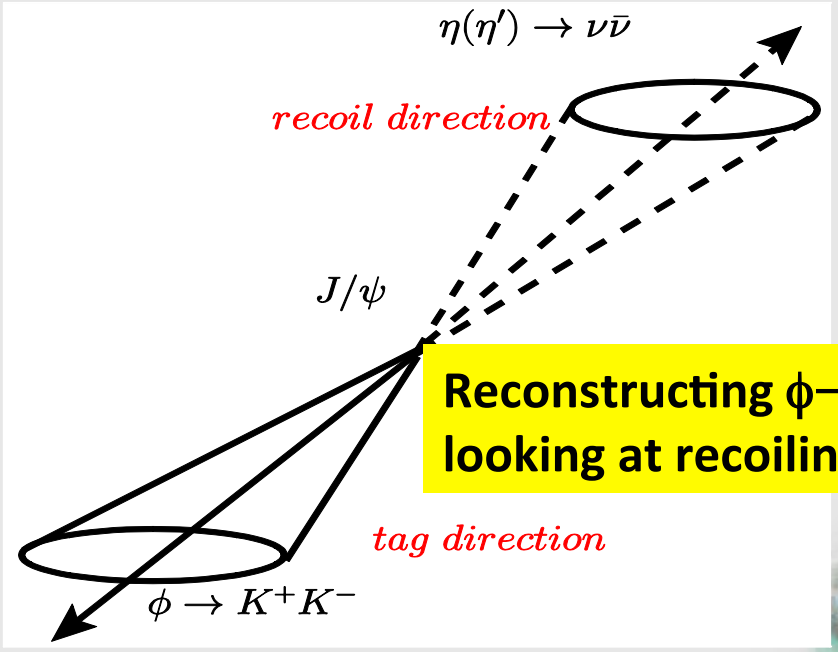
$B(\eta' \to \pi^+\pi^- \mu^+ \mu^-) < 2.9 \times 10^{-5}$ @90%C.L.

$B(\eta' \to \pi^+\pi^- e^+ e^-) = (2.5^{+1.2}_{-0.9} \pm 0.5) \times 10^{-3}$ (CLEOc)

$B(\eta' \to \pi^+\pi^- \mu^+ \mu^-) < 2.4 \times 10^{-4}$ @90%C.L. (CLEOc)

Search for $\eta/\eta' \to$ invisible in $J/\psi \to \phi\eta/\eta'$

- offer a window for physics beyond the standard model
- observation of the invisible final states (may) provides information of light dark matter
- easy to tag with $J/\psi \to \phi\eta/\eta'$: two body decays; ϕ's width is quite narrow



Reconstructing $\phi \to K^+K^-$ and looking at recoiling mass of ϕ

$B(\eta' \to \text{invisible}) < 1.4 \times 10^{-3}$

$B(\eta \to \text{invisible}) < 6.0 \times 10^{-4}$

@ 90% C.L.

BESII result: PRL 97, 202002 (2006)

Search for $\eta/\eta' \to$ invisible in $J/\psi \to \phi\eta/\eta'$

Phys. Rev. D87, 032006 (2013)

$B(\eta \to \text{invisible})/B(\eta \to \gamma\gamma) < 2.6 \times 10^{-4}$

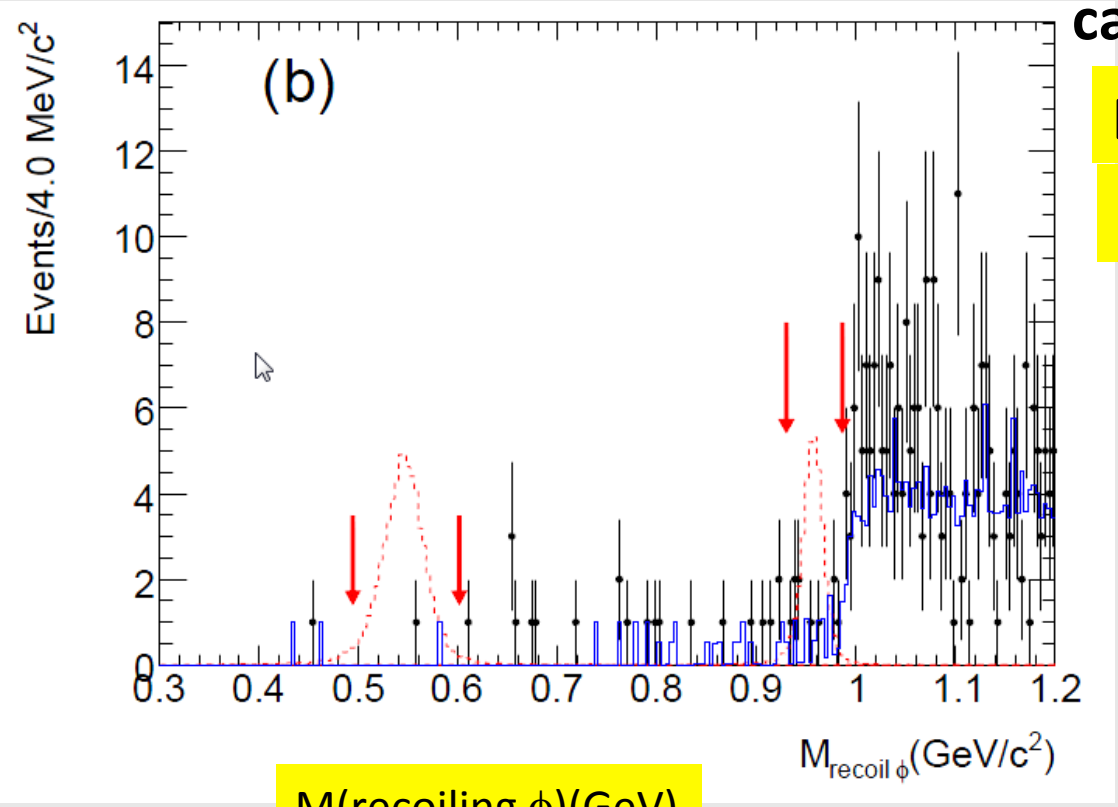
$B(\eta' \to \text{invisible})/B(\eta' \to \gamma\gamma) < 2.4 \times 10^{-2}$

@90%C.L.

Many uncertainty related to tag side and Detector noise cancelled in the ratio

$B(\eta \to \text{invisible}) < 1.0 \times 10^{-4}$

$B(\eta' \to \text{invisible}) < 5.3 \times 10^{-4}$



M(recoiling ϕ)(GeV)

Theory:
B. McElrath PRD 72, 103508(2005)

$BR(\eta \to \chi\chi) \sim 7.4 \times 10^{-5}$

$BR(\eta' \to \chi\chi) \sim 8.1 \times 10^{-7}$

Search for weak decays of η/η'

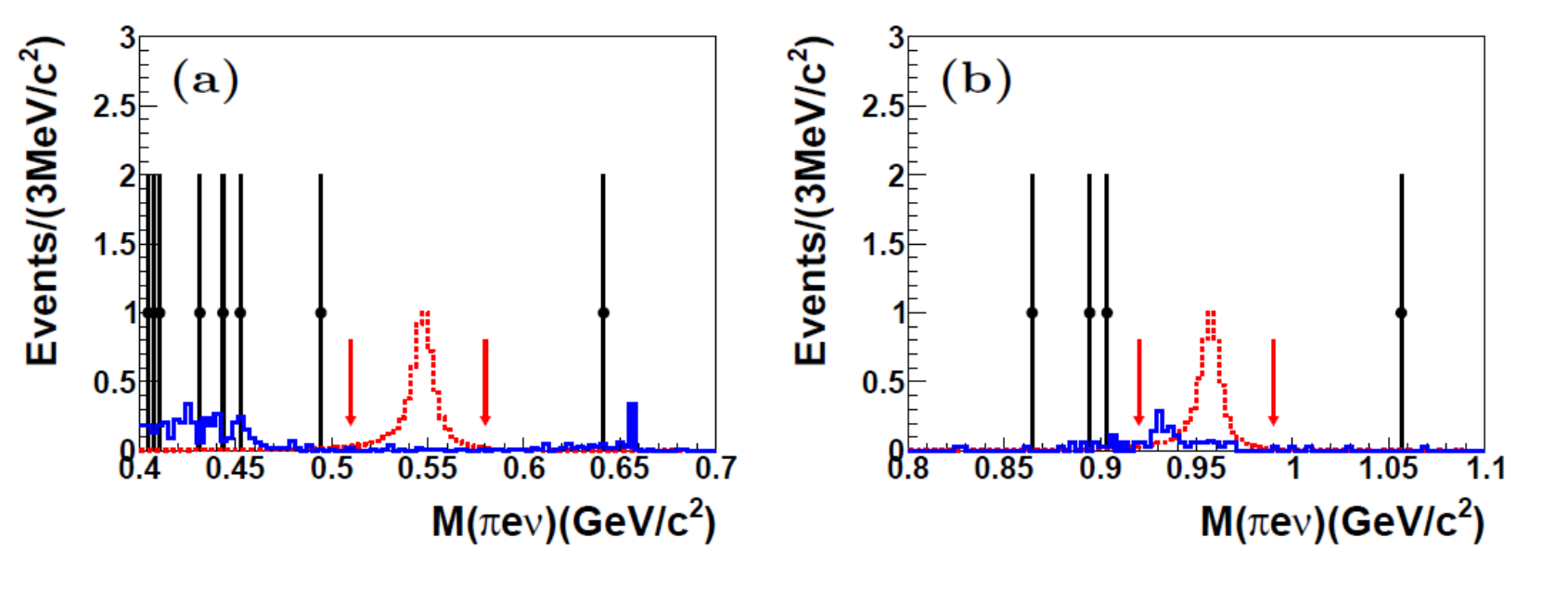
Phys. Rev. D87, 032006 (2013)

- within SM : $B(\eta \to \pi^- e^+ \nu + c.c.) \sim 2 \times 10^{-13}$

  H. Neufeld and H. Rupertsberger, Z. Phys. C 68, 91 (1995)

- by considering scalar or vector type interactions:

$B(\eta \to \pi^- e^+ \nu + c.c.) \sim 10^{-8} - 10^{-9}$ P. Herczeg, Prog. Part. Nucl. Phys. 46, 413 (2001)



$B(\eta \to \pi^- e^+ \nu + c.c.) < 1.7 \times 10^{-4}$
$B(\eta' \to \pi^- e^+ \nu + c.c.) < 2.2 \times 10^{-4}$ @90%C.L.

Summary & Perspective

- η/η' decays: a rich physics field
- Recent results from BESIII are presented
  - $\eta' \to \pi^+\pi^-\eta$,
  - $\eta\ (\eta') \to \pi^+\pi^-, \pi^0\pi^0$,
  - $\eta' \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$
  - $\eta' \to \pi^+\pi^- l^+ l^-$
  - invisible & weak decays
- ~1 billion J/ψ events were taken last year

Summary & Perspective

- plan to update the study of η' decays
  - Study dynamics of $\eta/\eta' \to \gamma\pi^+\pi^-$
  - Dalitz plot of $\eta' \to \pi^+\pi^-\eta$,
  - Dalitz plot of $\eta/\eta' \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$
  - Search for η´ new decay modes (4π, $\gamma\gamma\pi^0$ …)
  - Test of C,P or CP violations
  - ……
- η decays: complementary to other experiments
- more results are expected to come soon !

Thanks for you attention