η and η' physics at BESIII

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(for the BESIII Collaboration)
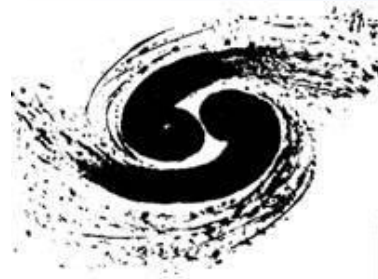
Institute of High Energy Physics

OUTLINE

Introduction

Discovered about 50 years ago
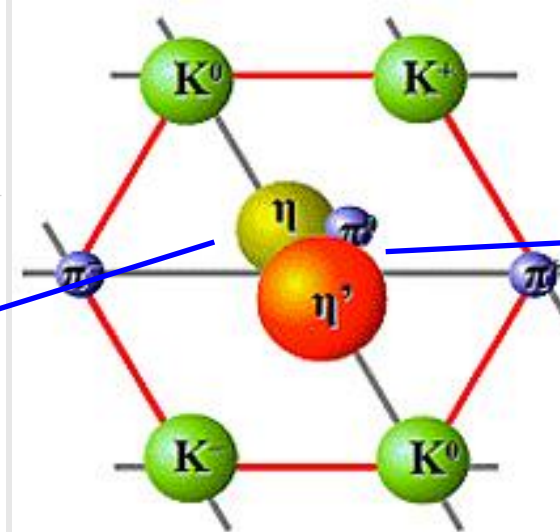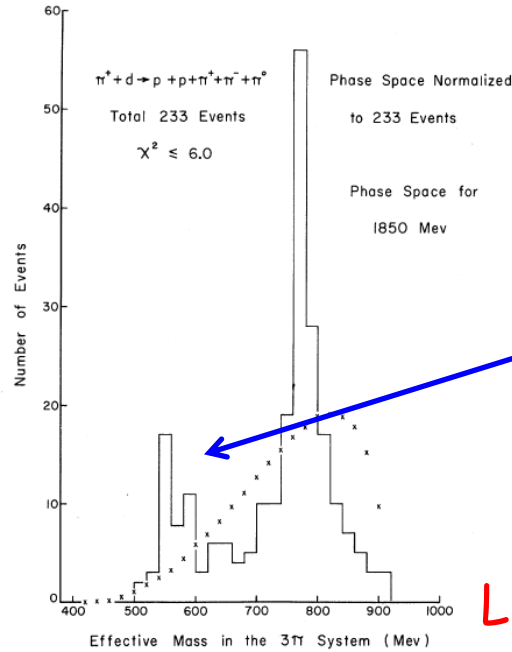
Lightest pseudoscalar nonet
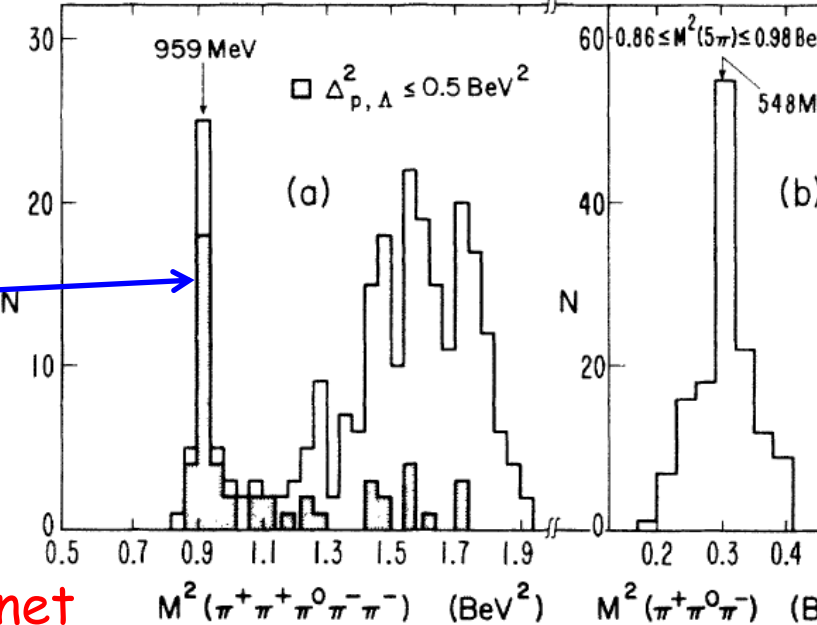
- Dominant decay modes were observed

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

INTRODUCTION

- Still listed in many facilities' physics program
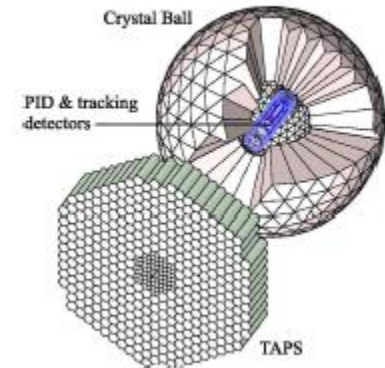(KLOE, WASA-at-COSY, CB at MAMI, GlueX,BESIII …)
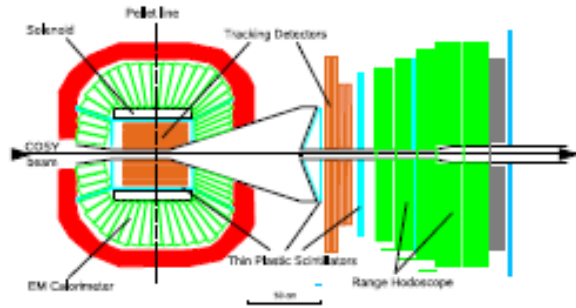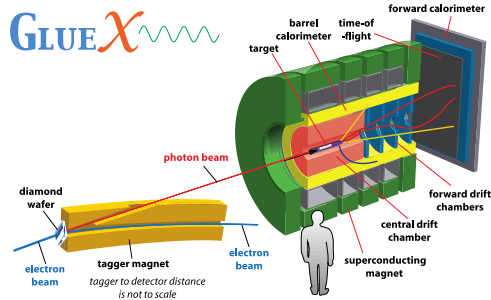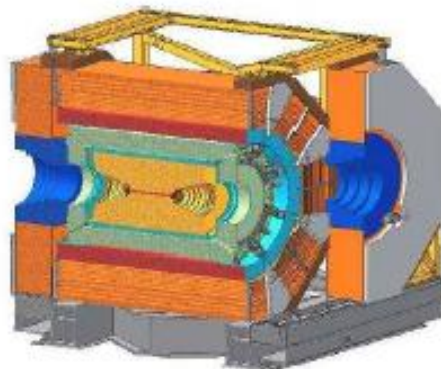
INTRODUCTION

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

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

Bird view of BEPCII /BESIII
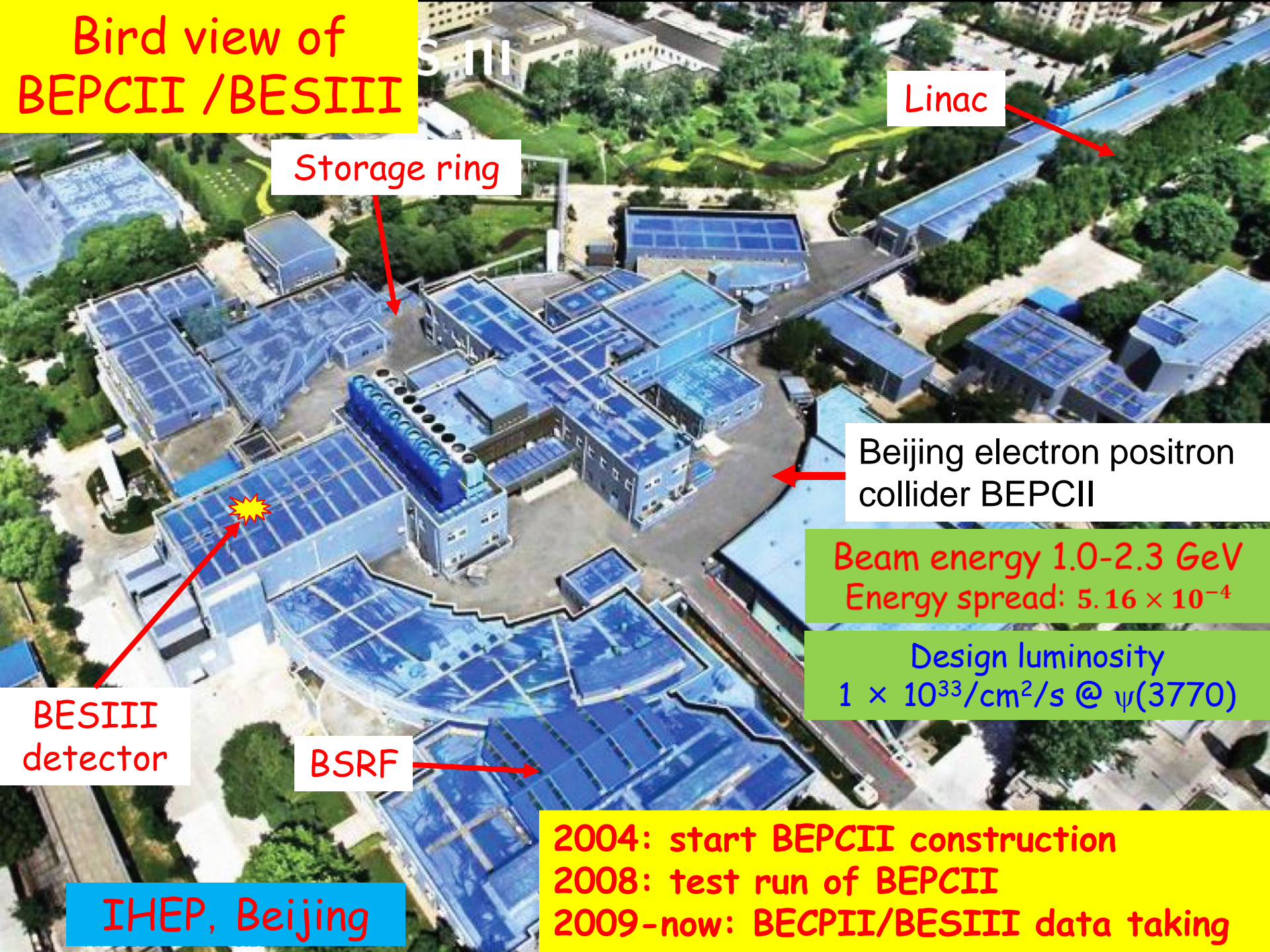
Linac

Storage ring

Beijing electron positron collider BEPCII

Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}

Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$

BESIII detector

BSRF

IHEP, Beijing

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

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)
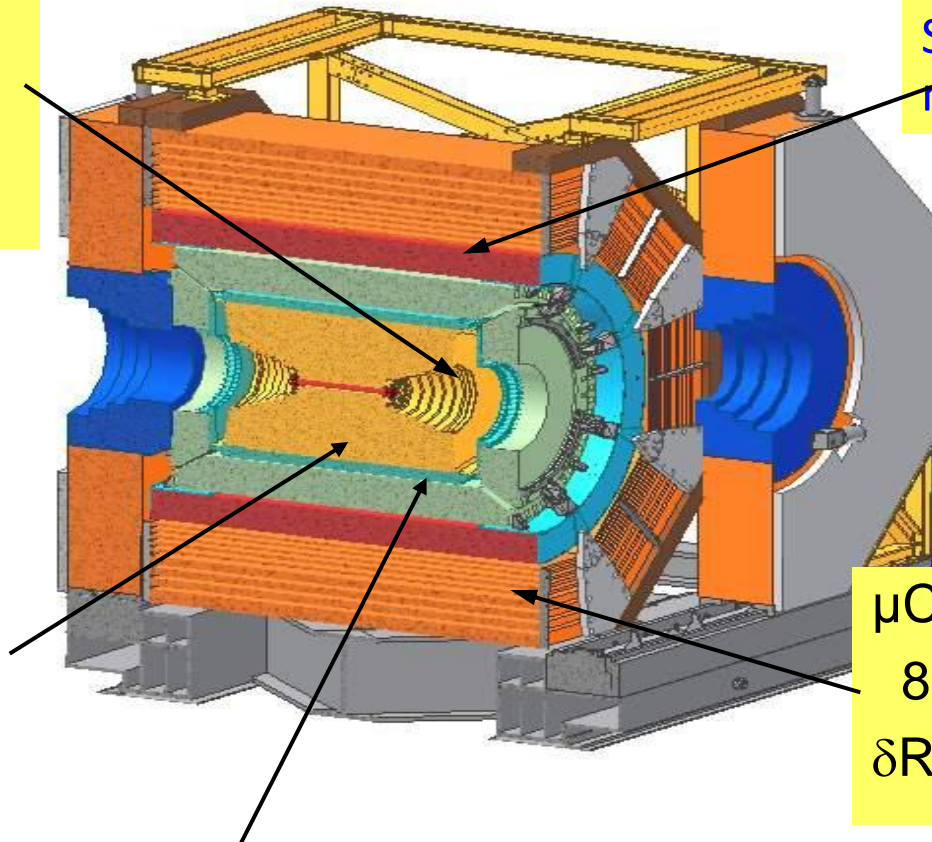
Time Of Flight (TOF)

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 and η′ events at BESIII

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

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

- **η and η′ production in J/ψ decays**
  - BF(J/ψ →γη)~1.1×10^{-3} → 2.3×10^{5} η events
  - BF(J/ψ →γη′)~5.3×10^{-3} → 1.2×10^{6} η′ events
  - BF(J/ψ →φη)~7.5×10^{-4} → 1.7×10^{5} η events
  - BF(J/ψ →φη′)~4.0×10^{-4} → 0.9×10^{5} η′ 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 and weak decays**

- **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

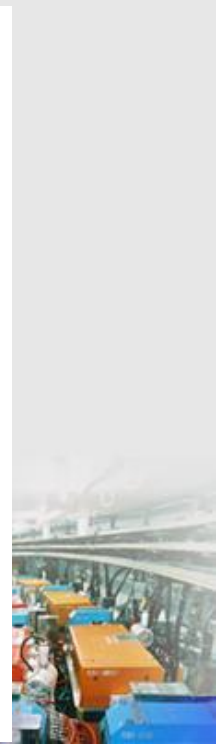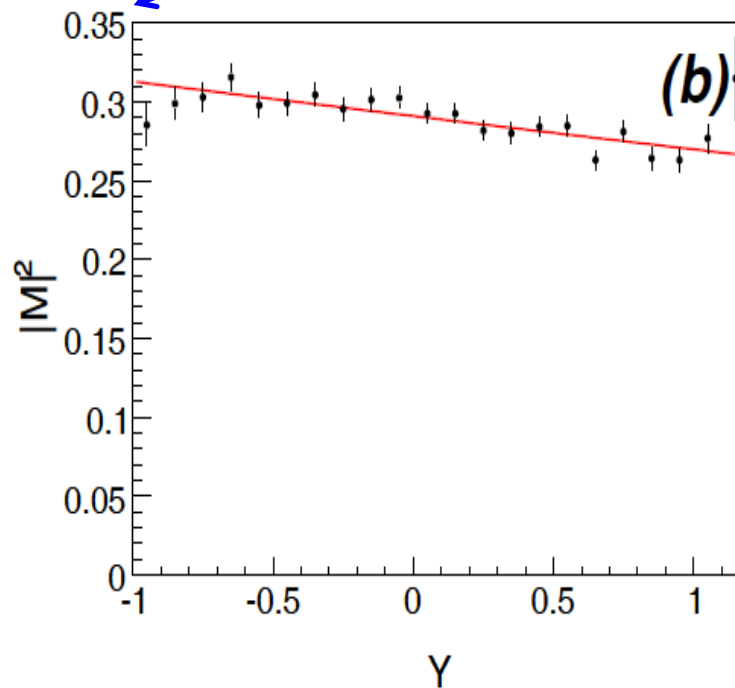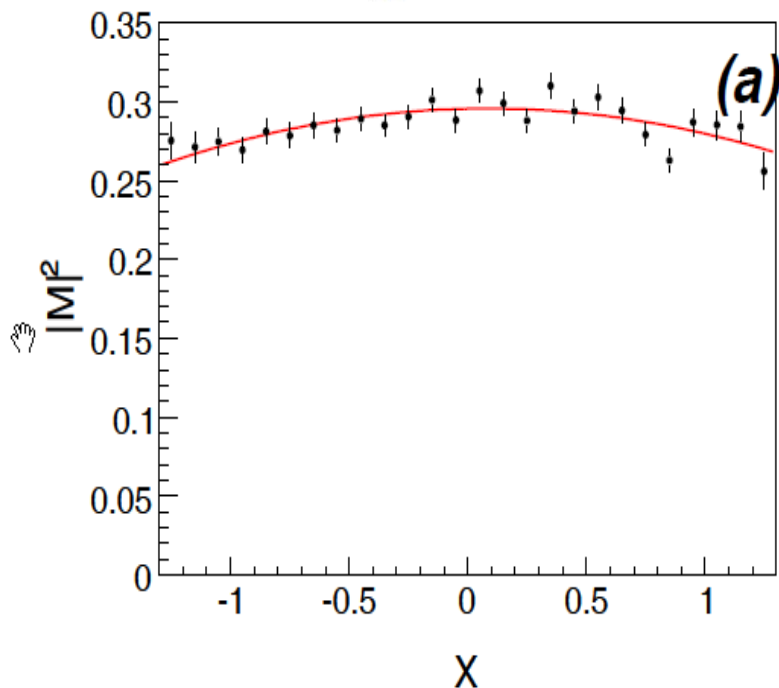$$Q = T_\eta + T_{\pi+} + T_{\pi-} = m_{\eta'} - m_\eta - 2m_\pi$$
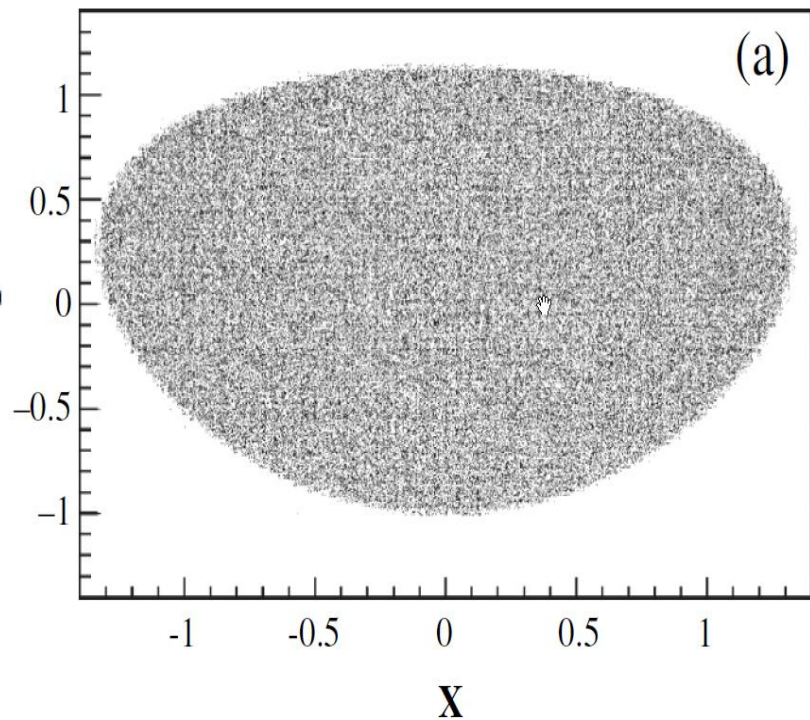
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Flat, seems no dynamics is involved

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]	Theory [26]	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
	-0.015 ± 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]	VES [27]	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

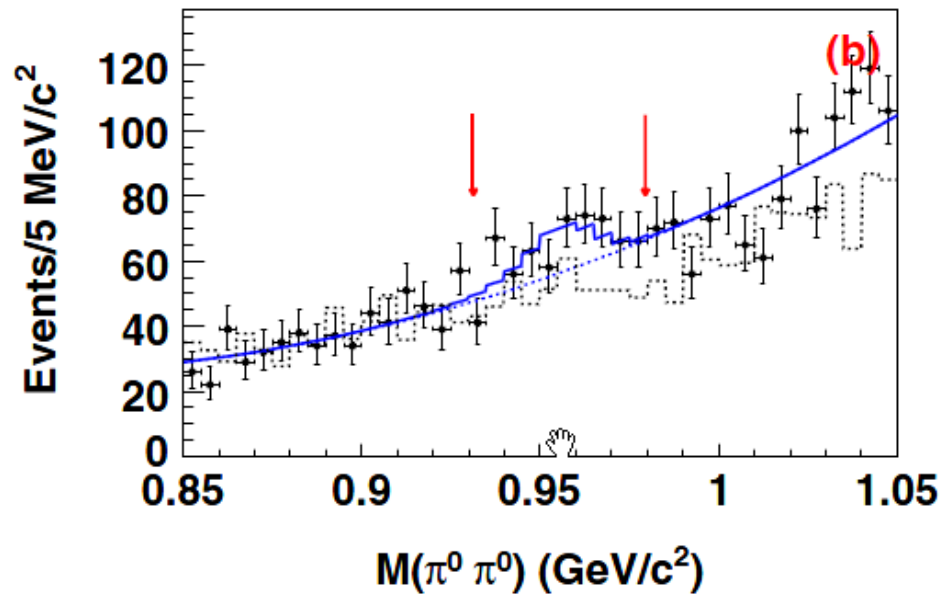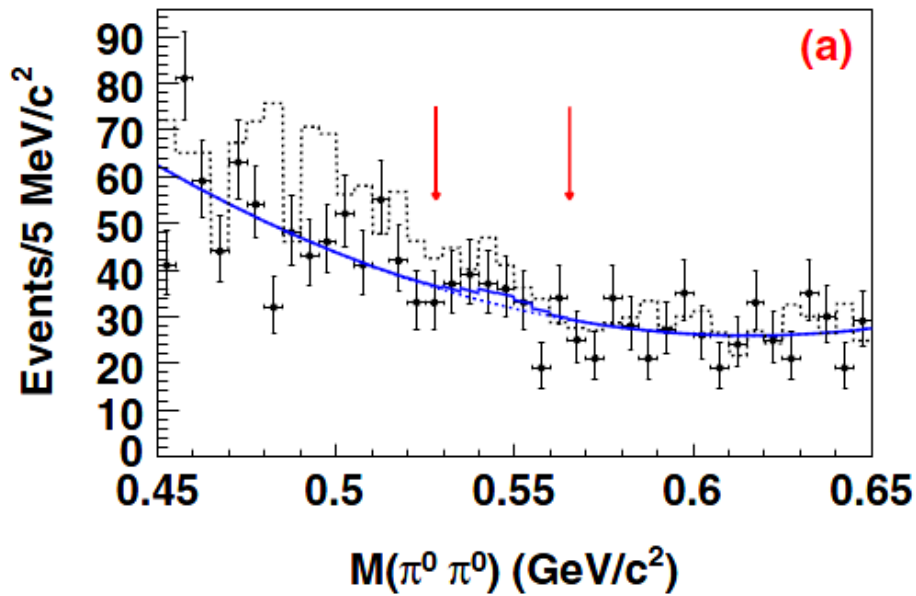● "c", defined for C parity violation, is consistent with zero with 2 standard deviations

Search for CP violation in η/η′ →ππ

- Offer an excellent laboratory for testing P and CP invariance

- Theoretically proceed via the weak interaction at a level of $10^{-15} \sim 10^{-27}$
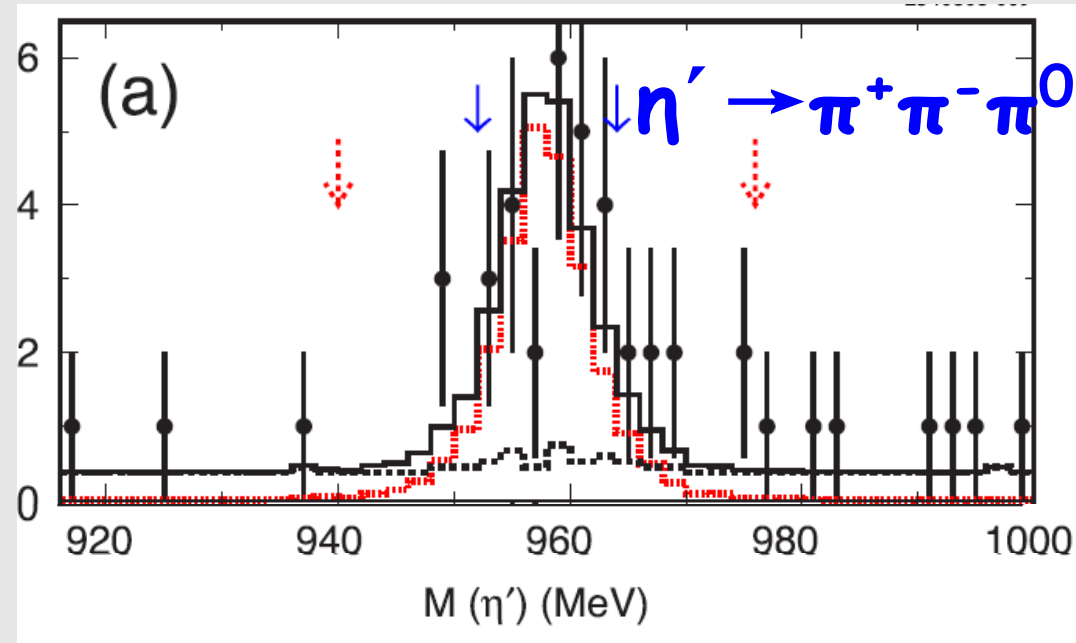
(a)

(b)

M($\pi^0 \pi^0$) (GeV/c^2)
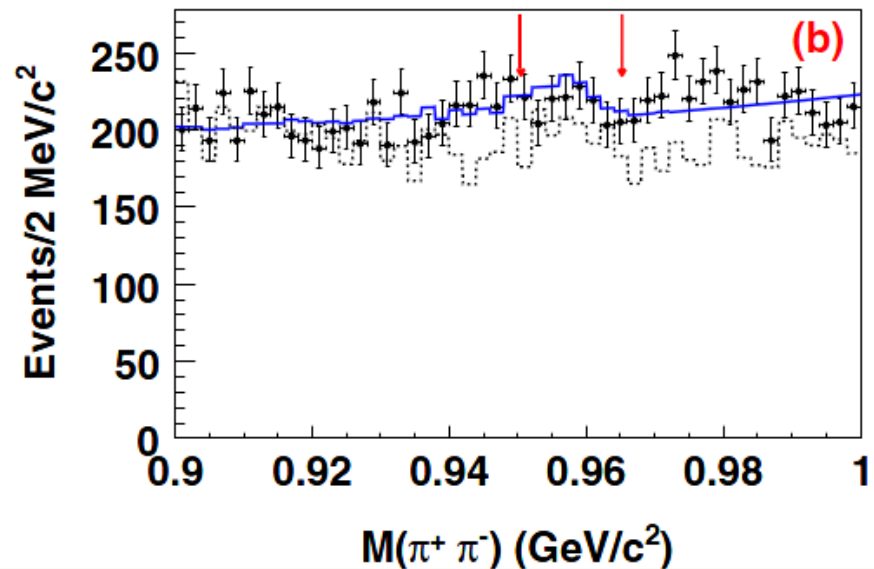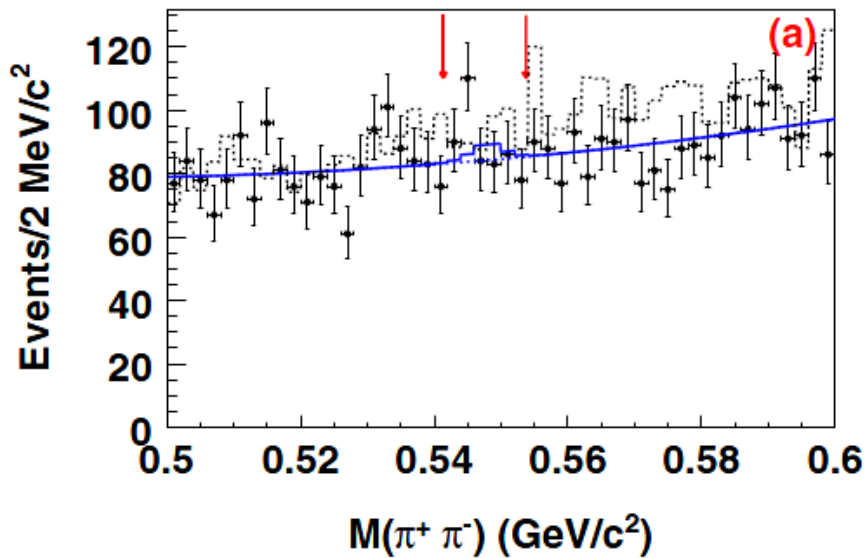
Process	$\mathcal{B}^{\mathrm{UP}}$	$\mathcal{B}^{\mathrm{UP}}_{\mathrm{PDG}}$
$\eta \to \pi^+\pi^-$	3.9×10^{-4}	1.3×10^{-5}
$\eta' \to \pi^+\pi^-$	5.5×10^{-5}	2.9×10^{-3}
$\eta \to \pi^0\pi^0$	6.9×10^{-4}	3.5×10^{-4}
$\eta' \to \pi^0\pi^0$	4.5×10^{-4}	9×10^{-4}

- **Isospin violating decay modes, related with the quarks**
- **Previous measurements are from GAMS and CLEO**

$\eta' \to \pi^0\pi^0\pi^0$
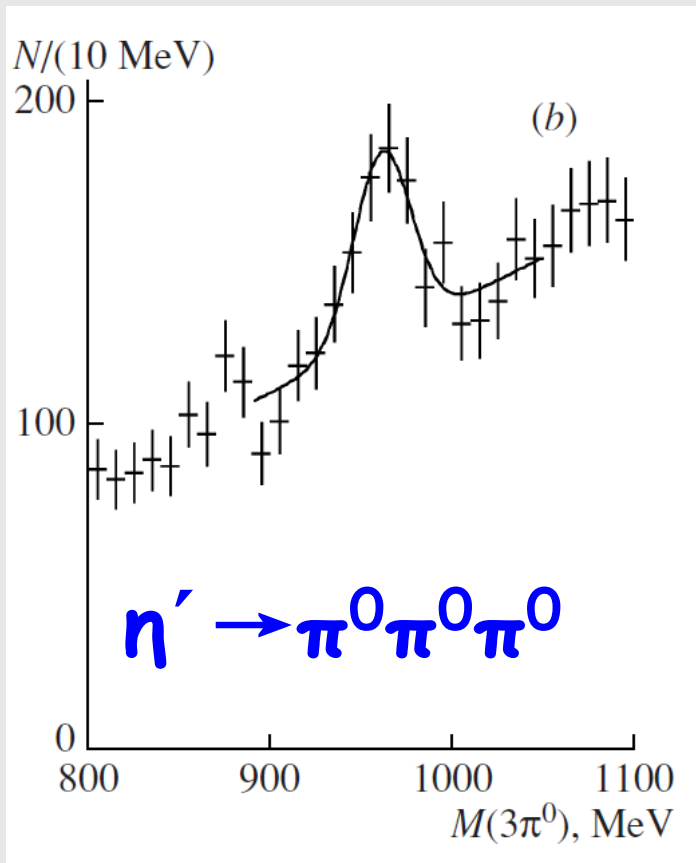
Phys. At.Nucl.71,2124(2008)

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

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

PRL 108, 182001 (2012)
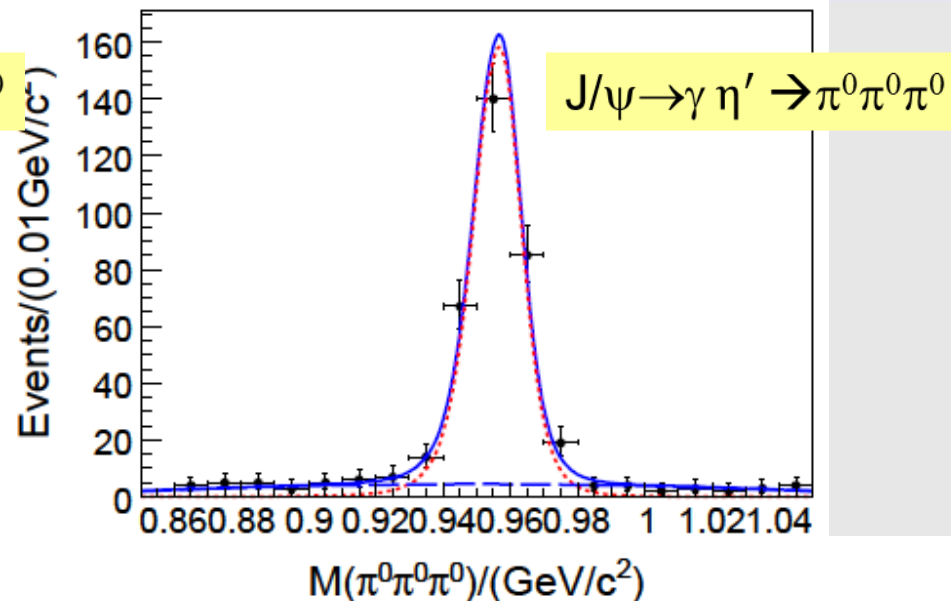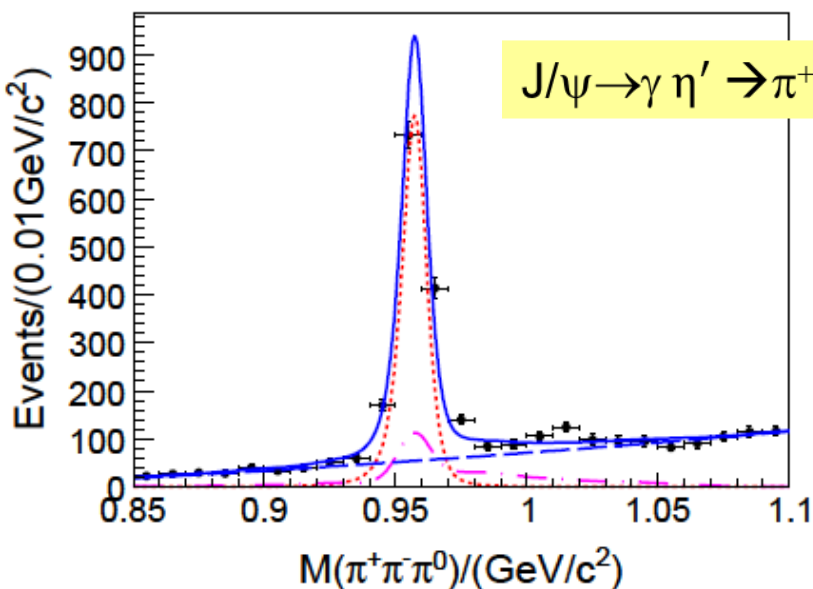
$$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3} \quad (\text{PDG2010}: (3.6^{+1.1}_{-0.93}) \times 10^{-3})$$

$$Br(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3} \quad (\text{PDG2010}: (1.68 \pm 0.22) \times 10^{-3})$$

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 η'→ππ :

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

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Search for η/η′→invisible in J/ψ→ϕη/η′

- **offer a window for beyond the standard model**
- **observation of the invisible final states provides information of light dark matter**
- **easy to tag with J/ψ→ϕη/η′ : two body decays; ϕ's width is quite narrow**

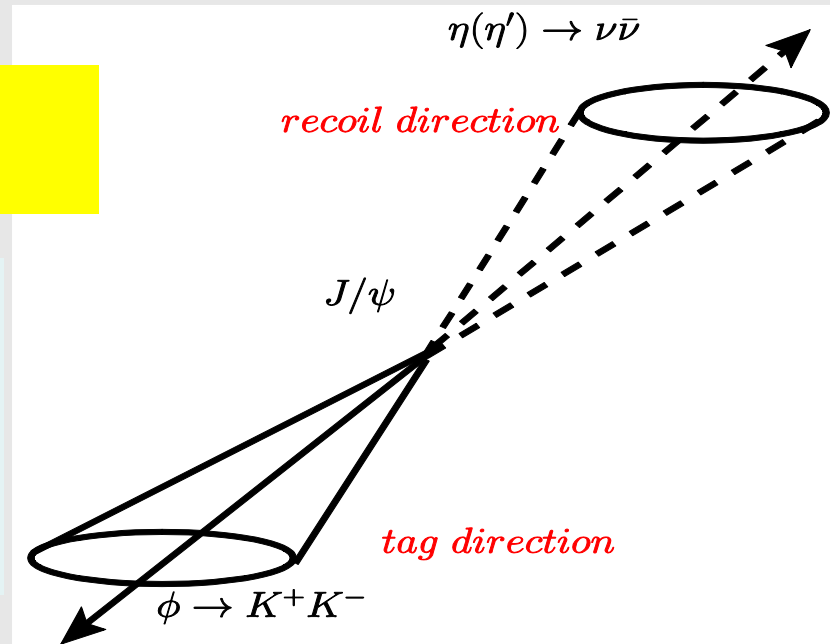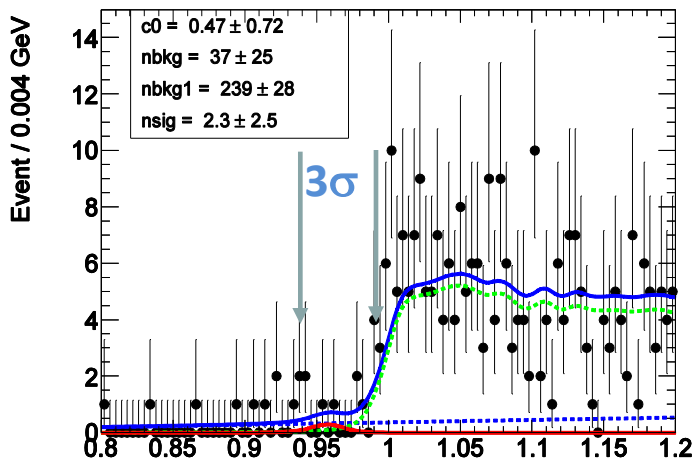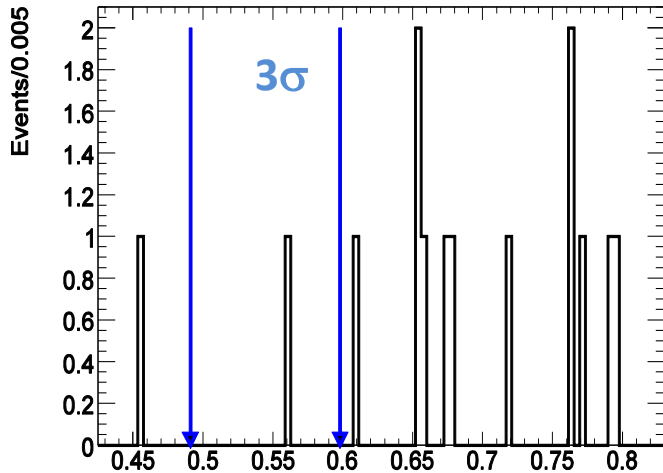**Reconstructing ϕ→K⁺K⁻ and looking at recoiling mass of ϕ**

Theoretical predictions:
B. McElrath PRD 72, 103508(2005)

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

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

$\eta(\eta') \to \nu\bar{\nu}$

recoil direction

J/ψ

tag direction

$\phi \to K^+ K^-$

Search for η/η′→invisible in J/ψ→ϕη/η′ (Preliminary results)

M(recoiling ϕ)(GeV)

BESIII Preliminary Result

η→Invisible
N^{up} = 4.36   90%C.L.(Feldman-Cousins)

An Unbinned extended Maximum Likelihood fit

PDF = N_{sig}×**PDF$_{sig}$**+ N_{bkg1}×**PDF$_{bkg1}$** + N_{bkg}×**PDF$_{bkg}$**

PDF$_{sig}$:   shape of J/ψ→ϕη′(π⁻π⁺η) from data

PDF$_{bkg1}$: shape of J/ψ→ϕf$_0$(980)(K$_L$K$_L$) from MC

PDF$_{bkg}$:   1st chebychev poly.

η′→Invisible
N^{up} = 10.1   90%C.L.(Bayesian)

Search for $\eta/\eta' \rightarrow$ invisible in $J/\psi \rightarrow \phi\eta/\eta'$ (Preliminary results)

$B(\eta' \rightarrow \text{invisible})/B(\eta' \rightarrow \gamma\gamma) < 2.39 \times 10^{-2}$ @ 90% C.L.

$B(\eta \rightarrow \text{invisible})/B(\eta \rightarrow \gamma\gamma) < 3.37 \times 10^{-4}$ @ 90% C.L.

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

$B(\eta' \rightarrow \text{invisible}) < 5.31 \times 10^{-4}$ @ 90% C.L.

$B(\eta \rightarrow \text{invisible}) < 1.32 \times 10^{-4}$ @ 90% C.L.

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

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

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

$B(\eta' \rightarrow \text{invisible}) < 1.4 \times 10^{-3}$ @ 90% C.L.

$B(\eta \rightarrow \text{invisible}) < 6.0 \times 10^{-4}$ @ 90% C.L.

BESII result:
PRL 97, 202002 (2006)

BF measurement of η′→π⁺π⁻e⁺e⁻,π⁺π⁻μ⁺μ⁻

- **Theoretical predictions**

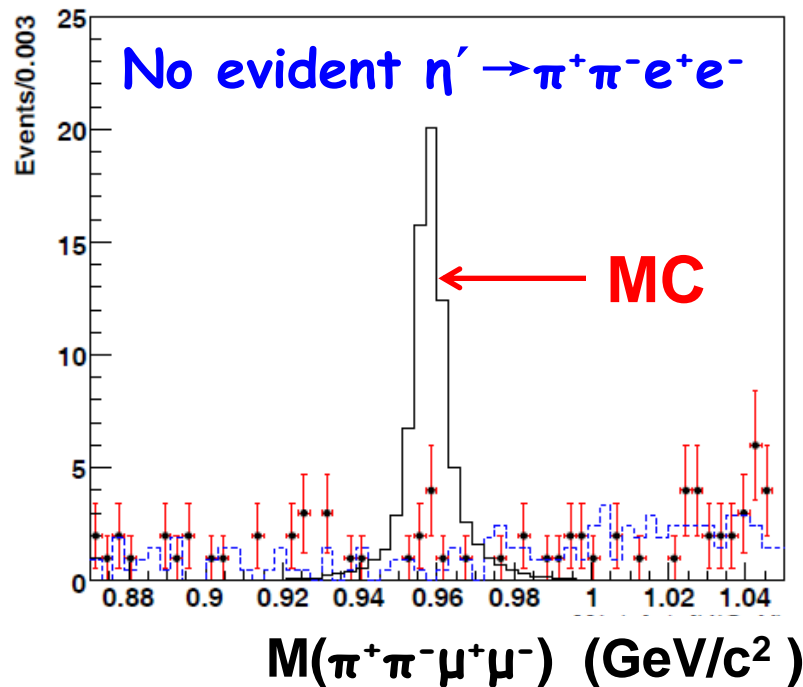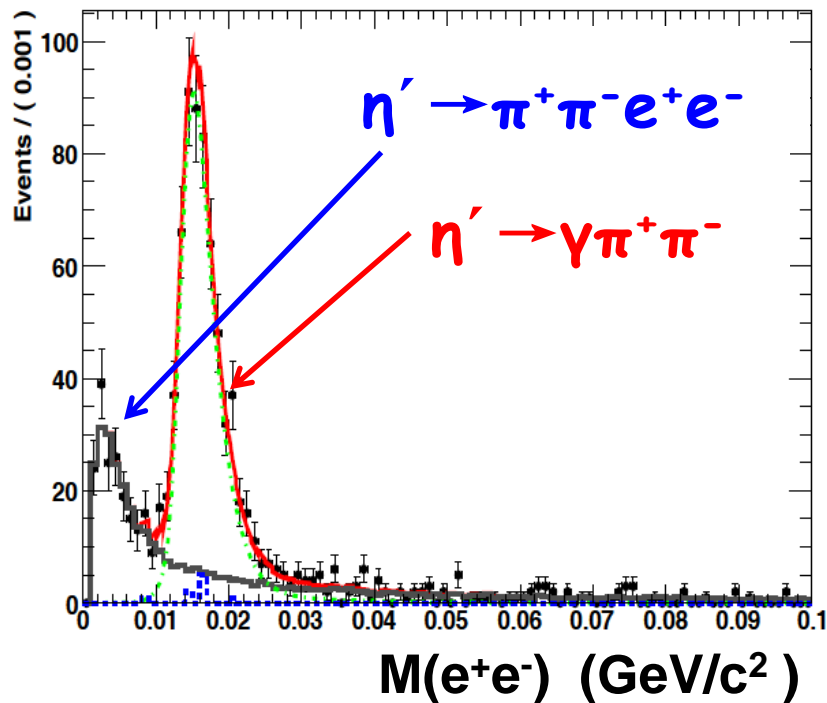| Decay	Effective meson theory PRC 61,0305206(2000)	Chiral Unitary EPJA33,95(2007)
$B(\eta' \to \pi^+\pi^- e^+e^-)$	1.8×10^{-3}	$(2.13^{+0.19}_{-0.32}) \times 10^{-3}$
$B(\eta' \to \pi^+\pi^- \mu^+\mu^-)$	2.0×10^{-4}	$(1.57^{+0.96}_{-0.75}) \times 10^{-3}$

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

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

$B(\eta' \to \pi^+\pi^- \mu^+\mu^-) < 2.4 \times 10^{-4}$ @90%C.L.
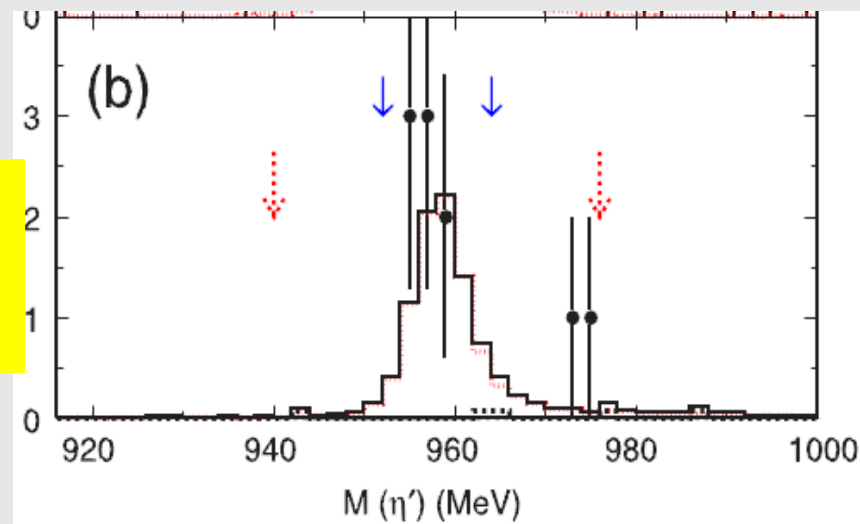
Phys. Rev.Lett.102,061801(2009)

BF measurement of η′→π⁺π⁻e⁺e⁻,π⁺π⁻µ⁺µ⁻ （Preliminary results）

η′→π⁺π⁻e⁺e⁻

η′→γπ⁺π⁻

M(e⁺e⁻) (GeV/c²)

No evident η′→π⁺π⁻e⁺e⁻

MC

M(π⁺π⁻µ⁺µ⁻) (GeV/c²)

$B(η′→π⁺π⁻e⁺e⁻)=(2.13±0.13) ×10^{-3}$
$B(η′→π⁺π⁻µ⁺µ⁻)< 2.65×10^{-5}$ @90%C.L.

in good agreement with predictions and previous measurements

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Summary

■ η/η′: a rich physics field

■ Recent results from BESIII are presented

- η′ → π+π-η
- η (η′) → π+π-, π⁰π⁰
- η′ → π+π-π⁰, π⁰π⁰π⁰
- η′ → π+π-e+e-, π+π-μ+μ-
- invisible decays

■ ~1 billion J/ψ events were taken this year

■ more results are expected to come soon !