η and η' physics at BESIII

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OUTLINE

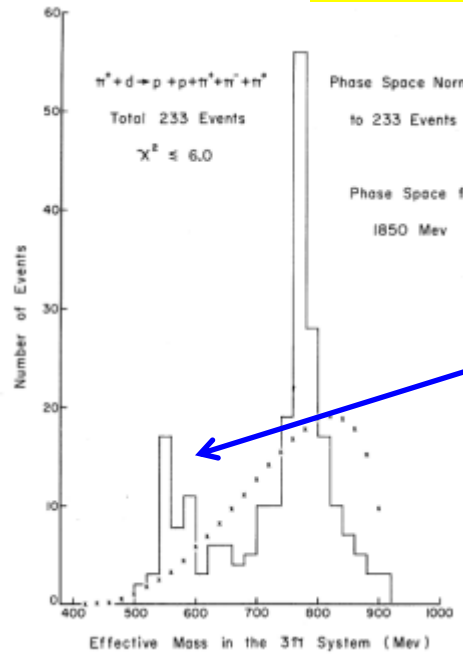
- Introduction
- η/η′ events at BESIII
- Recent results on η/η′ decays
- Summary

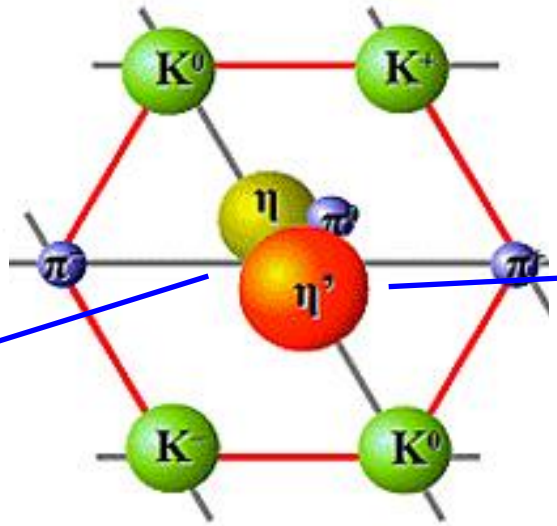
Introduction

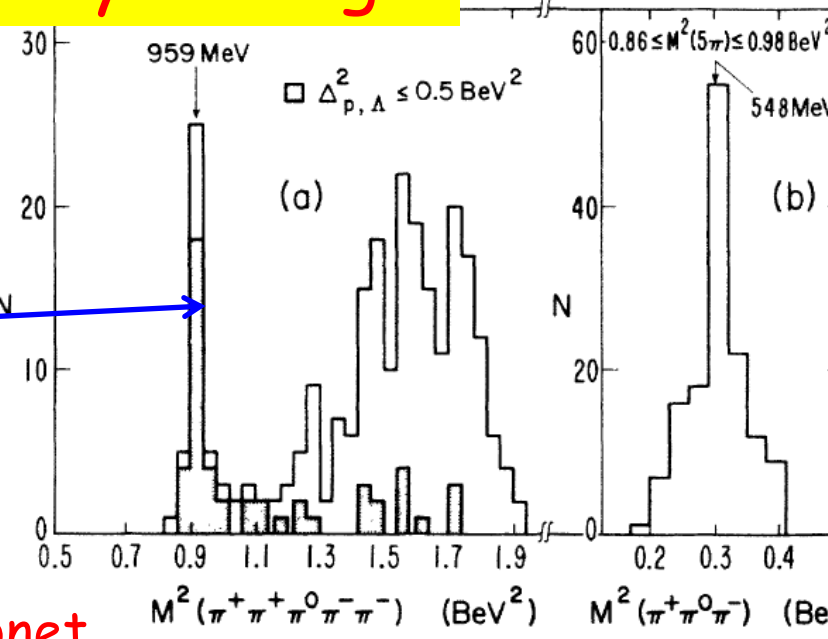
Phys. Rev. Lett. 7,421(1961)

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

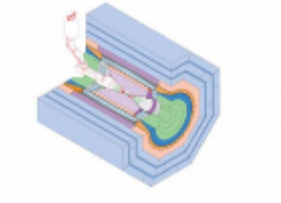
- **η/η′ : a rich physics field**
  - Unique place to test fundamental symmetries in QCD at low energy region
  - Probe physics beyond the Standard Model (SM)

$\eta/\eta' \to 2\gamma$	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
……	

Source of η/η' events

VES

Gams(-4π)



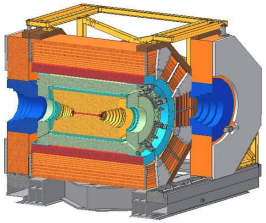
CLEO

CLAS

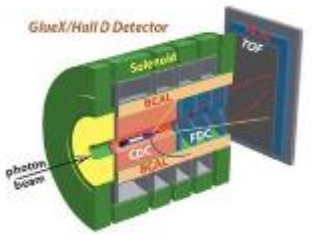
Crystal Ball

WASA-at-COSY

KLOE-2

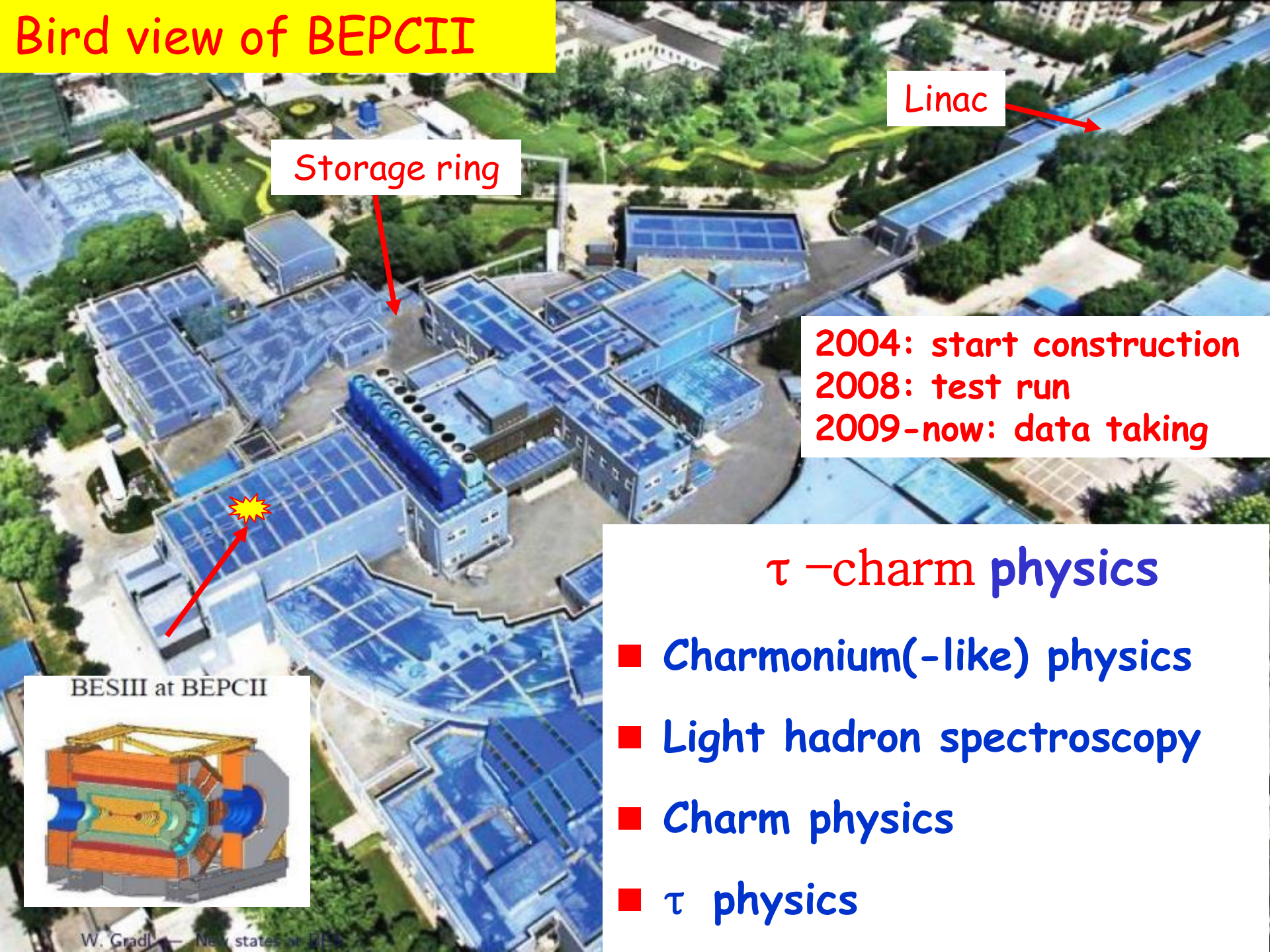


BESIII



GlueX

Bird view of BEPCII



2004: start construction
2008: test run
2009-now: data taking

τ –charm physics

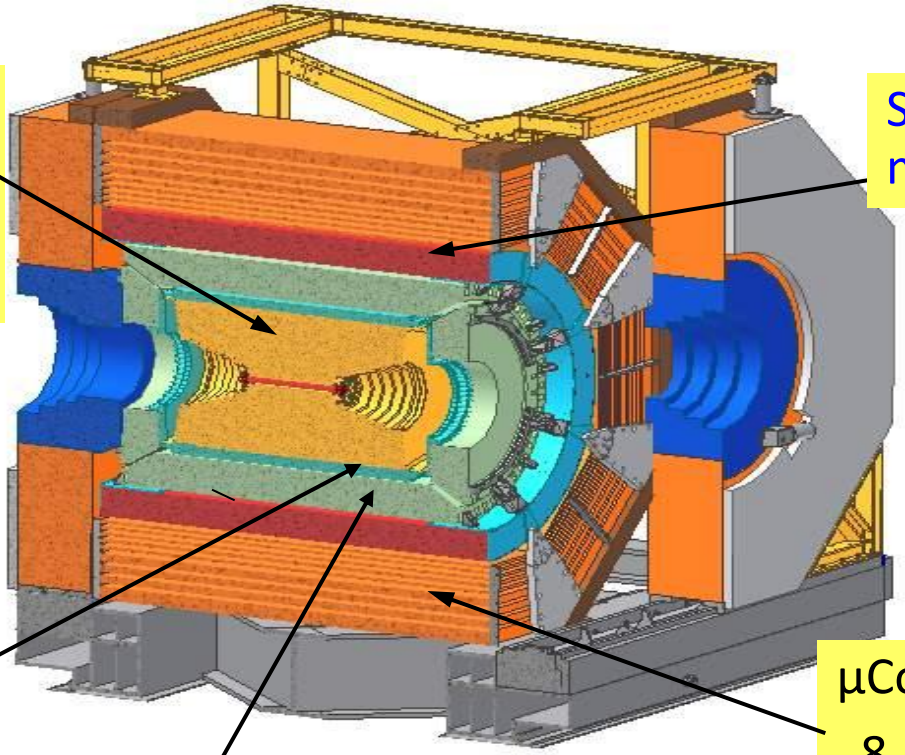
- Charmonium(-like) physics
- Light hadron spectroscopy
- Charm physics
- τ physics

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' events at BESIII

- 1.3×10^9 J/ψ events (2009+2012)
- η/η' from J/ψ radiative decays
  - → 1.4×10^6 η
  - → 6.8×10^6 η'
- η/η' from J/ψ hadronic decays (e.g., $J/\psi\to\phi\eta$)
  - → 5×10^5 η
  - → 3×10^5 η'

Recent results on η/η′ decays

- Hadronic decays
  - $\eta \to \pi^+\pi^-\pi^0$, $\eta/\eta' \to \pi^0\pi^0\pi^0$
  - $\eta' \to \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0$
- Radiative decays
  - $\eta' \to \gamma e^+e^-$
  - $\eta' \to \gamma\gamma\pi^0$ (Prel.)
  - $\eta' \to \gamma\pi^+\pi^-$ (Prel.)

Matrix Element for the Decays $\eta \to \pi^+\pi^-\pi^0$, $\eta/\eta' \to \pi^0\pi^0\pi^0$

arXiv:1506.05360

- Investigate the fundamental symmetries
- Measure the light quark masses difference
- Comparison to the theoretical calculations
- Previous measurements (KLOE, WASA-at-COSY …)

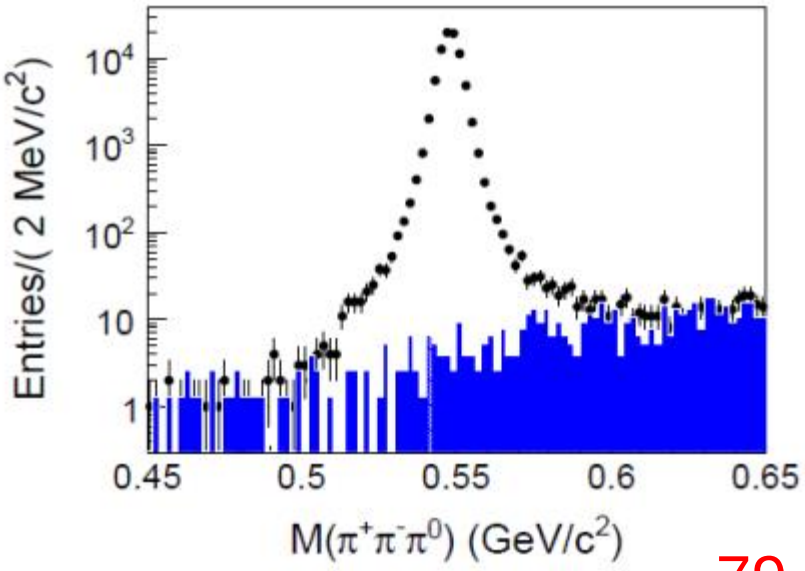
$$X = \frac{\sqrt{3}}{Q}(T_{\pi^+} - T_{\pi^-}) \qquad Y = \frac{3T_{\pi^0}}{Q} - 1,$$

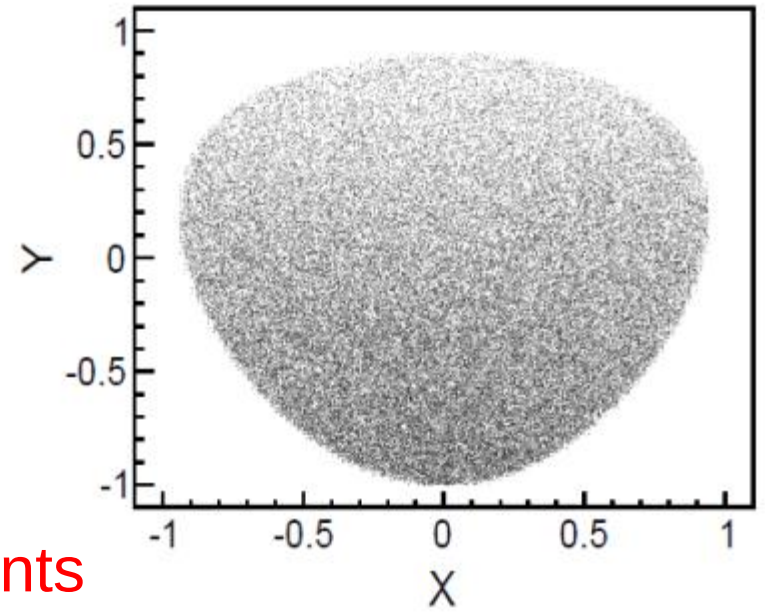
T_π denotes the kinetic energy of a given pion in the η rest frame

$$Q = m_\eta - m_{\pi^+} - m_{\pi^-} - m_{\pi^0}$$

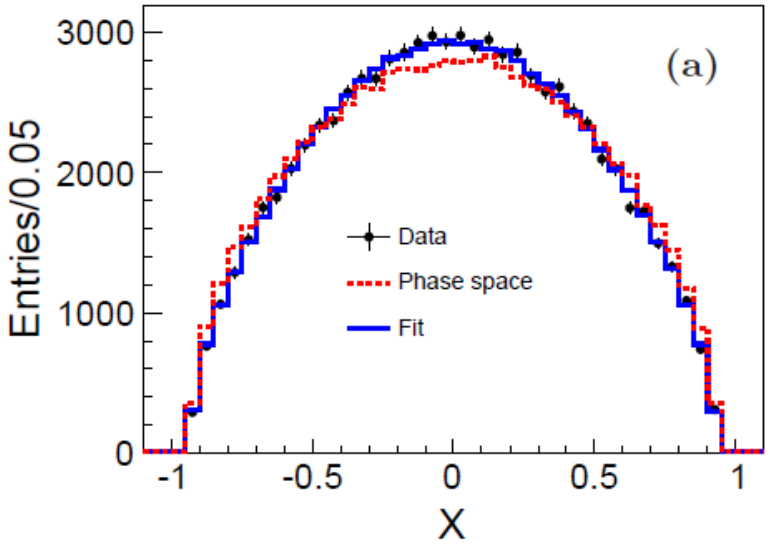
$$|A(X,Y)|^2 = N(1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + \ldots),$$

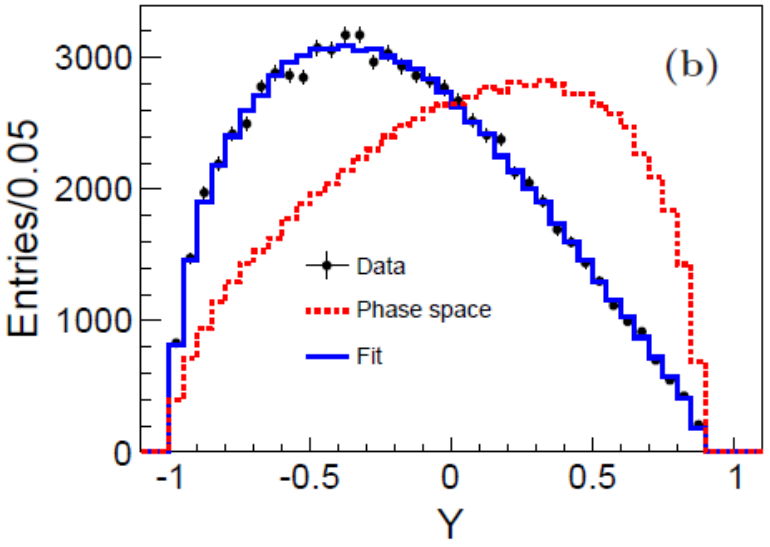
$\eta \to \pi^+\pi^-\pi^0$





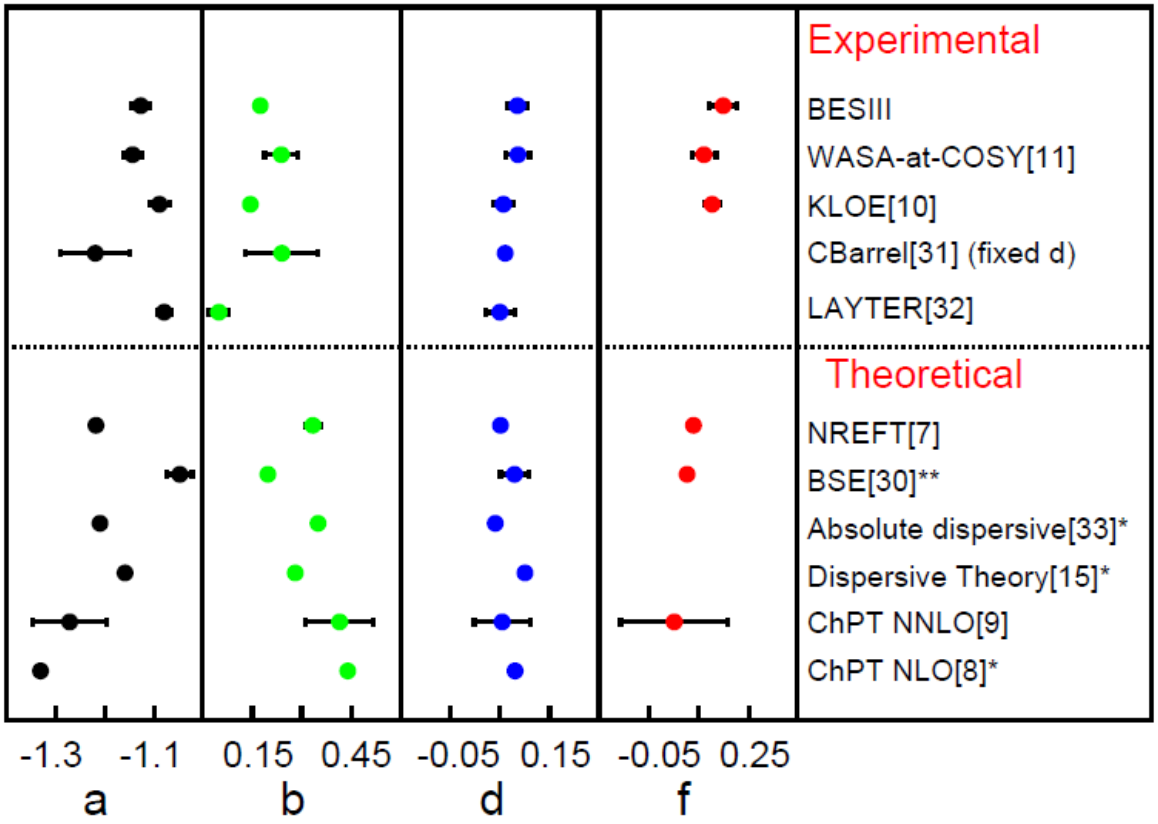
79,625 events





Comparison to experimental and theoretical results

$$
\begin{aligned}
a &= -1.128 \pm 0.015 \pm 0.008 \\
b &= 0.153 \pm 0.017 \pm 0.004 \\
d &= 0.085 \pm 0.016 \pm 0.009 \\
f &= 0.173 \pm 0.028 \pm 0.021
\end{aligned}
$$

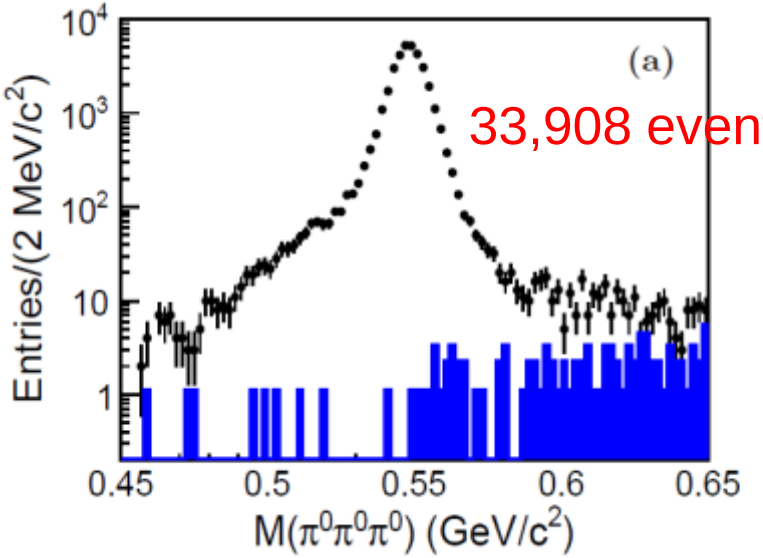


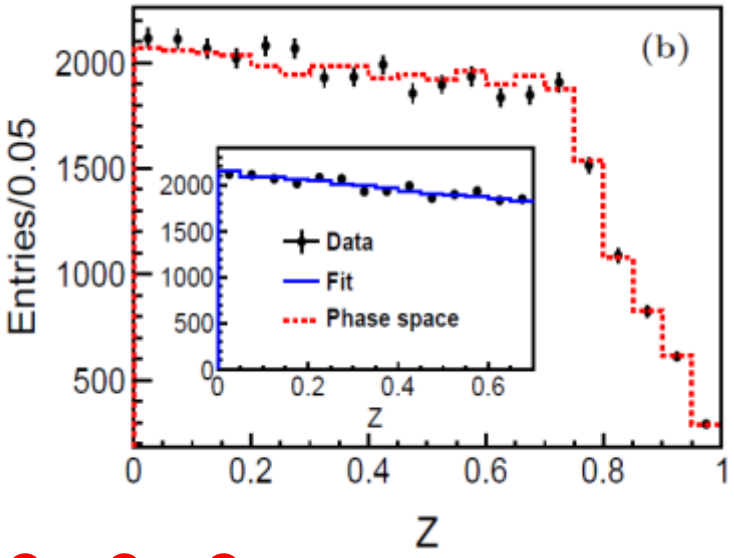
$$
\begin{aligned}
a &= -1.128 \pm 0.015, \\
b &= 0.153 \pm 0.017, \\
c &= (0.047 \pm 0.851) \times 10^{-2} \\
d &= 0.085 \pm 0.016, \\
e &= 0.017 \pm 0.019, \\
f &= 0.173 \pm 0.028.
\end{aligned}
$$

No charge conjugation violation is seen

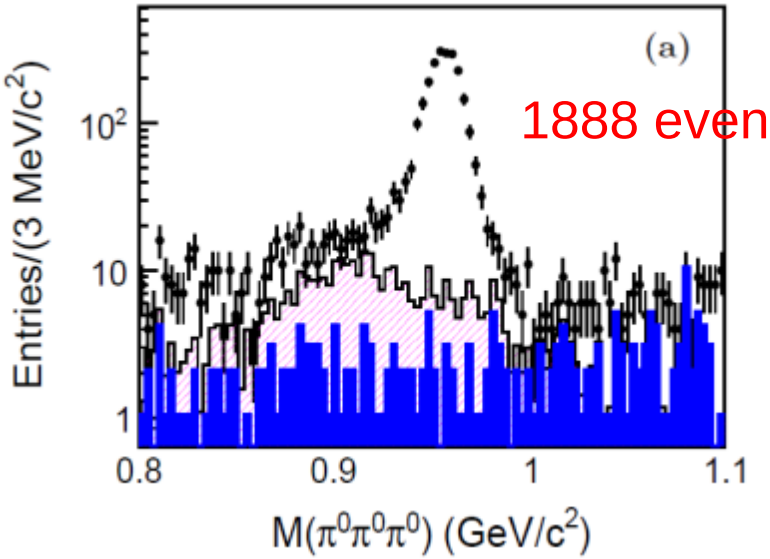
$\eta \to \pi^0\pi^0\pi^0$

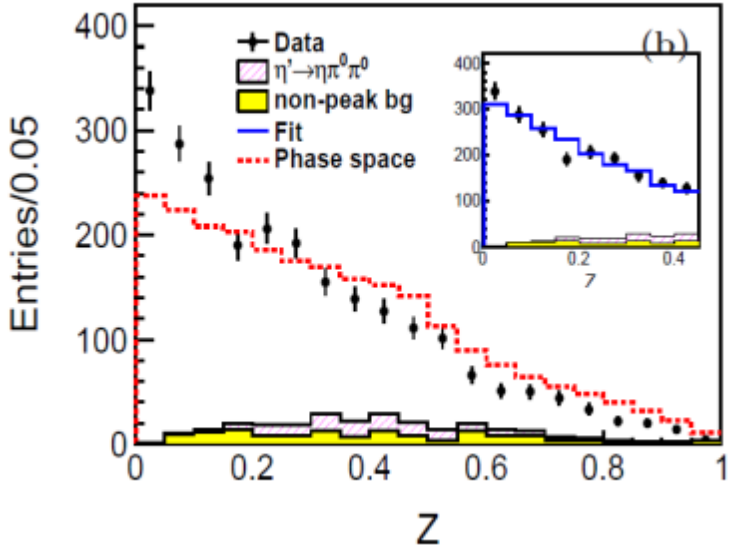
$$|A(Z)|^2 = N(1 + 2\alpha Z + \ldots)$$



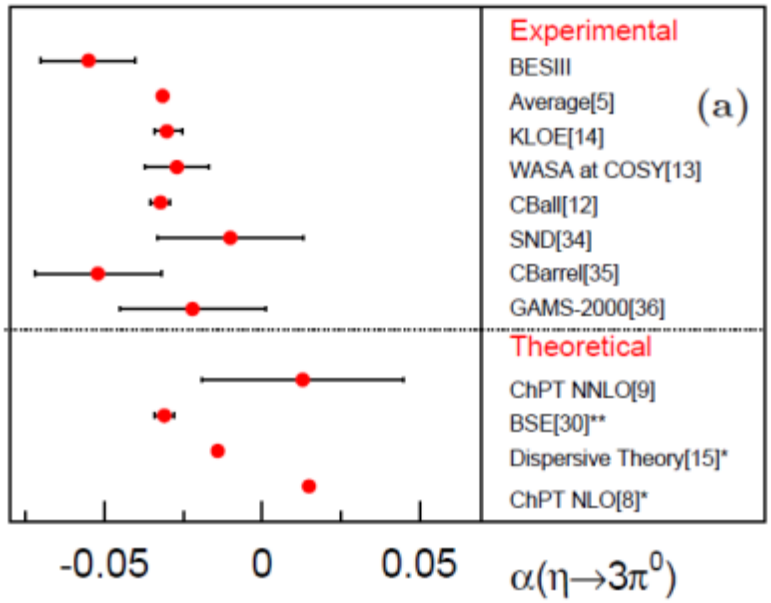


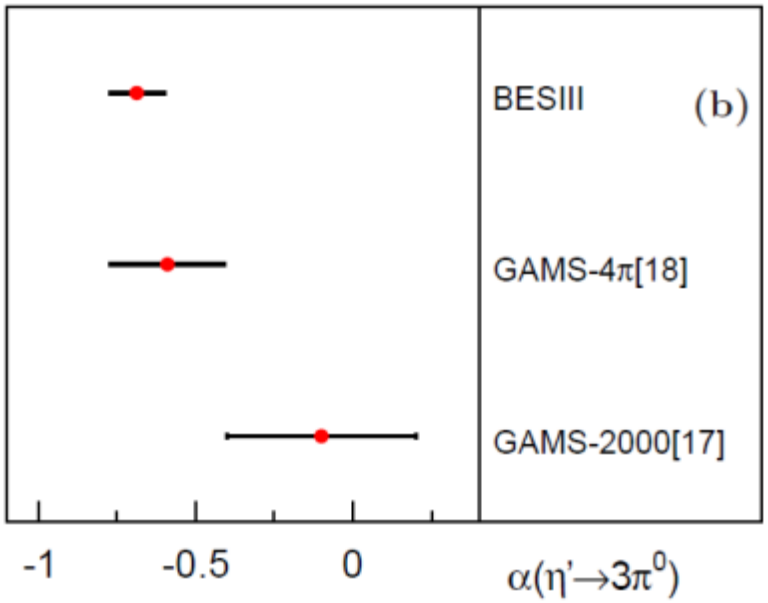
$\eta' \to \pi^0\pi^0\pi^0$





Comparison to experimental and theoretical results

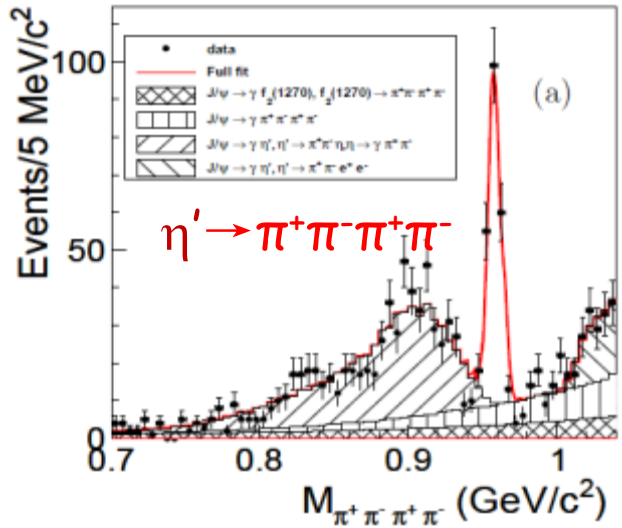




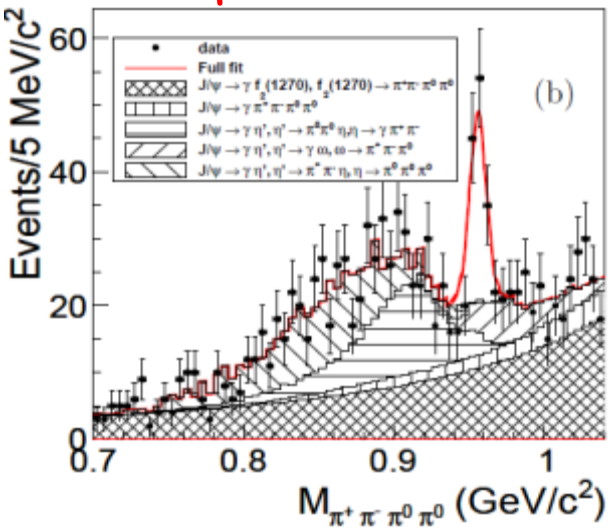
- In agreement with previous measurements
- α for $\eta' \to \pi^0\pi^0\pi^0$ significantly deviates from zero

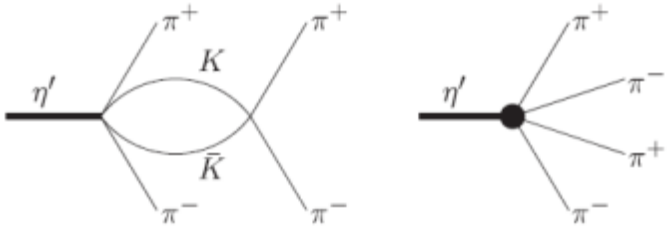
$\eta' \to \pi^+\pi^-\pi^+\pi^-, \pi^+\pi^-\pi^0\pi^0$

PRL112,251801(2014)



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



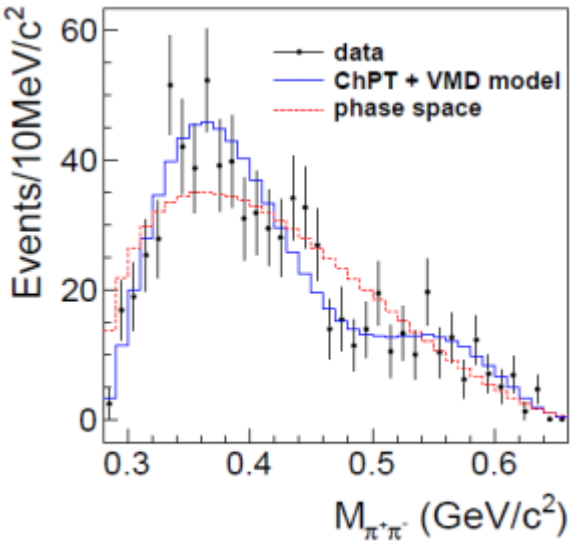


ChPT+VMD:
only occur at $O(p^6)$

ChPT+VMD : $B(\eta' \to \pi^+\pi^-\pi^+\pi^-) = (1.0 \pm 0.3) \times 10^{-4}$
$B(\eta' \to \pi^+\pi^-\pi^0\pi^0) = (2.4 \pm 0.7) \times 10^{-4}$

F.K. Guo, B. Kubis, A. Wirzba,Phys. Rev. D 85,014014 (2012)

$B(\eta' \to \pi^+\pi^-\pi^+\pi^-) = (8.63 \pm 0.69 \pm 0.64) \times 10^{-5}$
$B(\eta' \to \pi^+\pi^-\pi^0\pi^0) = (1.82 \pm 0.35 \pm 0.18) \times 10^{-4}$

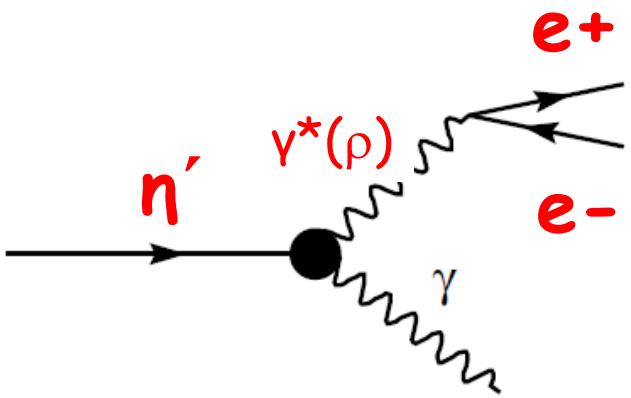


BESIII

Observation of $\eta' \to \gamma e^+ e^-$

arXiv:1504.06016

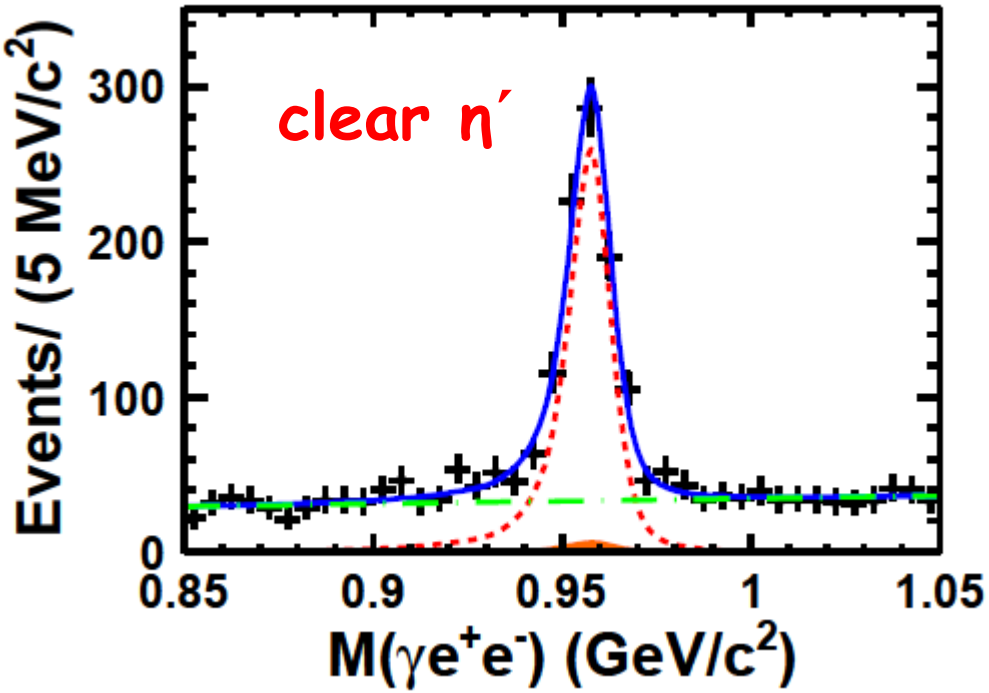
- Investigate the inner structure of the meson
- Transition form factor

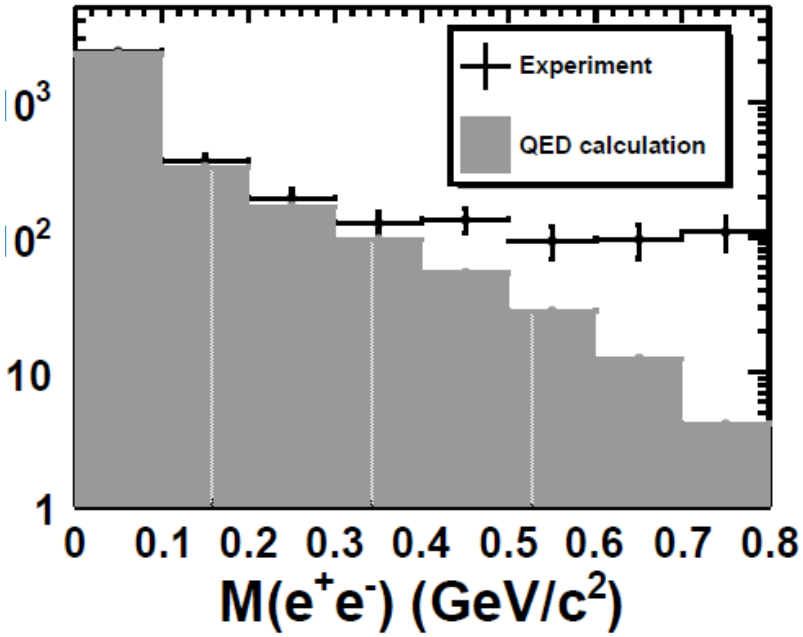


$$\frac{d\Gamma(\eta' \to \gamma l^+ l^-)}{dq^2 \Gamma(\eta' \to \gamma\gamma)}$$

$$= \frac{2\alpha}{3\pi}\frac{1}{q^2}\sqrt{1-\frac{4m_l^2}{q^2}}\left(1+\frac{2m_l^2}{q^2}\right)\left(1-\frac{q^2}{m_{\eta'}^2}\right)^3 |F(q^2)|^2$$

$$= [\mathrm{QED}(q^2)] \times |F(q^2)|^2,$$

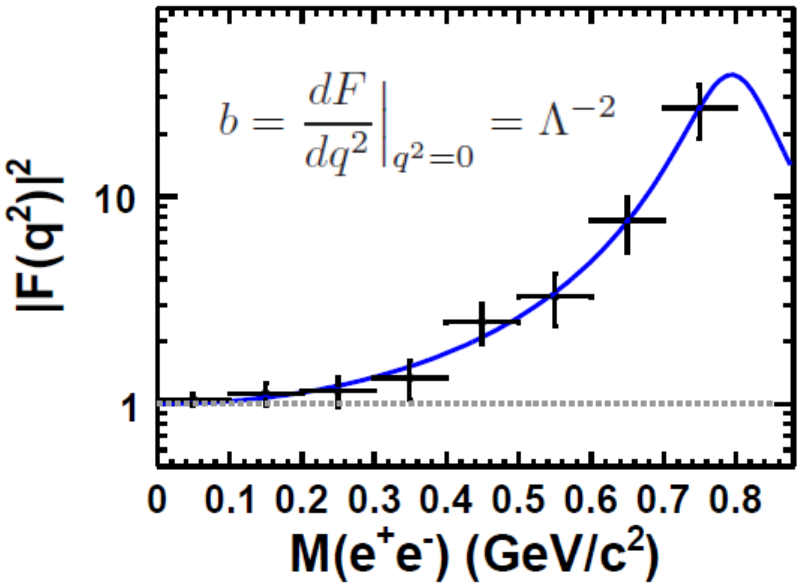




$$\frac{\Gamma(\eta' \to \gamma e^+ e^-)}{\Gamma(\eta' \to \gamma\gamma)} = (2.13 \pm 0.09(\text{stat.}) \pm 0.07(\text{sys.})) \times 10^{-2}$$

$$\mathcal{B}(\eta' \to \gamma e^+ e^-) = (4.69 \pm 0.20(\text{stat.}) \pm 0.23(\text{sys.})) \times 10^{-4}$$

4.2×10^{-4} effective meson theory, PRC61,035206



$$|F(q^2)|^2 = \frac{\Lambda^2(\Lambda^2+\gamma^2)}{(\Lambda^2-q^2)^2+\Lambda^2\gamma^2}$$

$$\Lambda_{\eta'} = (0.79 \pm 0.04(\text{stat.}) \pm 0.02(\text{sys.}))\ \text{GeV}$$

$$\gamma_{\eta'} = (0.13 \pm 0.06(\text{stat.}) \pm 0.03(\text{sys.}))$$

$$b_{\eta'} = (1.60 \pm 0.17(\text{stat.}) \pm 0.08(\text{sys.}))\ \text{GeV}^{-2}$$

- In agreement with the results of $\eta' \to \gamma\mu^+\mu^-$ from CELLO

$$b_{\eta'} = (1.7 \pm 0.4)\ \text{GeV}^{-2}$$

- Theoretical predictions:

$$b_{\eta'} = 1.45\ \text{GeV}^{-2} \quad \text{VMD}$$

$$b_{\eta'} = 1.60\ \text{GeV}^{-2} \quad \text{ChPT}$$

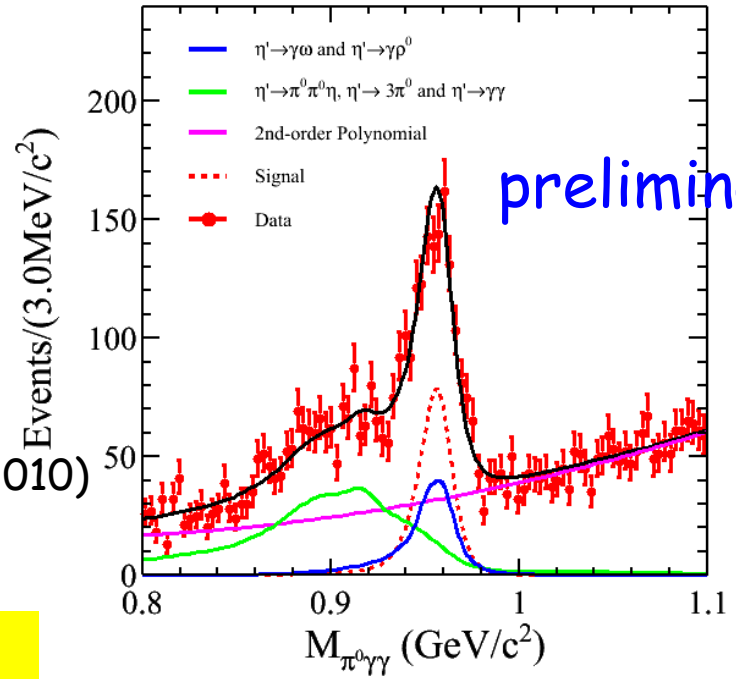
$$b_{\eta'} = 1.53^{+0.15}_{-0.08}\ \text{GeV}^{-2} \quad \text{Dispersion}$$

Observation of $\eta' \to \gamma\gamma\pi^0$

- check the high order of ChPT
- no experimental evidence yet

ω excluded, ρ-ω mxing?

$B=[6.91\pm0.51\pm0.54\pm0.20(PDG)] \times 10^{-4}$



Consistent with theoretical predictions:

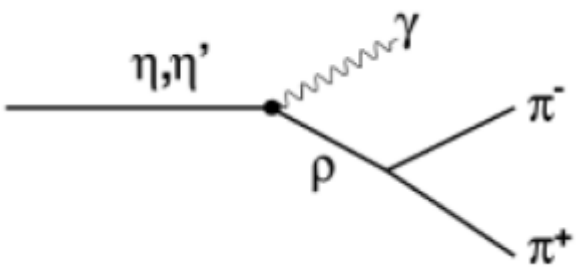
$B(\eta' \to \gamma\gamma\pi^0)$: ~$6 \times 10^{-4}$

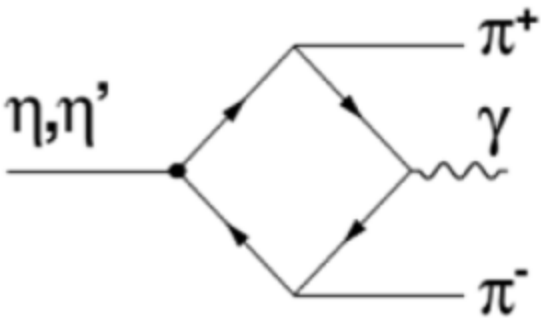
P. Jora, Nucl. Phys. Proc. Suppl. 207-208, 224 (2010)
R. Escribano, PoS QNP 2012, 079 (2012)

Linear σ model & VMD

$\eta' \to \gamma\pi^+\pi^-$ decay dynamics

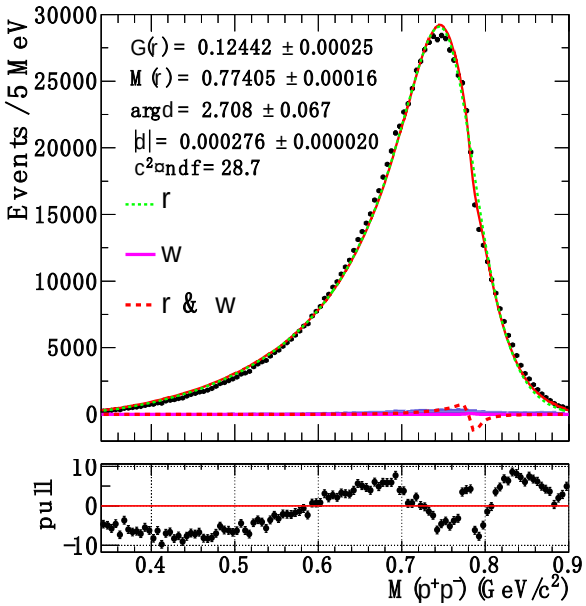
- high term of WZW ChPT$\to$ box anomaly
- studied by many experiments (CB, L3 …)
- no consistent picture due to limited statistics
  - ρ mass shift or not ?
  - box anomaly or not ?



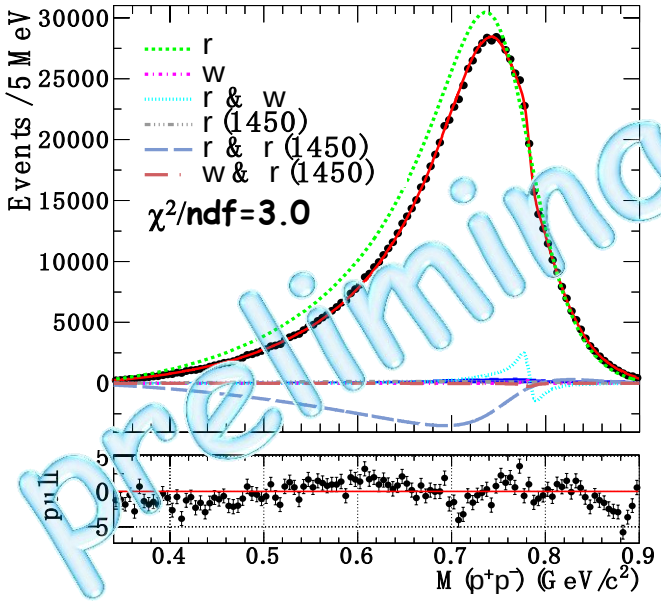


Model-dependent fit

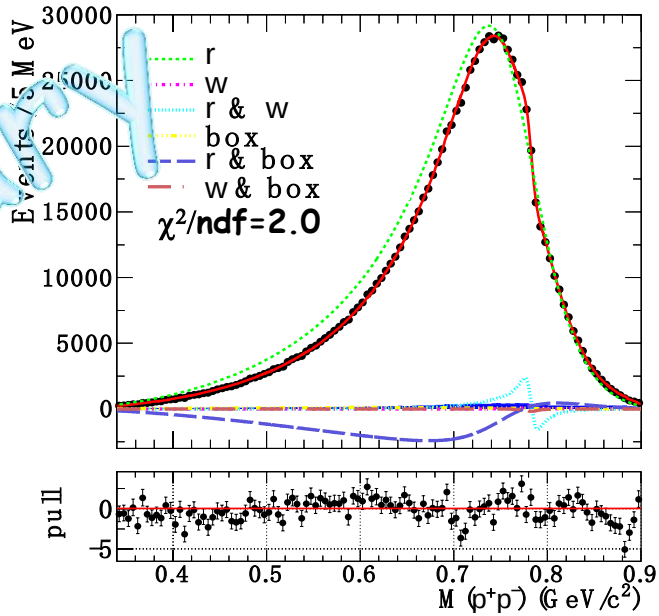
1). fit with ρ(770)-ω



2). fit with ρ(770)-ω-ρ(1450)



3). fit with ρ(770)-ω-box anomaly

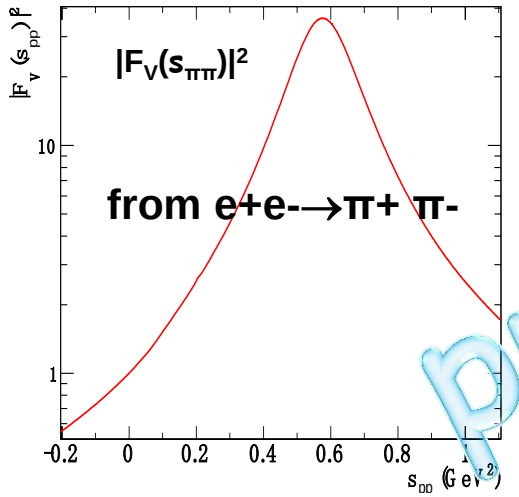


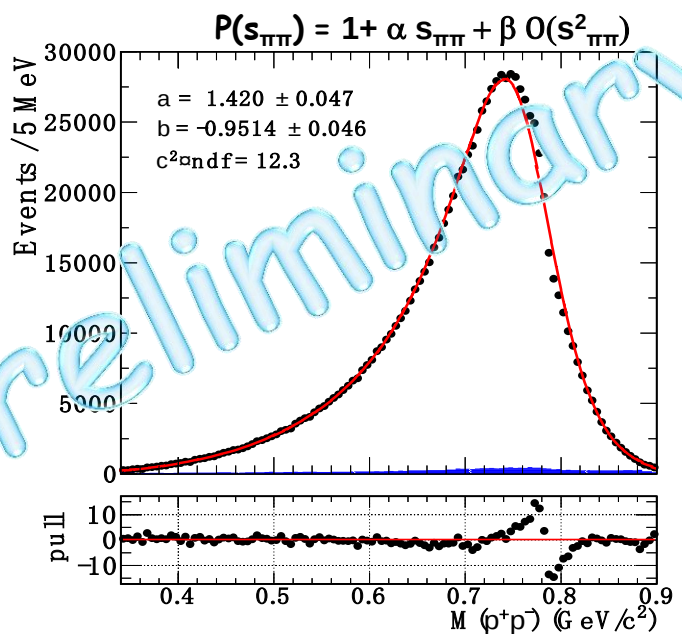
- ✓ Besides ρ(770), the ω is needed
- ✓ ρ(770)-ω cannot describe data well
- ✓ Extra contribution (maybe ρ(1450) or box-anomaly, maybe both of them) is also necessary to provide a good description of data

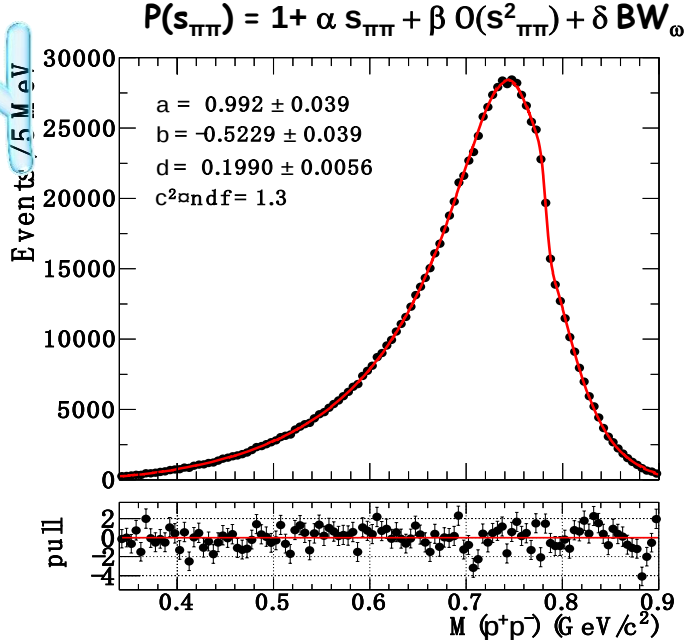
Model-independent fit

$$\frac{d\Gamma}{ds_{\pi\pi}} = \left|AP(s_{\pi\pi})F_V(s_{\pi\pi})\right|^2 \Gamma_0(s_{\pi\pi})$$

* Physics Letters B 707 (2012) 184-190







Crystal barrel: $\alpha = (1.80 \pm 0.49 \pm 0.04)\text{GeV}^{-2}$
$\beta = (0.04 \pm 0.36 \pm 0.03)\text{GeV}^{-4}$

GAMS-2000: $\alpha = (2.7 \pm 1.0)\text{GeV}^{-2}$

- ω is necessary
- Linear polynomial is insufficient

BESIII status on η/η' decays

- $\eta' \to \pi^+\pi^-\eta$ PRD83, 012003(2011)
- $\eta/\eta' \to \pi^+\pi^-, \pi^0\pi^0$ PRD83, 032006(2011)
- $\eta' \to \pi^+\pi^- \pi^0, \pi^0\pi^0\pi^0$ PRL108, 182001(2012)
- $\eta/\eta' \to$ invisible PRD87,012009(2013)
- $\eta/\eta' \to \pi^+ e\nu$ PRD87,032006(2013)
- $\eta' \to 3(\pi^+\pi^-)$ PRD88,091502(2013)
- $\eta' \to 2(\pi^+\pi^-), \pi^+\pi^-\pi^0\pi^0$ PRL112,251801(2014)
- $\eta' \to \gamma e^+e^-$ arXiv:1504.06016, accepted by PRD
- $\eta \to \pi^+\pi^- \pi^0, \eta/\eta' \to \pi^0\pi^0\pi^0$ arXiv:1506.05360, submitted to PRD
- $\eta' \to \gamma\gamma\pi^0$ (preliminary)
- $\eta' \to \gamma\pi^+\pi^-$ (Preliminary)

Summary

- η/η' decays: a rich physics field
- Recent results from BESIII are presented
  - $\eta \to \pi^+\pi^-\pi^0$, $\eta/\eta' \to \pi^0\pi^0\pi^0$
  - $\eta' \to \pi^+\pi^-\ \pi^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0$
  - $\eta' \to \gamma e^+e^-$
  - $\eta' \to \gamma\pi^+\pi^-$
  - $\eta' \to \gamma\gamma\pi^0$
- BESIII: η/η' factory
- more results are expected to come soon

  ($\eta' \to \pi^+\pi^-\pi^0$, ωe^+e^-,…)

Thanks for you attention