Light meson decays at BESIII

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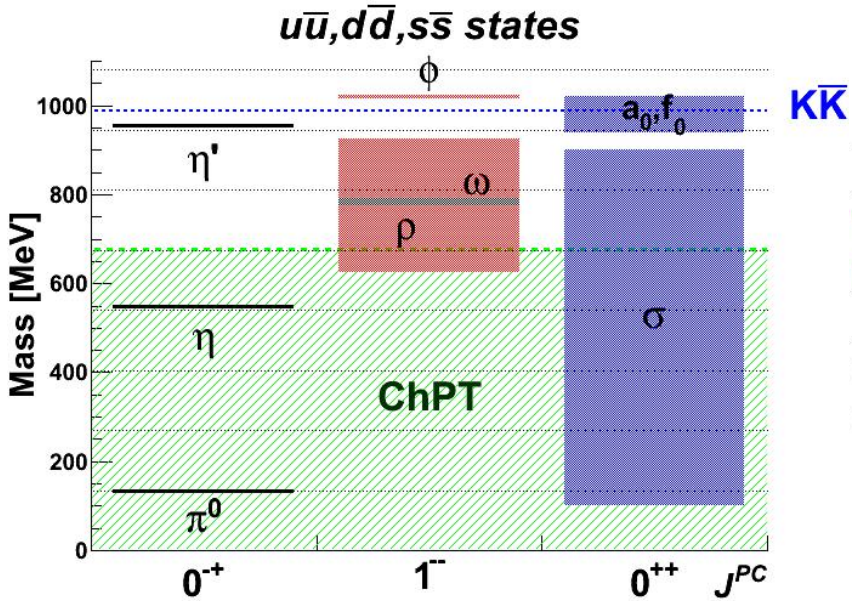
Outline

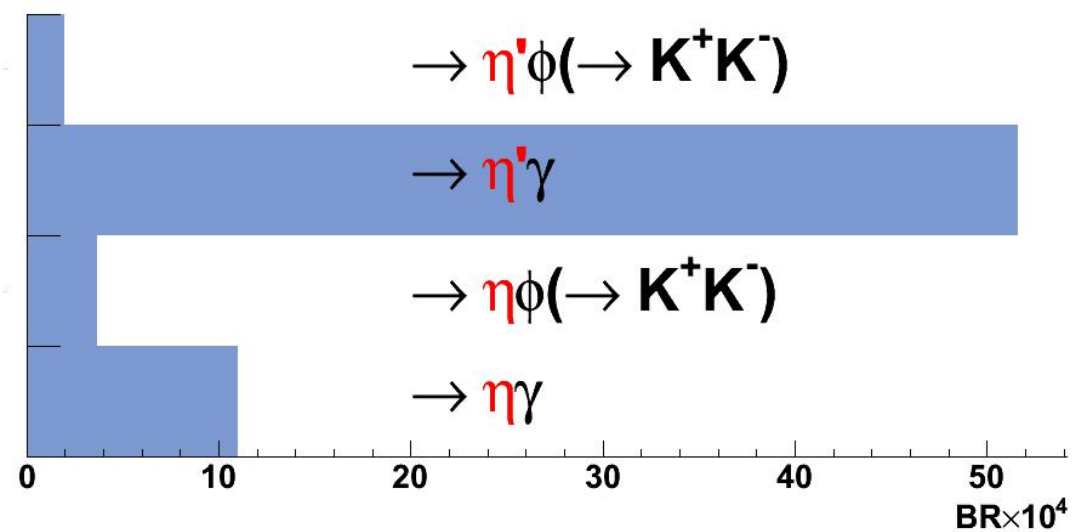
- Introduction
- $\eta' \rightarrow \gamma e^+ e^-$
- $\eta' \rightarrow \gamma \pi^+ \pi^-$
- $\eta' \rightarrow 3\pi$
- Summary

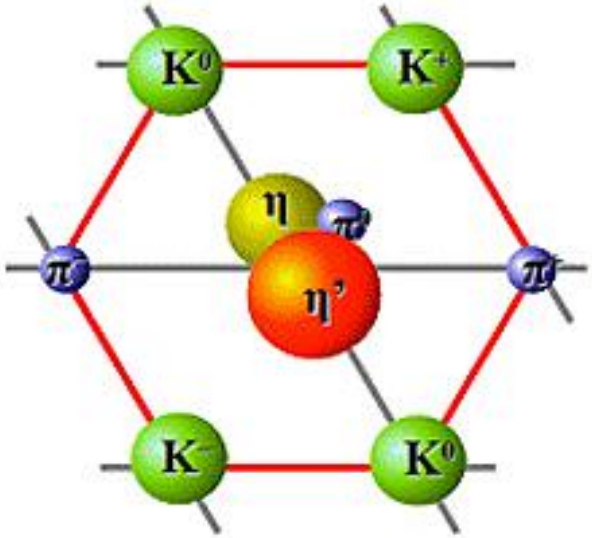
Introduction



- 548 MeV, $\Gamma = 1.3$ keV
- 958 MeV, $\Gamma = 200$ keV

Hadronic Decays			
$\eta \to \pi^0\pi^0\pi^0$	32%	$\eta' \to \pi^+\pi^-\eta$	44%
$\eta \to \pi^+\pi^-\pi^0$	23%	$\eta' \to \pi^0\pi^0\eta$	21%
Radiative Decays			
$\eta \to \gamma\gamma$	39%	$\eta' \to \rho^o\gamma$	29%
$\eta \to \pi^+\pi^-\gamma$	5%	$\eta' \to \omega\gamma$	3%
		$\eta' \to \gamma\gamma$	2%
	Σ 99%		Σ 99%





Introduction

- 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)
  - VMD, ChPT(Box Anomaly, U(3) ChPT), Dispersion, ...

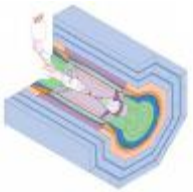
$\eta/\eta' \to 2\gamma$	chiral anomaly
$\eta' \to \gamma e^+e^-$	Transition Form Factors (TFF)
$\eta' \to \gamma\pi^+\pi^-$	box anomaly
$\eta' \to \pi^+\pi^-\pi^0, 3\pi^0$	quark masses
$\eta/\eta' \to \mu^+\mu^-\pi^0, e^+e^-\pi^0$	C violation
$\eta/\eta' \to \mu e$	LF violation

……

Source of η/η' events

VES

Gams(-4π)



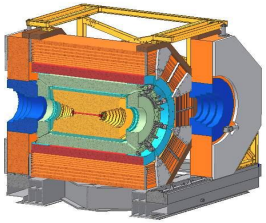
CLEO

CLAS

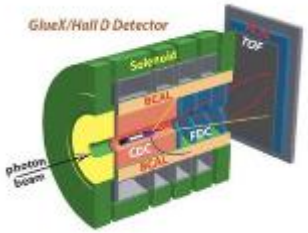
Crystal Ball

WASA-at-COSY

KLOE-2



BESIII



GlueX

Introduction

- 1.3×10^9 J/ψ events (2009+2012)
- η/η' from J/ψ radiative decays

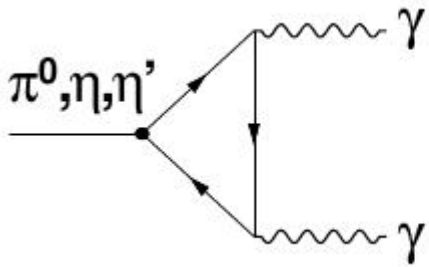
  → 1.4×10^6 η

  → 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'

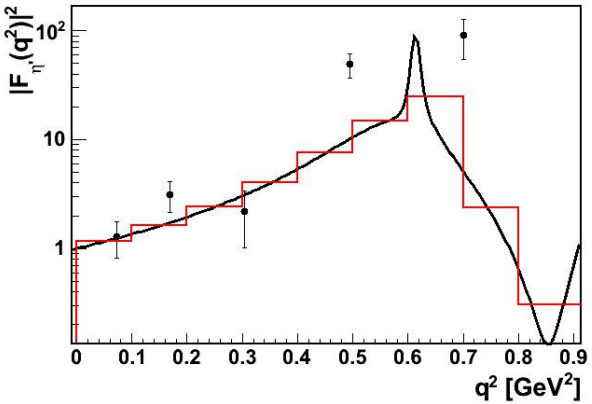
$\eta' \to \gamma e^+ e^-$

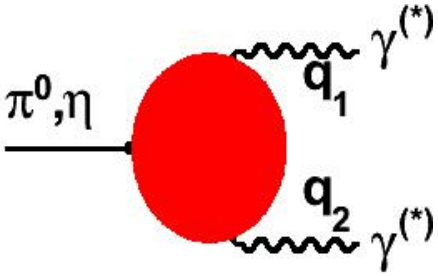


$\Gamma(\eta' \to \gamma e^+ e^-)/\Gamma(\eta' \to \gamma\gamma)$ is 4.1×10^{-2} at the 90% confidence level (CL) from the CLEO Collaboration.

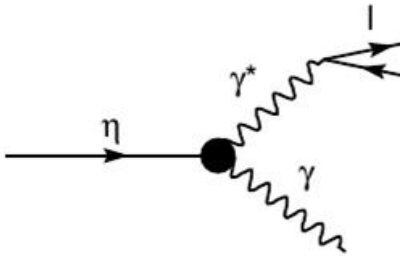
DATA: Lepton G:

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





$F_P(q_1^2, q_2^2)$



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

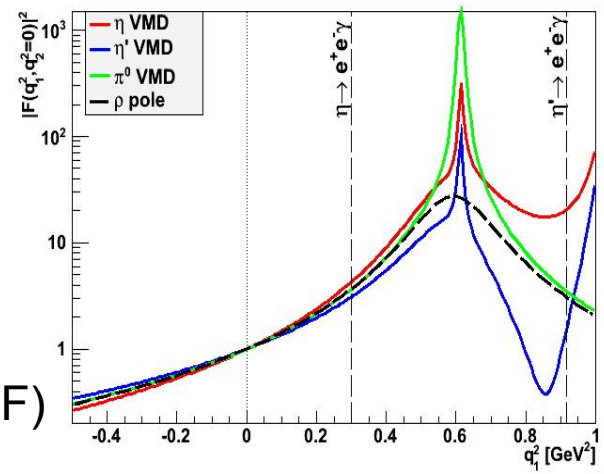
$$\frac{d\Gamma(\eta' \to \gamma l^+ l^-)}{dq^2\Gamma(\eta' \to \gamma\gamma)}$$

Vector Meson Dominance (VMD)

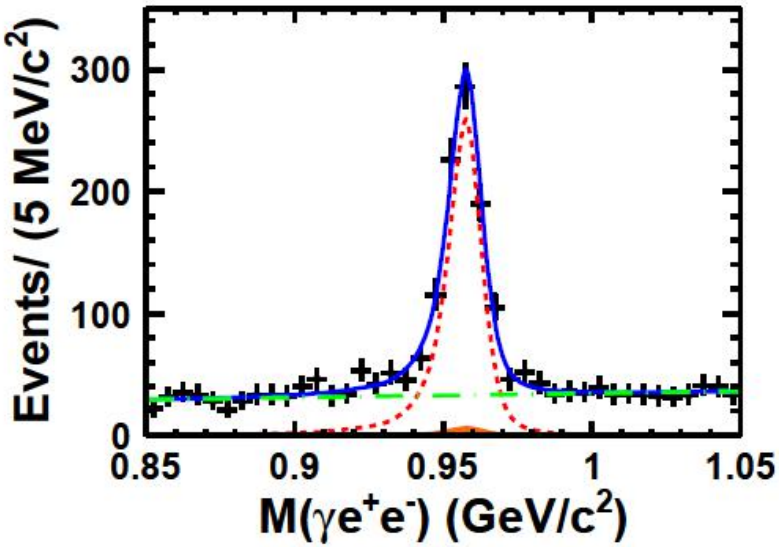
$$= \frac{2\alpha}{3\pi}\frac{1}{q^2}\sqrt{1-\frac{4m_l^2}{q^2}}\left(1+\frac{2m_l^2}{q^2}\right)\left(1-\frac{q^2}{m_{\eta'}^2}\right)^3 |F(q^2)|^2$$

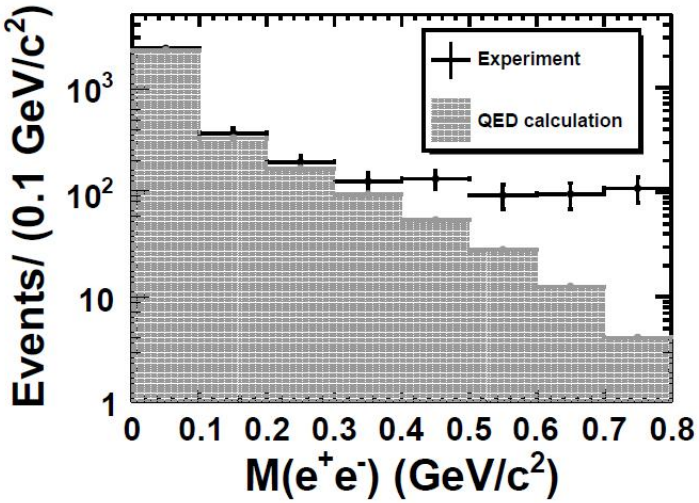
$$= [\mathrm{QED}(q^2)] \times |F(q^2)|^2$$

Transition Form Factor (TFF)



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





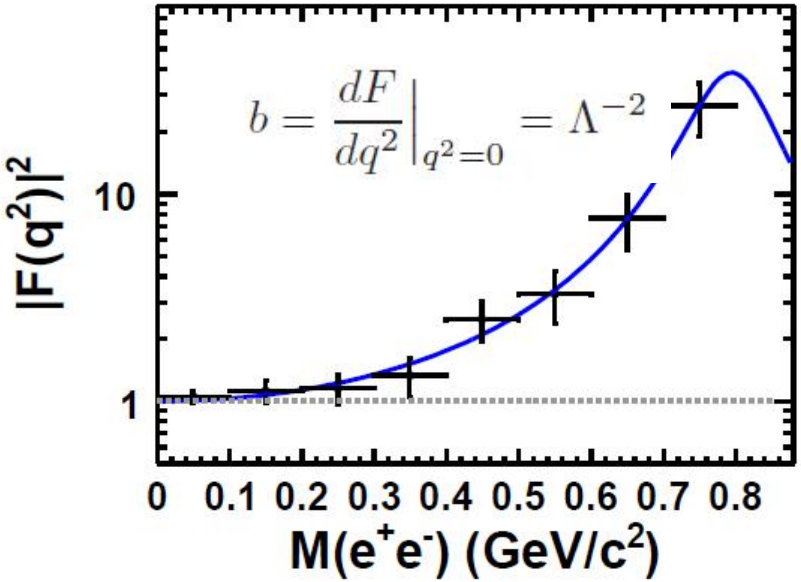
$$\frac{\Gamma(\eta' \to \gamma e^+ e^-)}{\Gamma(\eta' \to \gamma\gamma)} = (2.13 \pm 0.09(stat.) \pm 0.07(sys.)) \times 10^{-2}$$

PRD92 ('15) 012001

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

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

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



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

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

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

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

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

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

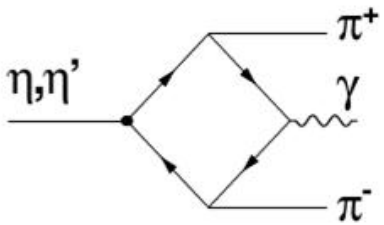
- **Theoretical predictions:**

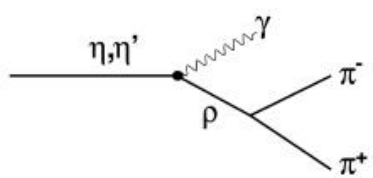
$$b_{\eta'} = 1.45GeV^{-2}$$ **VMD**

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

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

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





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

via $e^+e^- \to \pi^+\pi^-$

$$\Gamma_0(s_{\pi\pi}) = \frac{1}{3\cdot 2^{11}\cdot \pi^3 M_\eta^3}\left(M_\eta^2 - s_{\pi\pi}\right)^3 s_{\pi\pi}\cdot\beta_\pi^3$$

$$P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi}$$

$$\beta_\pi = \sqrt{1 - 4M_\pi^2/s_{\pi\pi}}$$

$$\frac{d\Gamma_{\eta(\eta')}}{ds_{\pi\pi}} \propto \left|C + \frac{1}{s_{\pi\pi} - m_\rho^2 - im_\rho\Gamma_\rho}\right|^2$$

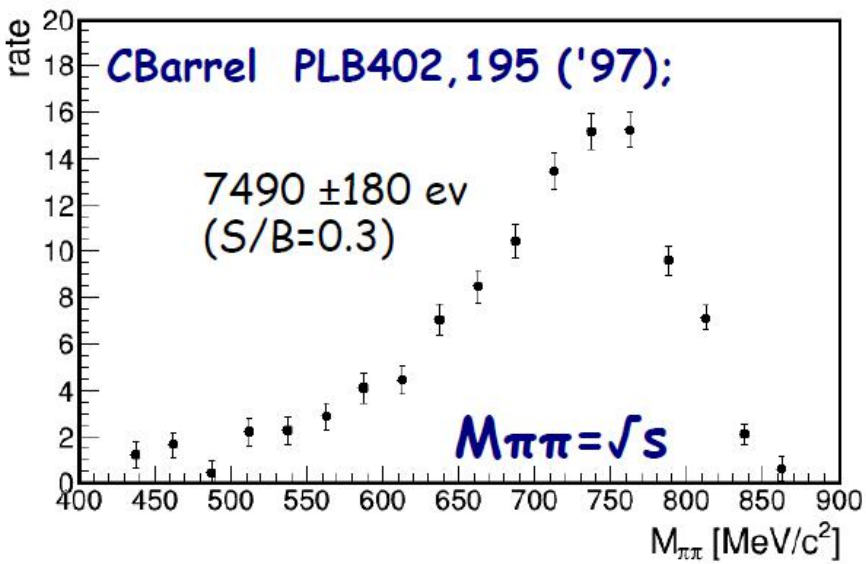
$\eta \to \pi^+\pi^-\gamma$

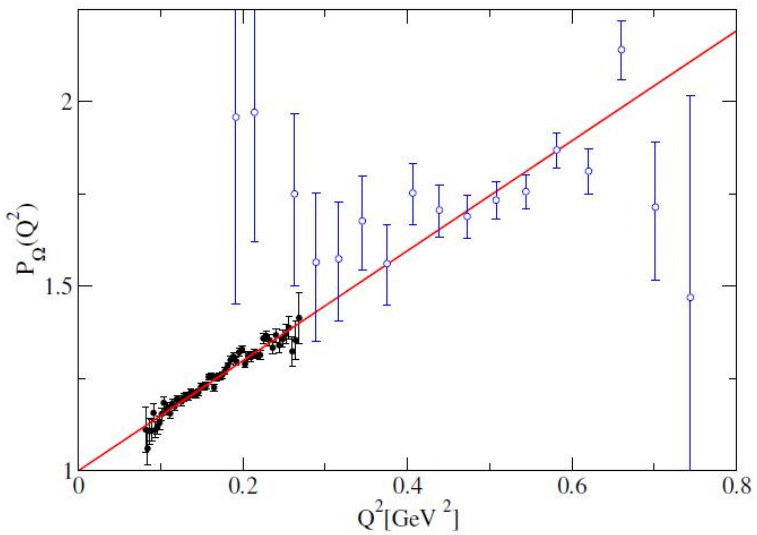
$\alpha = 1.89 \pm 0.25_{stat} \pm 0.59_{syst}$ GeV^{-2}

WASA PLB707 (2012) 243

$\alpha = 1.31 \pm 0.08_{stat} \pm 0.40_{syst}$ GeV^{-2}

KLOE PLB718 (2013) 910





Chiral Perturbation Theory (ChPT)

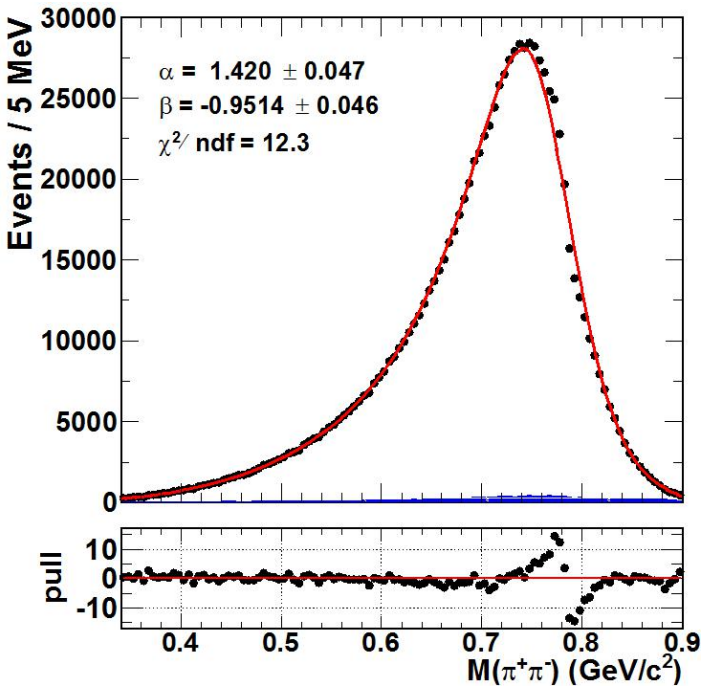
$\eta' \rightarrow \gamma\pi^+\pi^-$

$$Crystal\ Barrel: \alpha = (1.80 \pm 0.49 \pm 0.04) GeV^{-2}$$

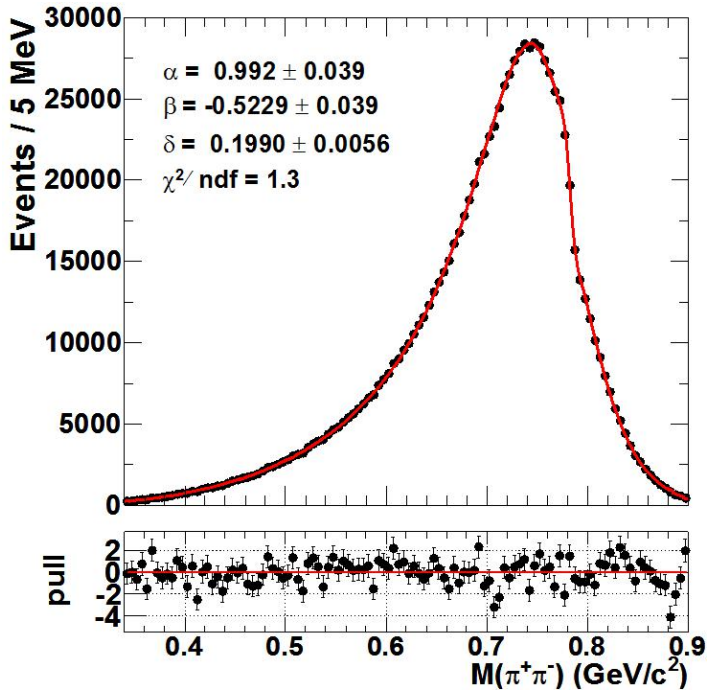
$$\beta = (0.04 \pm 0.36 \pm 0.03) GeV^{-2}$$

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

$$P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi} + \beta s_{\pi\pi}{}^2$$



$$P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi} + \beta s_{\pi\pi}{}^2 + \delta BW_{\omega}$$



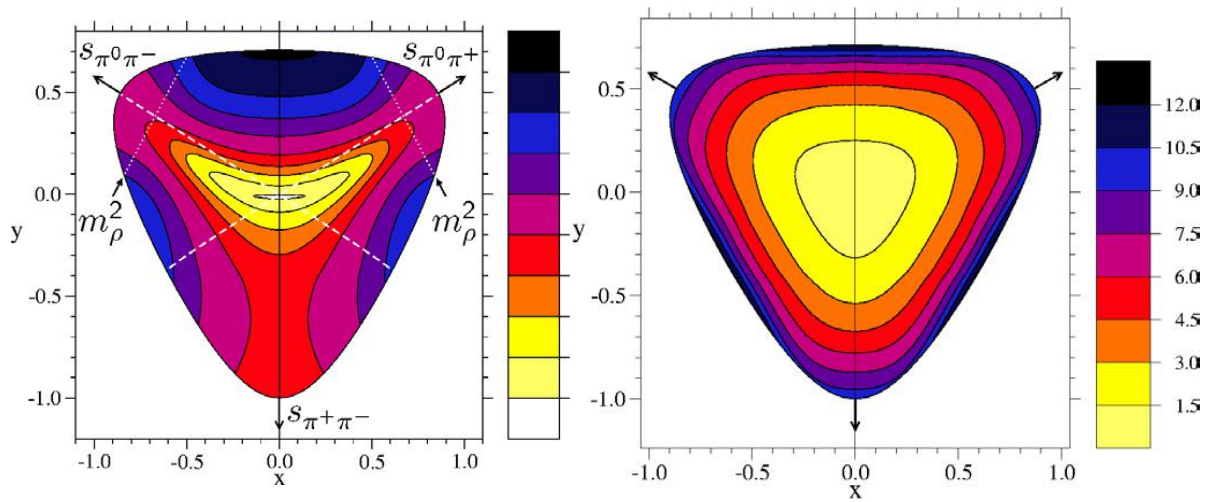
η' → 3π

$$V(p_V) \to \pi^+(p_+)\pi^-(p_-)\pi^0(p_0), \qquad V = \eta, \eta', \omega, \phi \ldots\ldots$$

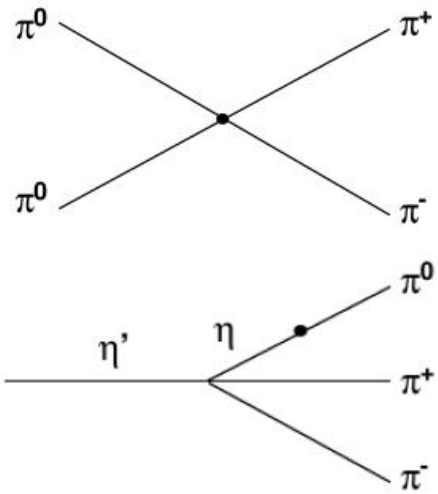
$$x = \frac{t-u}{\sqrt{3}R_V}, \quad y = \frac{s_0 - s}{R_V}, \qquad R_V = \frac{2}{3}M_V(M_V - 3M_\pi),$$

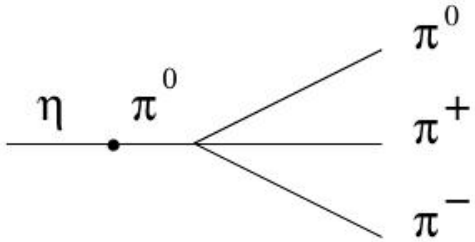
$$s_0 = \frac{M_V{}^2 + 3M_\pi{}^2}{3}, s = (p_V - p_0)^2, t = (p_V - p_+)^2, u = (p_V - p_-)^2$$

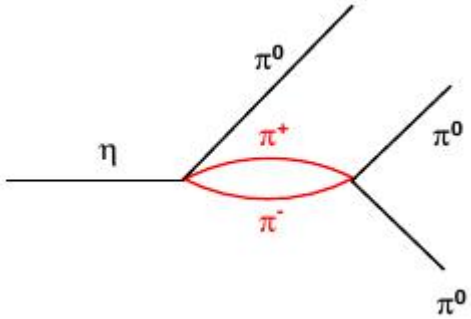
$$Z = x^2 + y^2$$



$\eta' \to 3\pi$



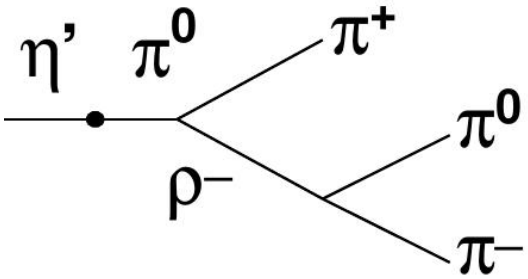




$$\frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} \; and \; \frac{BR(\eta' \to \pi^0\pi^0\pi^0)}{BR(\eta' \to \pi^0\pi^0\eta)}$$

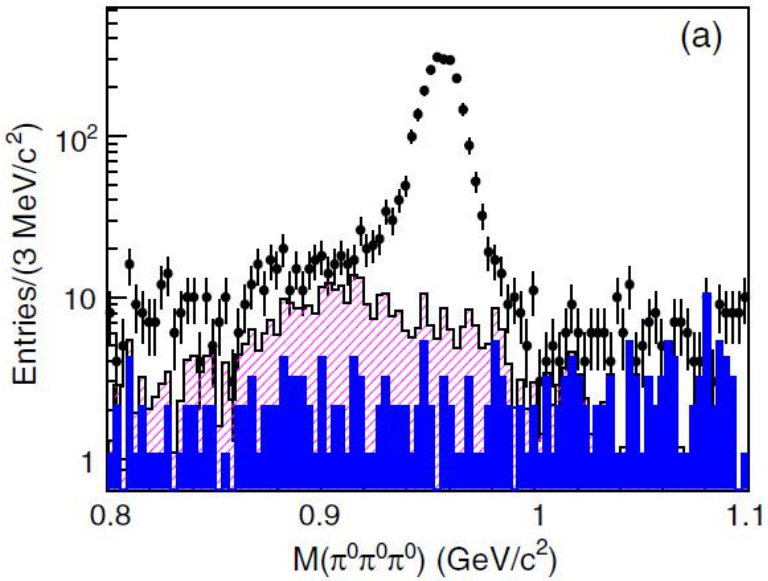
$$r = \frac{\Gamma_{\eta' \to \pi^+\pi^-\pi^0}}{\Gamma_{\eta' \to \pi^+\pi^-\eta}} \approx (16.8)\frac{3}{16}\left(\frac{m_d - m_u}{m_s}\right)^2$$

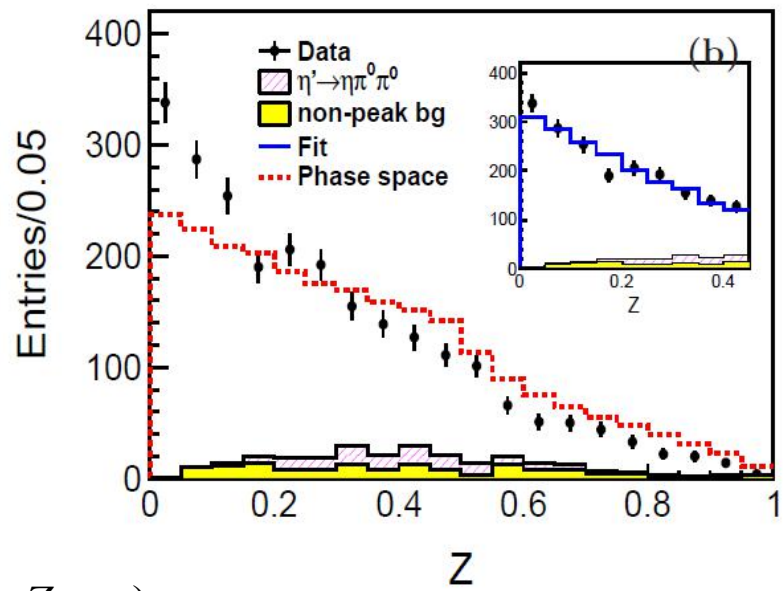
d-u quark masses



U(3) ChPT, Borasoy, Nißler 2005:
BR($\eta \to \pi^+\pi^-\pi^0$) ≈ 1.8% large $\rho^+\pi^-$ + cc

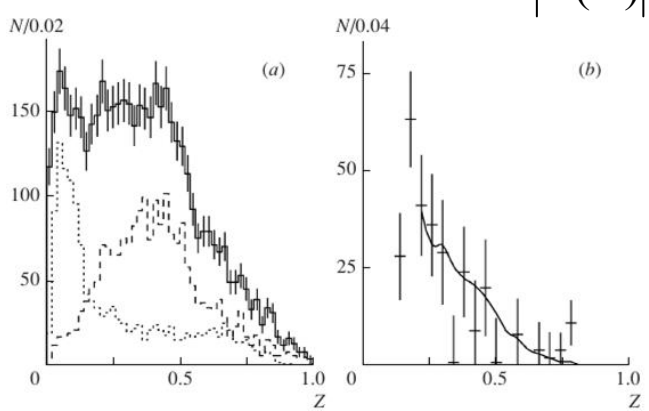
$\eta' \to 3\pi$





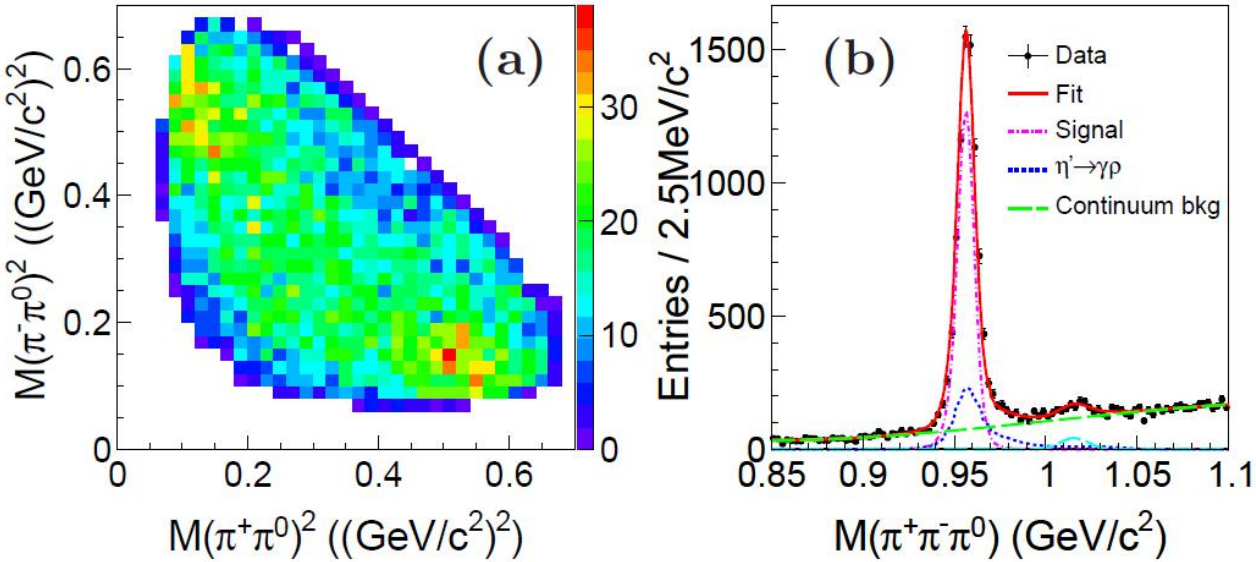
$$|A(Z)|^2 = N(1 + 2\alpha Z + \ldots)$$

decay width=1900 ev
BESIII:
PRD92 ('15) 012014
$\alpha = -0.640 \pm 0.046 \pm 0.047$

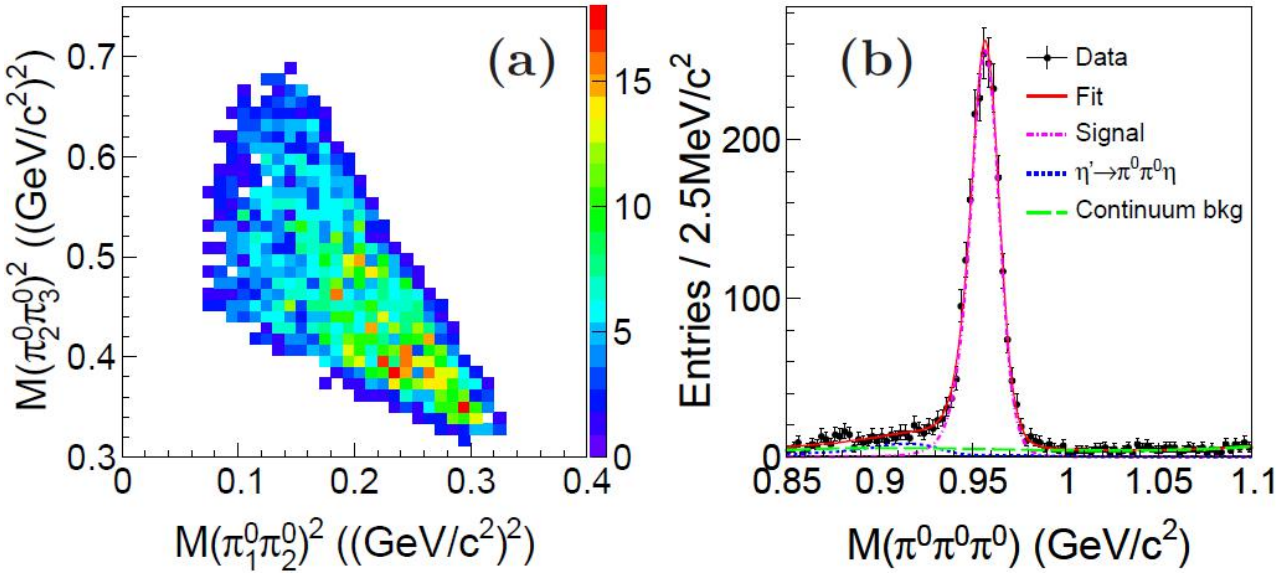


decay width=235 ev
GAMS:
PAN71,2124('08)
$\alpha = -0.59 \pm 0.18$

$\eta' \rightarrow 3\pi$



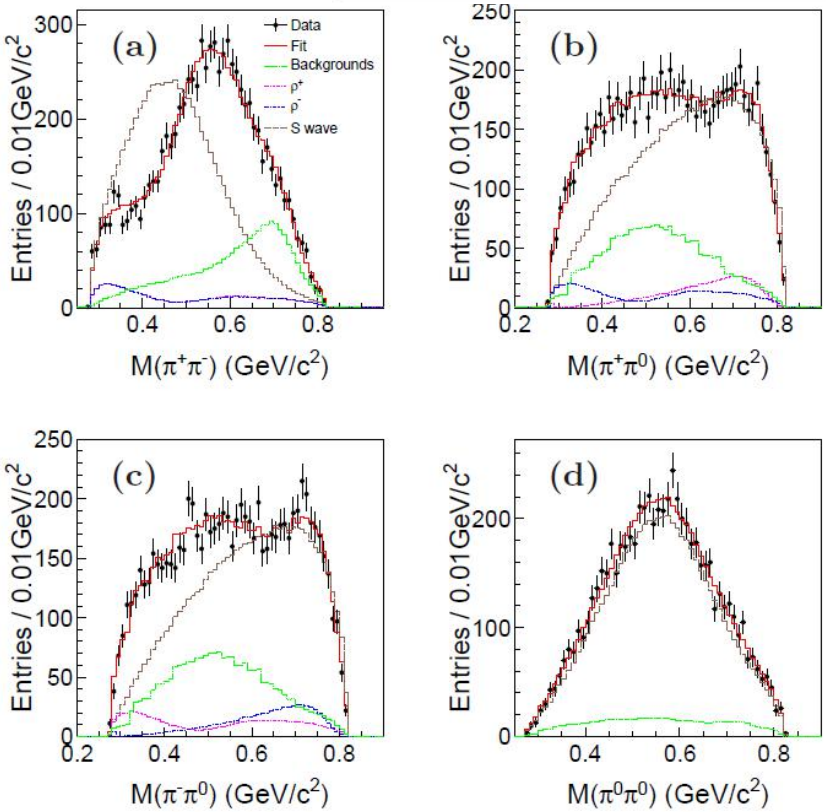
$\eta' \rightarrow \pi^+\pi^-\pi^0$



$\eta' \rightarrow \pi^0\pi^0\pi^0$

$\eta' \to 3\pi$

Decay Mode	Yield	ε (%)	$\mathcal{B}$ ($\times 10^{-4}$)
$\pi^+\pi^-\pi^0$	6067 ± 91	25.3	$35.91 \pm 0.54 \pm 1.74$
$\pi^0\pi^0\pi^0$	2015 ± 47	8.8	$35.22 \pm 0.82 \pm 2.60$
$\rho^+\pi^-$	616 ± 49	24.8	$3.72 \pm 0.30 \pm 0.63 \pm 0.92$
$\rho^-\pi^+$	615 ± 49	24.7	$3.72 \pm 0.30 \pm 0.63 \pm 0.92$
$(\pi^+\pi^-\pi^0)_S$	6580 ± 134	26.2	$37.63 \pm 0.77 \pm 2.22 \pm 4.48$



$B(\eta' \to \rho^+\pi^- + cc) = (7.44 \pm 0.60 \pm 1.26 \pm 1.84)\times 10^{-4}$

$B(\eta' \to \pi^0\pi^0\pi^0)$ puzzle

$B(\eta' \to \pi^0\pi^0\pi^0) / B(\eta' \to \eta\pi^0\pi^0)$
from GAMS ('84,'87,'08)
$(78\pm10) \times 10^{-4}$

vs BESIII $(159\pm12) \times 10^{-4}$
arXiv 1606.03847

Summary

- BESIII as η' factory
- Published as η/η' analysis:
  - $\eta' \to \pi^+\pi^-\pi^0$ DP PRD83, 012003 ('11)
  - $\eta/\eta' \to \pi^+\pi^-$ CPV, UL PRD84, 032006 ('11)
  - $\eta' \to \pi^+\pi^- l^+ l^-$ BR PRD87, 092011 ('13)
  - invisible decays UL PRD87, 012009 ('13)
  - weak decays UL PRD87, 032006 ('13)
  - $\eta' \to 4\pi$ BR PRL112, 251801 ('14)
  - $\eta' \to \gamma e^+e^-$ BR, TTF PRD92, 012001 ('15)
  - $\eta \to \pi^+\pi^-\pi^0$, $\eta/\eta' \to \pi^0\pi^0\pi^0$ DP PRD92, 012014 ('15)
  - $\eta' \to K^+\pi^- + cc$ UL PRD93, 072008 ('16)

Red results based on '09 J/ψ data.

more light mesons: ω, ϕ, ...