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Light meson decays at BESIII

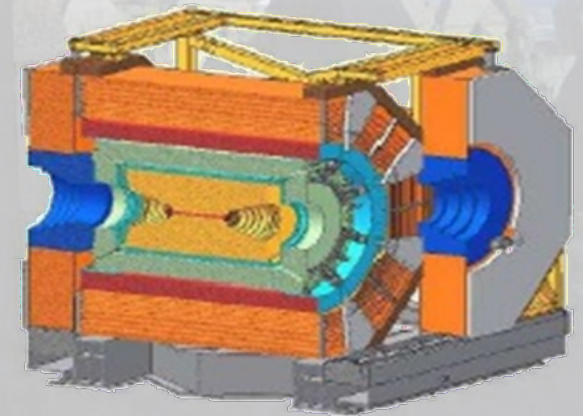
A. Kupsc

for the **BESIII** Collaboration

Recent results on η' meson decays

- $\eta' \rightarrow \gamma e^+ e^-, \omega e^+ e^-$ **new**
- $\eta' \rightarrow \gamma \pi^+ \pi^-$ **prel**
- $\eta' \rightarrow \pi^0 \gamma \gamma$ **new**
- $\eta' \rightarrow \eta \pi \pi$ **new**
- $\eta' \rightarrow \pi \pi \pi$ **new**

BESIII at BEPCII



Hadron2017 Salamanca, Sept 27th, 2017

background <http://www.flickr.com/photos/chicadelatele/>

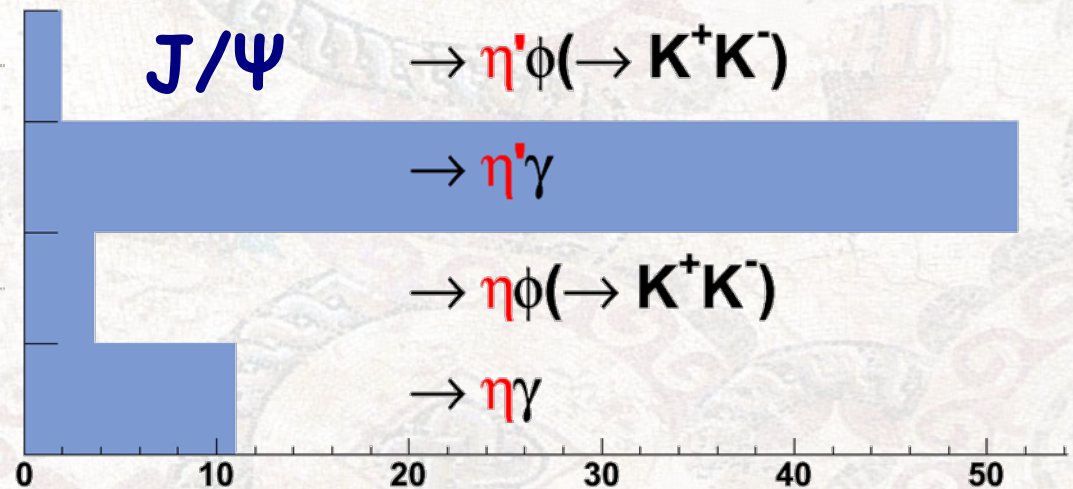
η, η' decays

- 548 MeV, $\Gamma = 1.3$ keV

- 958 MeV, $\Gamma = 200$ keV

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

BES III

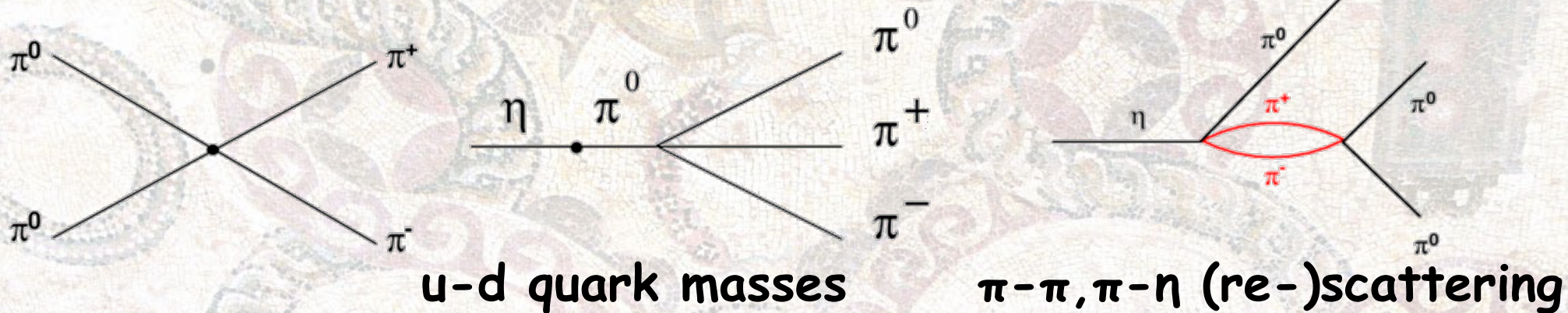


1.31×10^9 J/ψ events \rightarrow 6×10^6 η'

BR $\times 10^4$

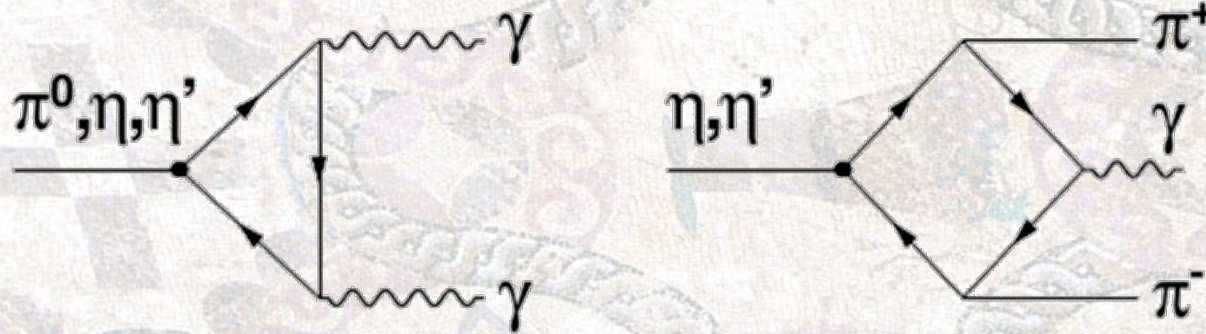
Low Energy QCD processes

Even # pseudoscalars (PPPP)



$$\eta' \rightarrow \pi\pi\pi, \quad \eta' \rightarrow \eta\pi\pi$$

Odd intrinsic parity: PVV/P $\gamma\gamma$, PPPV



$V \rightarrow PV$

Vector Meson Dominance

Radiative, Dalitz decays

π^0, η, η' Transition Form Factors (TFF)

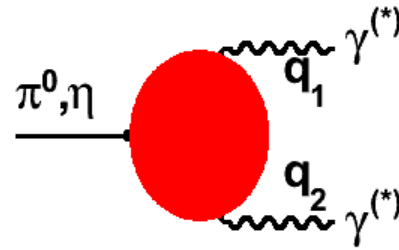
Low energy QCD

I^+I^- spectra for HI

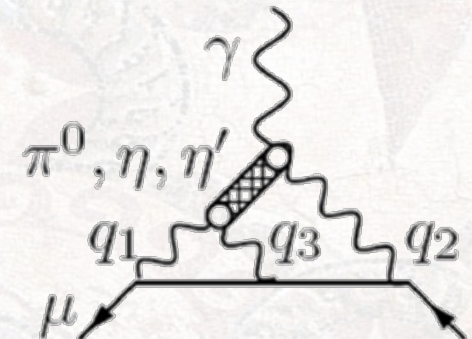
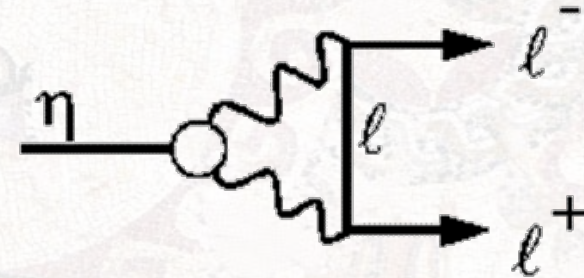
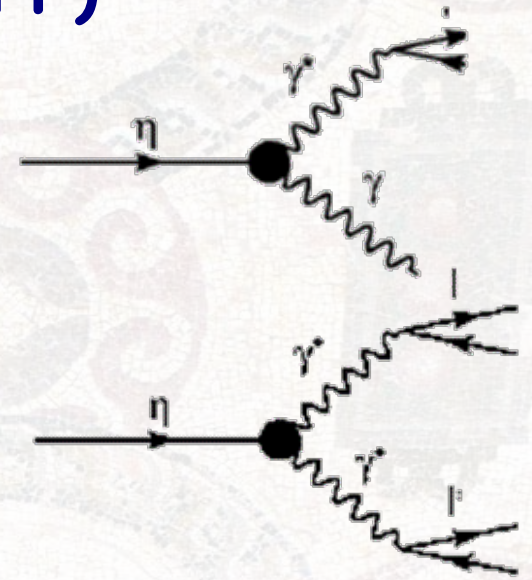
dark photon (U boson)

$F_{\pi^0} q^2 \rightarrow \infty$ puzzle: BaBar

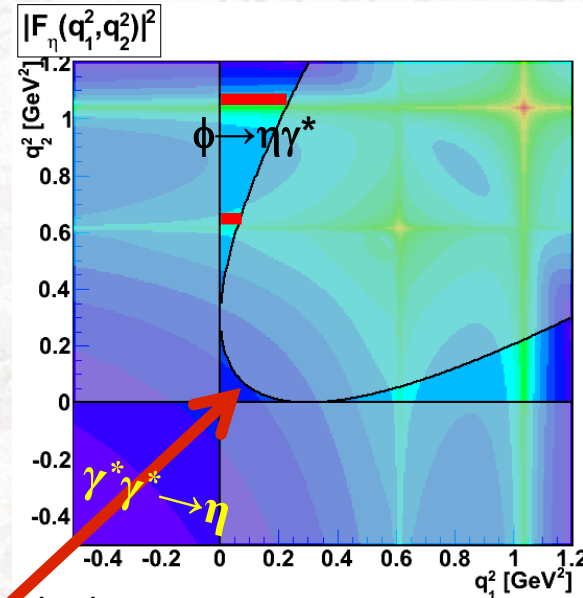
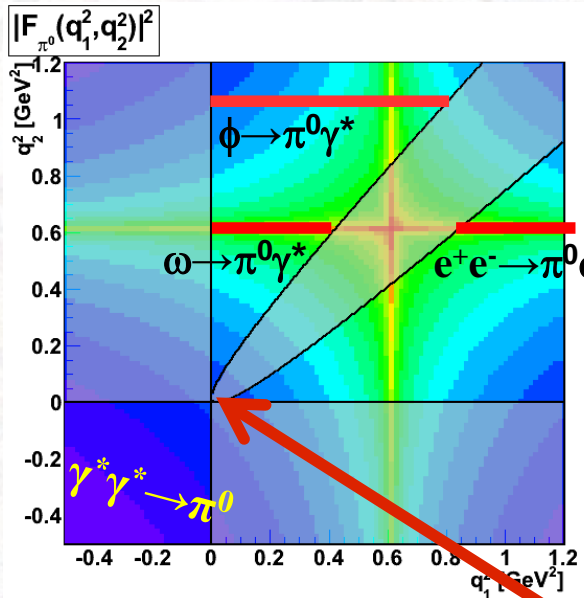
$$\Gamma(P \rightarrow \gamma\gamma)$$



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



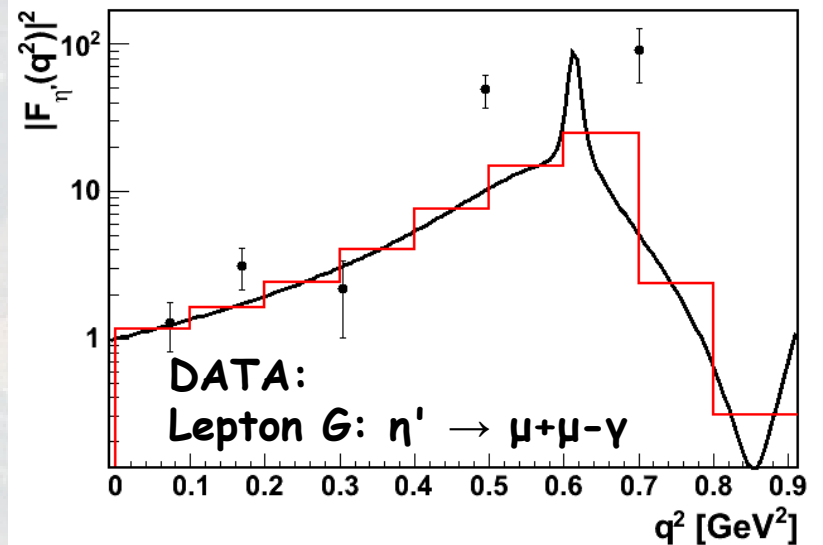
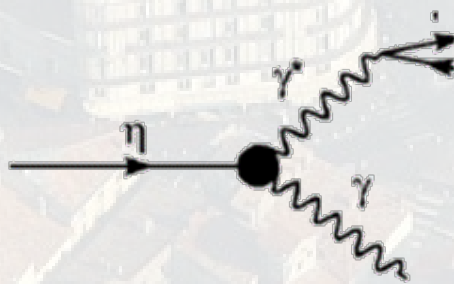
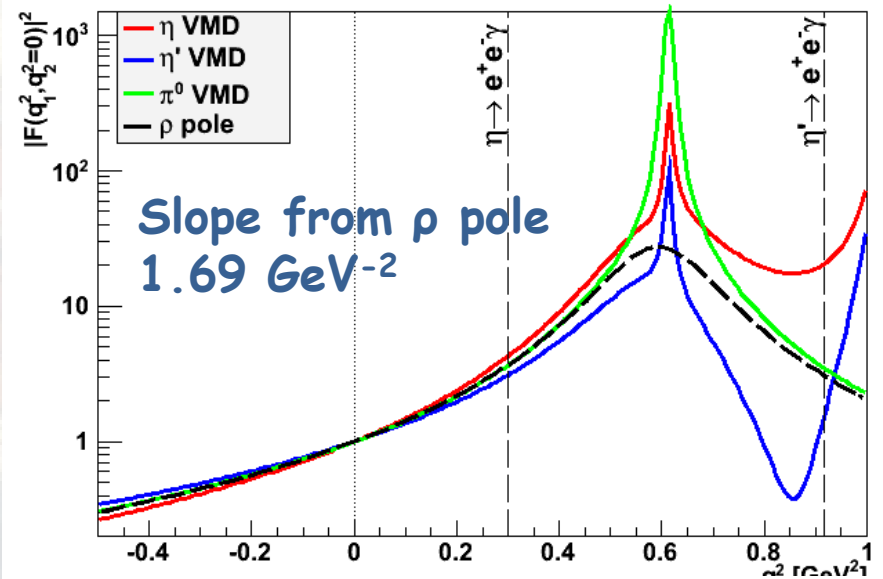
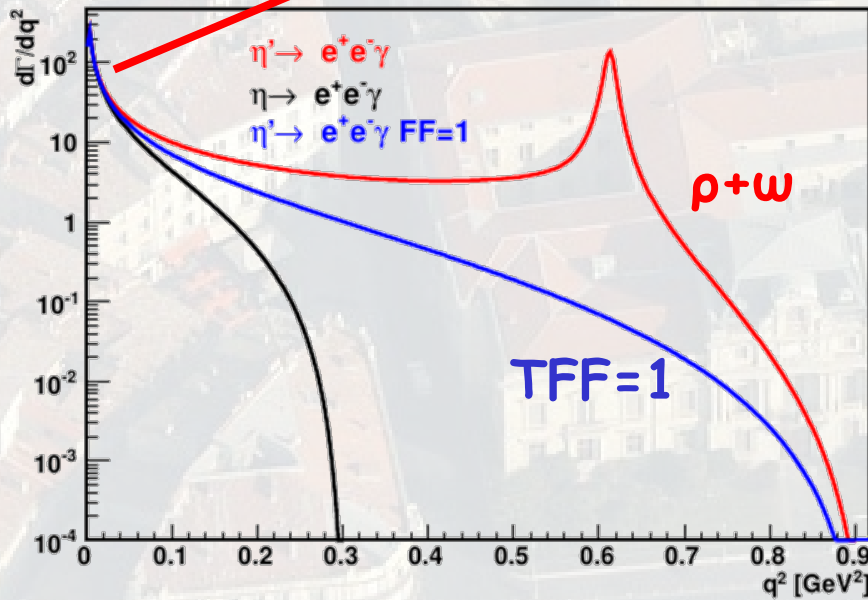
HLbL for $\alpha\mu$



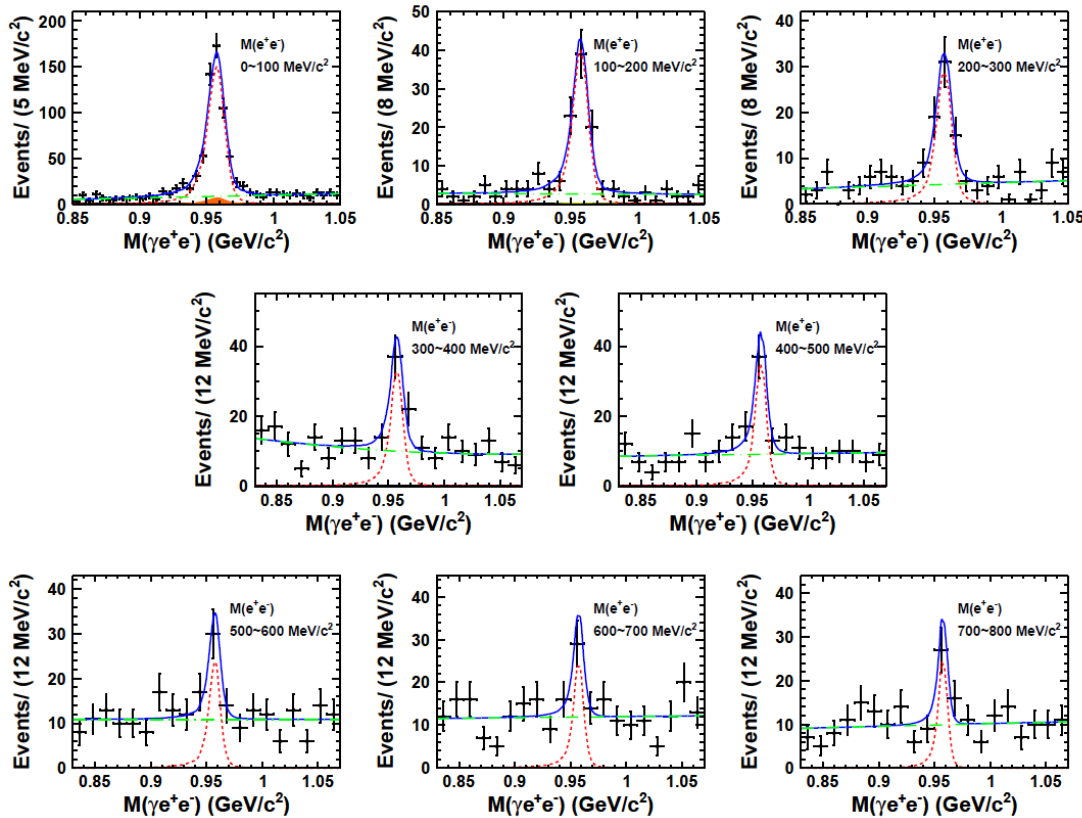
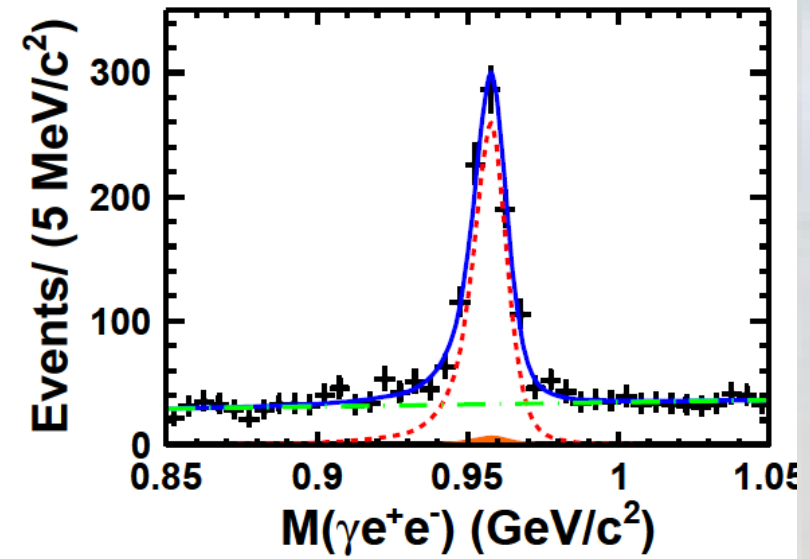
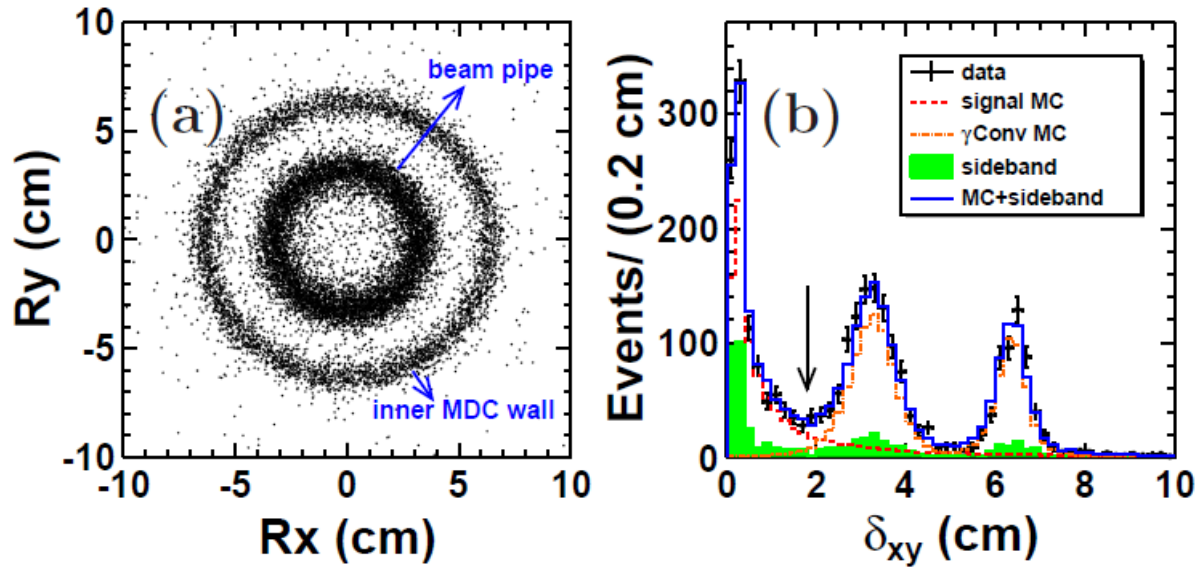
$$P \rightarrow \gamma^* \gamma^*$$

Dalitz decays

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



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



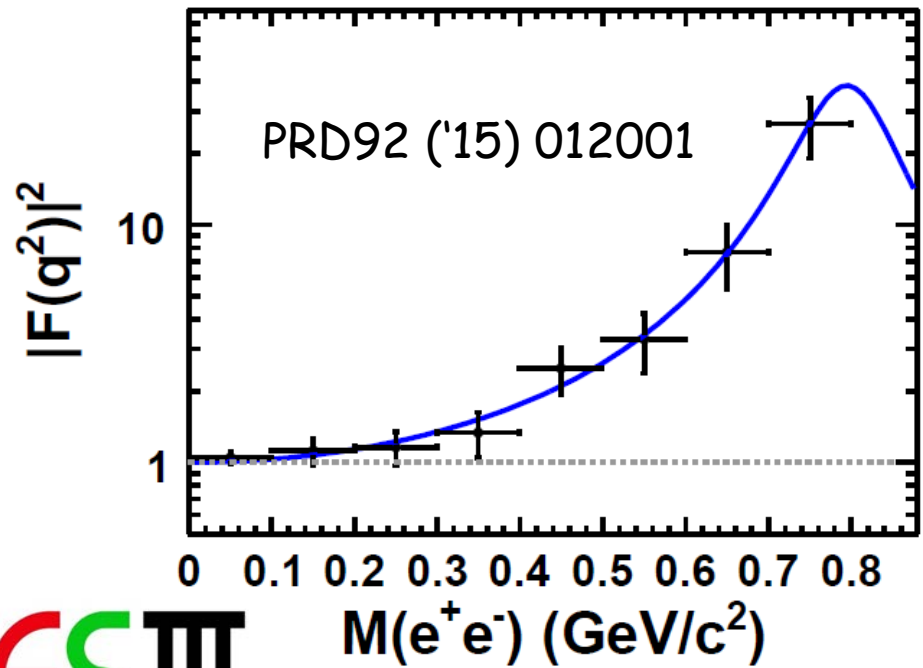
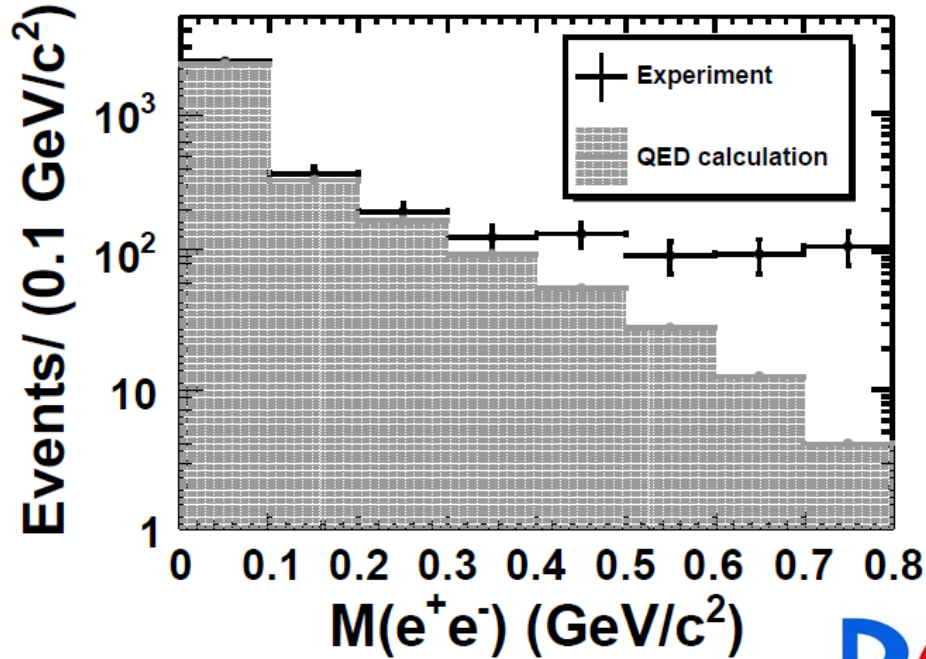
$$\Gamma(\eta' \rightarrow \gamma e^+ e^-) / \Gamma_{\gamma\gamma} = (2.13 \pm 0.09 \pm 0.07)\%$$

TFF=1: 1.8 %

PRD92 ('15) 012001

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Transition form factor $\eta' \rightarrow \gamma e^+ e^-$



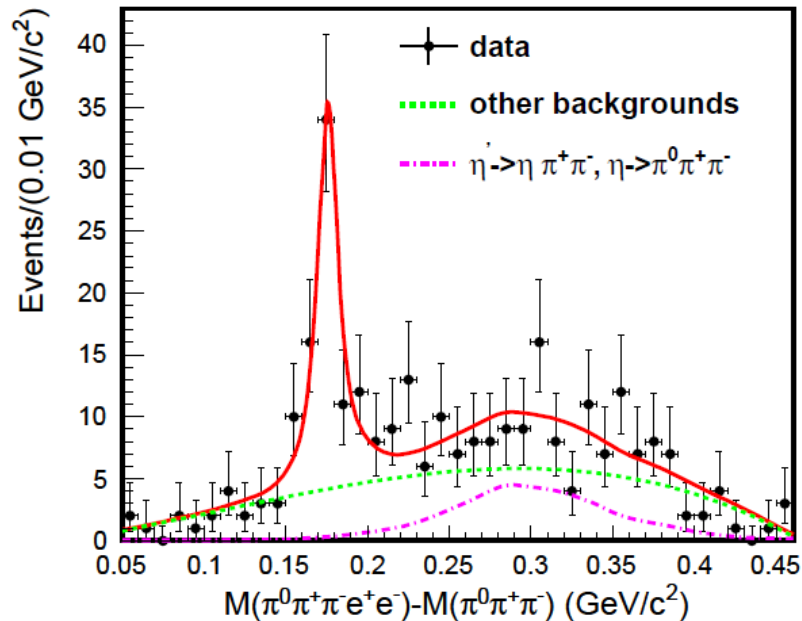
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Observation of $\eta' \rightarrow \omega e^+ e^-$

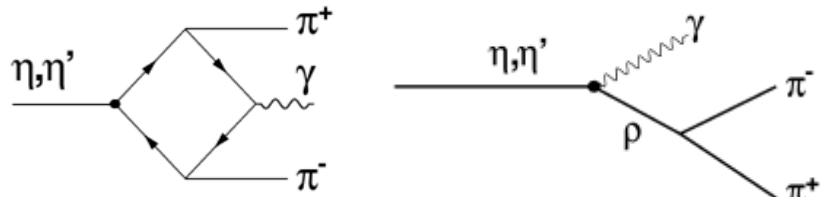
$$\Gamma(\eta' \rightarrow \omega e^+ e^-) / \Gamma(\eta' \rightarrow \omega \gamma) = (7.71 \pm 1.34_{\text{stat}} \pm 0.54_{\text{syst}}) \times 10^{-3}$$

$$\text{TFF}=1: 6.8 \times 10^{-3}$$

PRD92 ('15) 051101



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



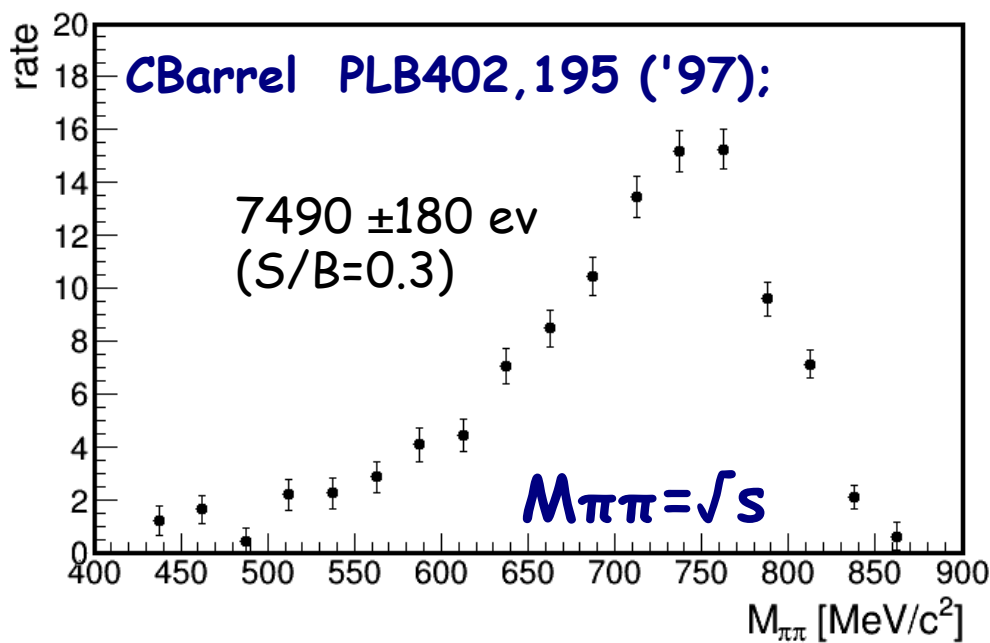
$$\frac{d\Gamma_{\eta(\eta')}}{ds_{\pi\pi}} \propto \left| C + \frac{1}{s_{\pi\pi} - m_\rho^2 - im_\rho\Gamma_\rho} \right|^2$$

$$\frac{d\Gamma}{ds} = |A(1 + \alpha s + \dots)F_V(s)|^2 K_P(s)$$

PLB707 ('12) 184

$e^+e^- \rightarrow \pi^+\pi^-$

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



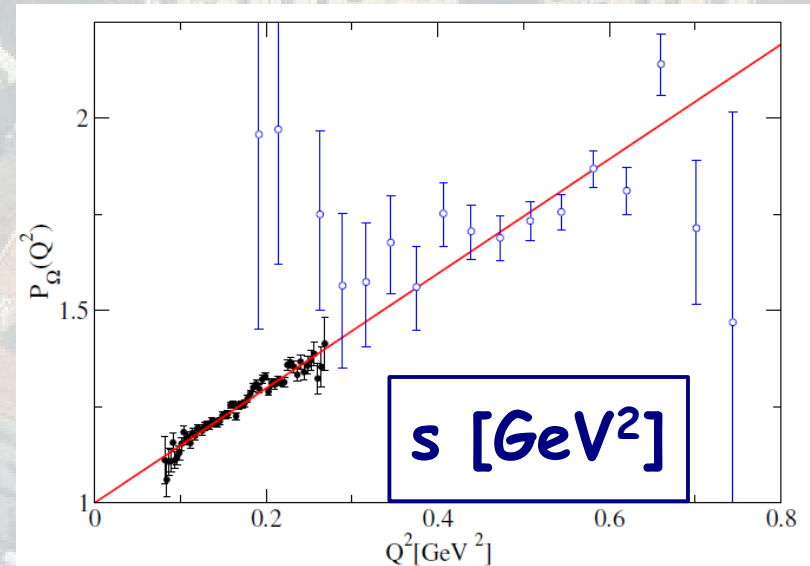
$\eta \rightarrow \pi^+\pi^-\gamma$

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

WASA PLB707 ('12) 243

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

KLOE PLB718 ('13) 910

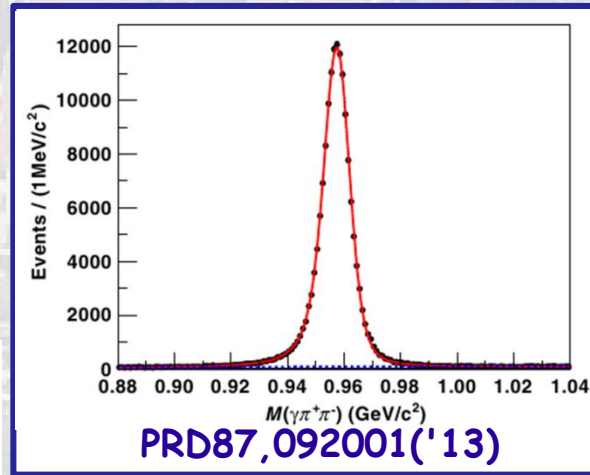


Prel. analysis based on $0.9 \times 10^6 \eta \rightarrow \pi^+\pi^-\gamma$

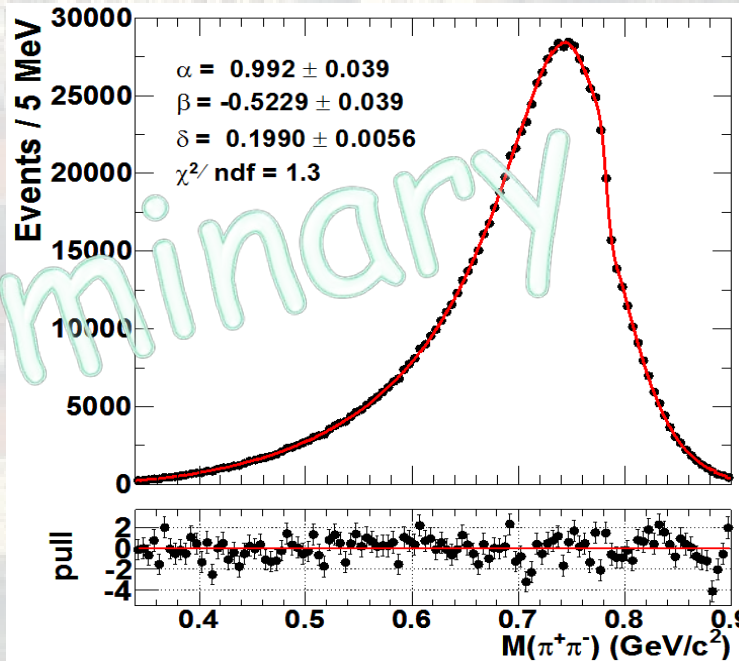
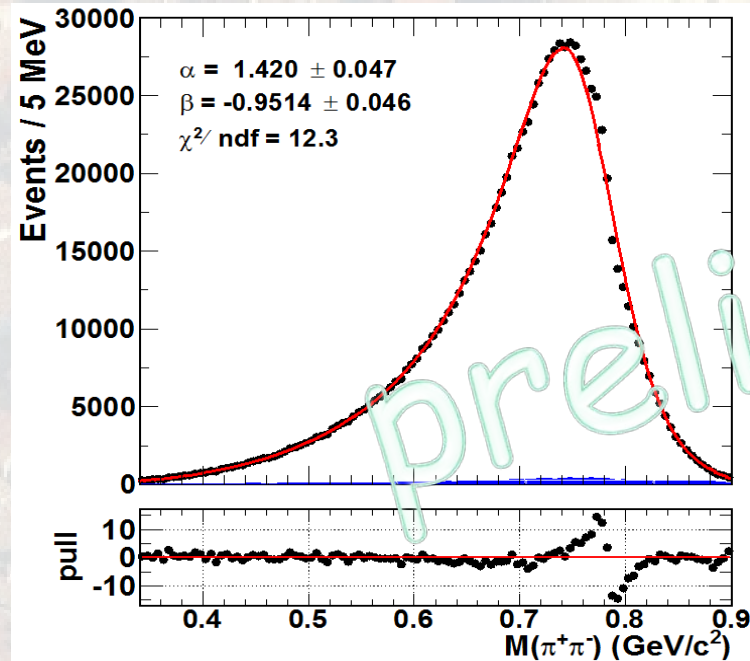
$$\frac{d\Gamma}{ds_{\pi\pi}} = |AP(s_{\pi\pi})F_V(s_{\pi\pi})|^2 \Gamma_0(s_{\pi\pi})$$

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

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



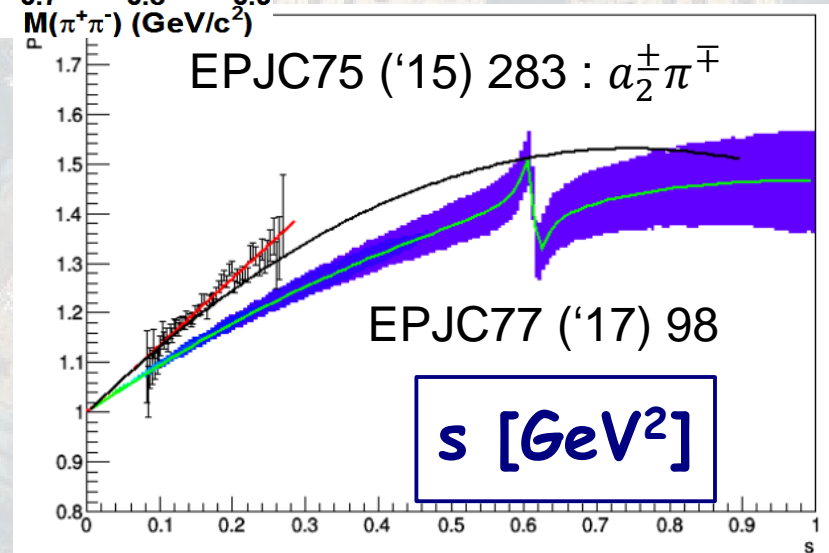
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ω contribution necessary

Linear polynomial is insufficient...

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

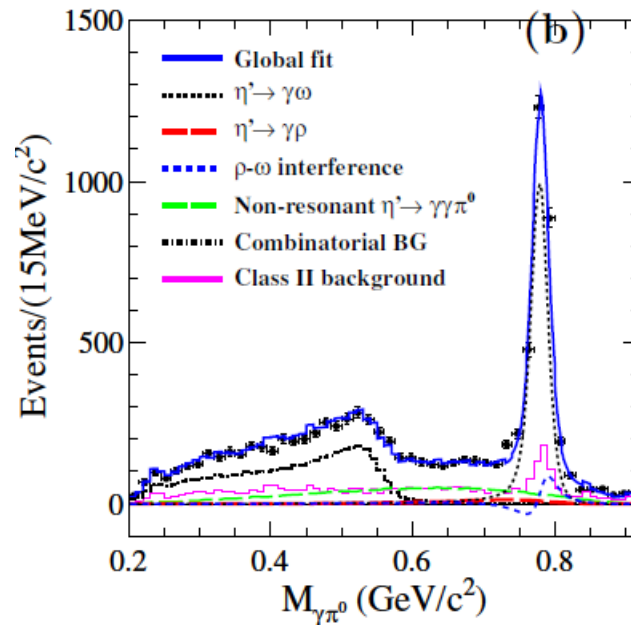
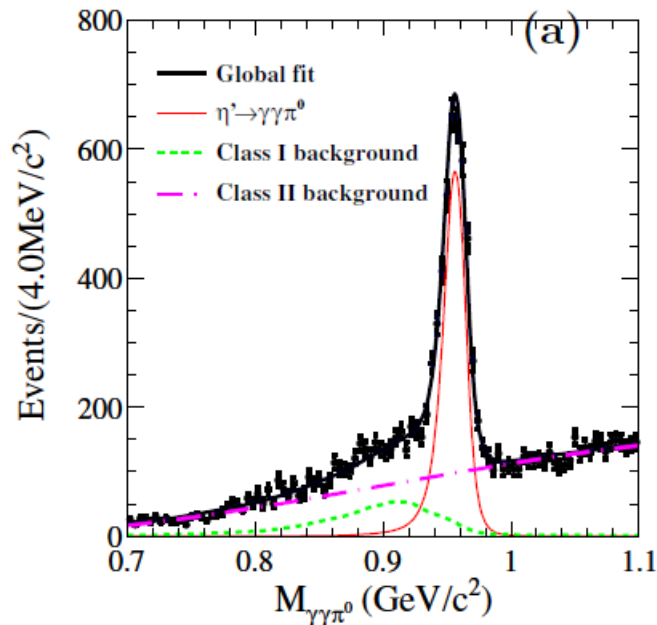
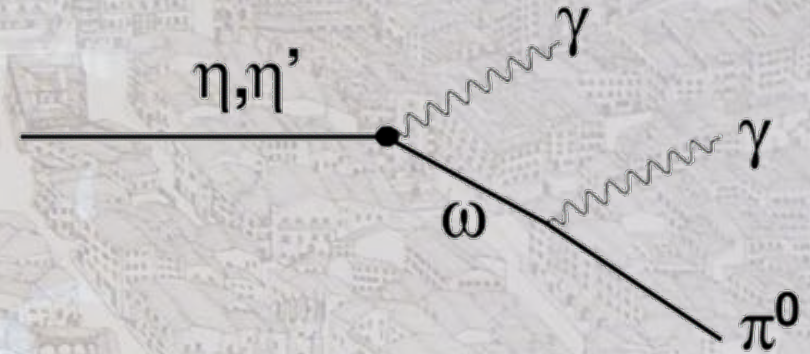


$$\eta' \rightarrow \pi^0 \gamma \gamma$$

	VMD	Exp	(BRx10 ⁴)
$\eta \rightarrow \pi^0 \gamma \gamma$	2.1	2.7 ± 0.5	
$\eta' \rightarrow \omega[\pi^0 \gamma] \gamma$		22	
$\eta' \rightarrow \pi^0 \gamma \gamma$	3	<8 (90% CL)	GAMS(87)
$\eta' \rightarrow \eta \gamma \gamma$	2.5	—	

$$\eta' \rightarrow \omega[\pi^0 \gamma] \gamma + \rho[\pi^0 \gamma] \gamma + \dots :$$

65x10⁻⁴ PoS CD12 (2013) 035



BES III

PRD96 (17) 012005

PWA $\eta' \rightarrow \eta \pi \pi$

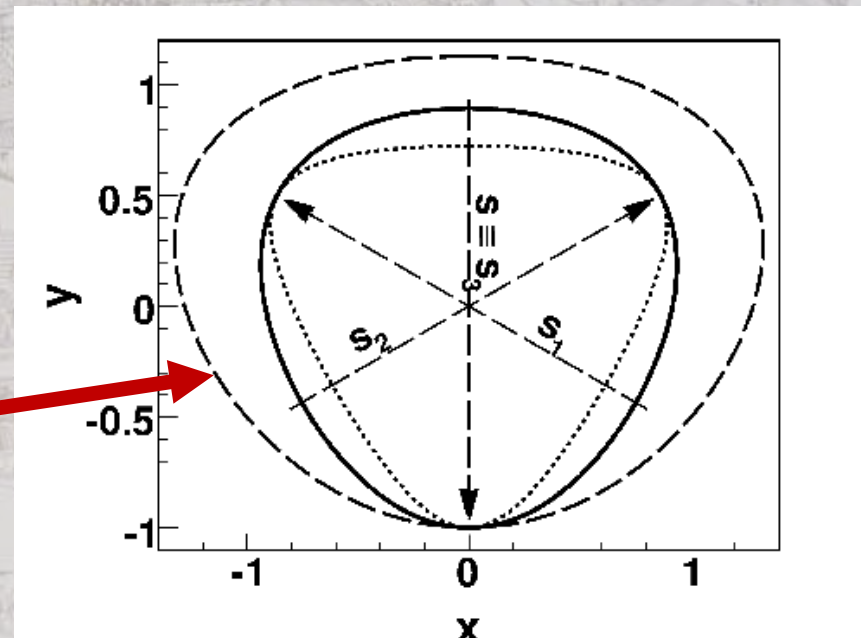
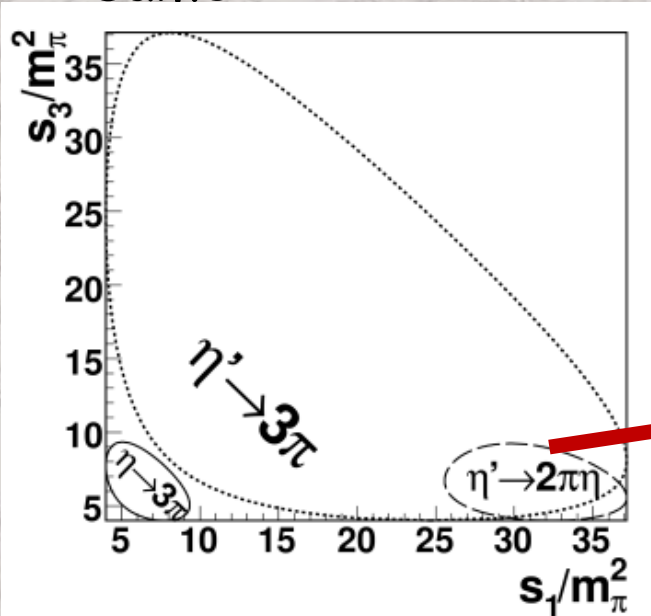
follow up of BESIII, PRD83, 012003 ('11)

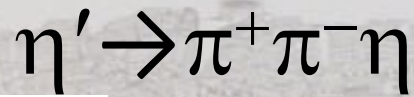
- Dalitz plot variables X, Y for $\eta' \rightarrow \pi^+ \pi^- \eta$:

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

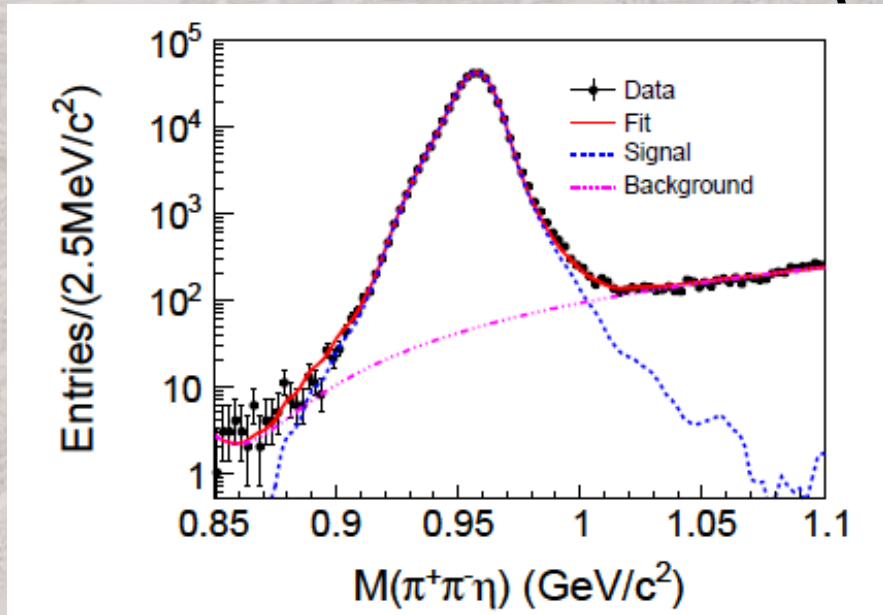
where T are the kinetic energies in η' rest frame

- Expansion $|A(X, Y)|^2 \propto 1 + aY + bY^2 + cX + dX^2 + \dots$
- For amplitude linear in Y : $|A(X, Y)|^2 \propto |1 + \alpha Y|^2 + cX + dX^2 + \dots$
where α is complex parameter
- The two are equivalent if $b > \alpha^2/4 > 0$
- In the isospin limit coefficients for $\eta' \rightarrow \pi^+ \pi^- \eta$ and $\eta' \rightarrow \pi^0 \pi^0 \eta$ are the same





arXiv 1709.04627

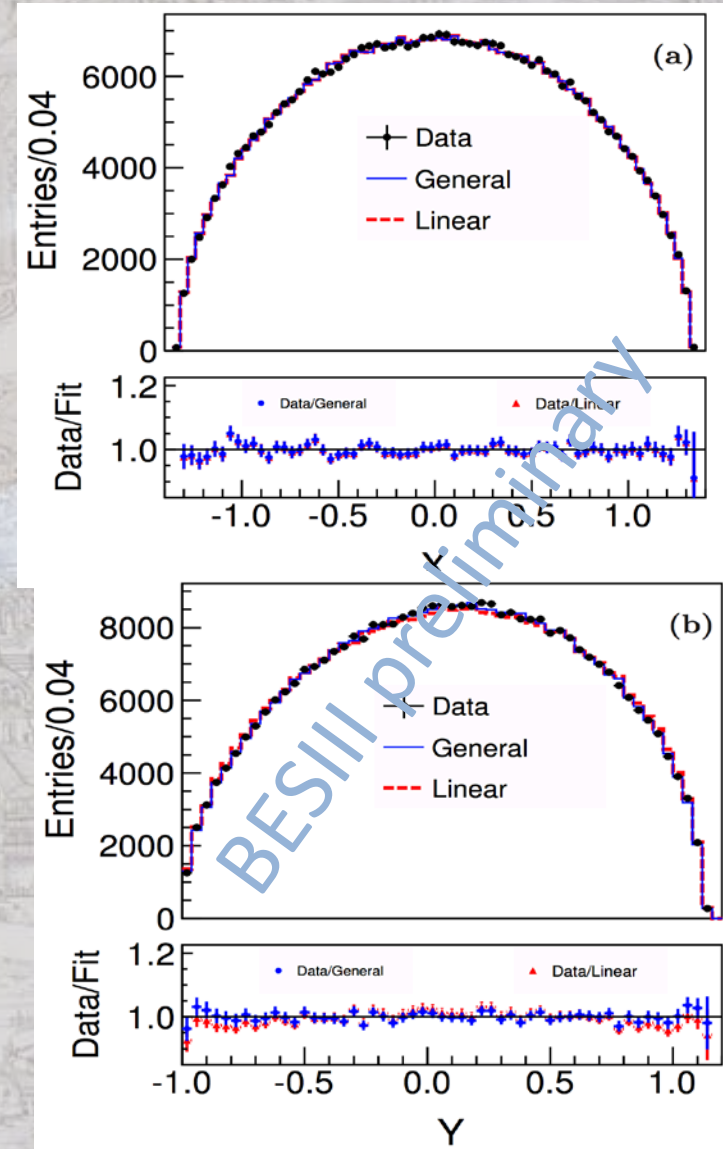


351016 events 0.3% background

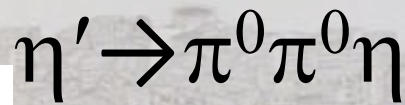
General parameterization

$$\begin{aligned}
 a &= -0.056 \pm 0.004 \pm 0.003 \\
 b &= -0.049 \pm 0.006 \pm 0.006 \\
 c &= (2.7 \pm 2.4 \pm 1.8) \times 10^{-3} \\
 d &= -0.063 \pm 0.004 \pm 0.004
 \end{aligned}$$

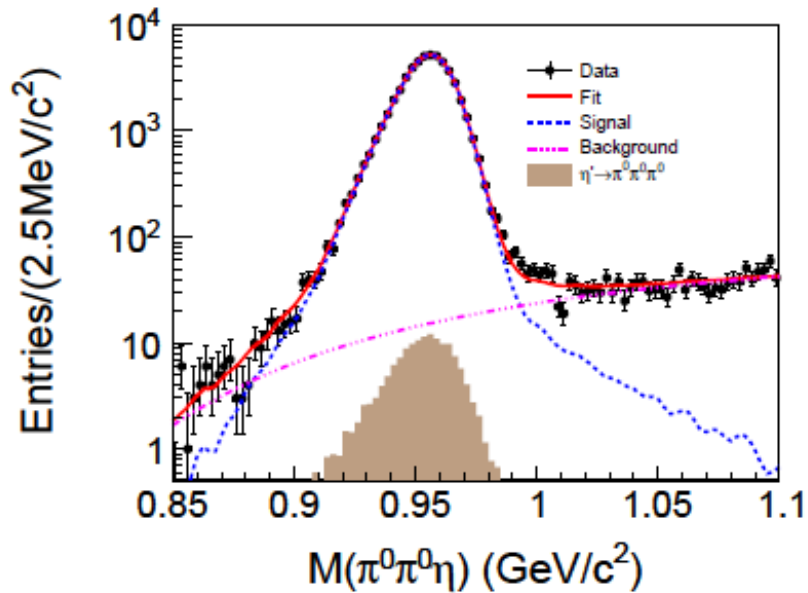
- $b < 0$ (5.8σ) \Rightarrow linear parameterization do not describe the data



The fitted parameters are consistent with and supersede the previous BESIII measurement. The discrepancy with VES value for parameter a is 4.5σ .



arXiv 1709.04627



56249 events 0.9% background

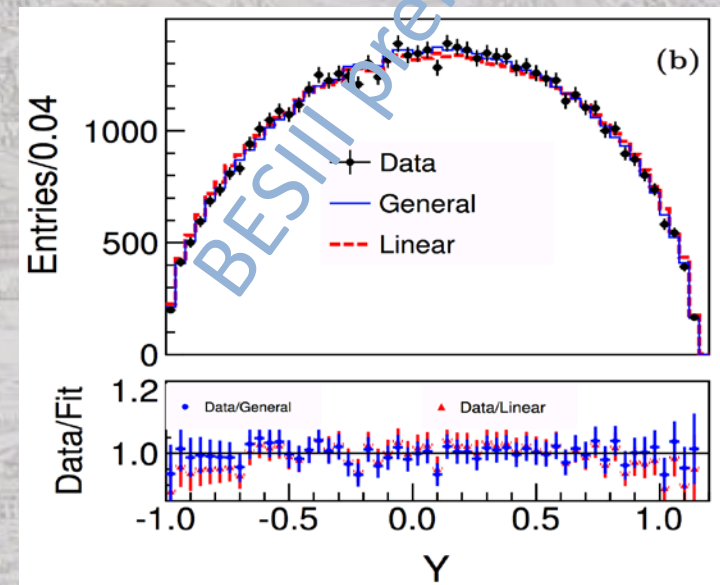
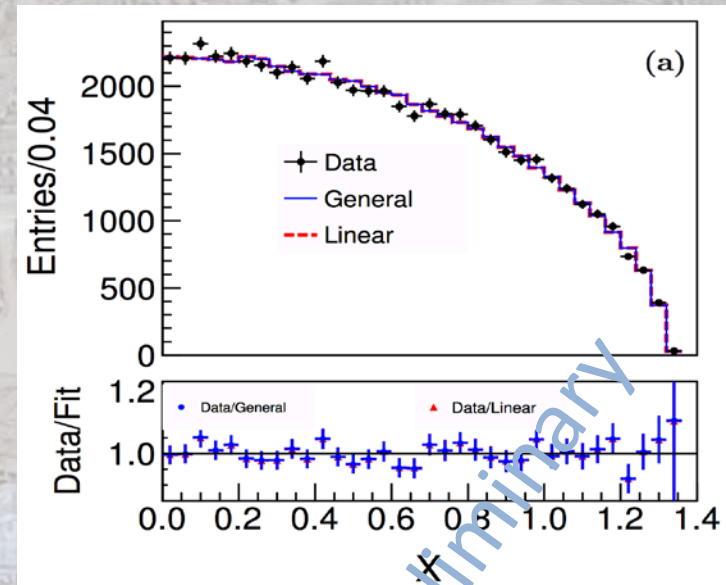
General parameterization

$$a = -0.087 \pm 0.009 \pm 0.006$$

$$b = -0.073 \pm 0.014 \pm 0.005$$

$$d = -0.074 \pm 0.009 \pm 0.004$$

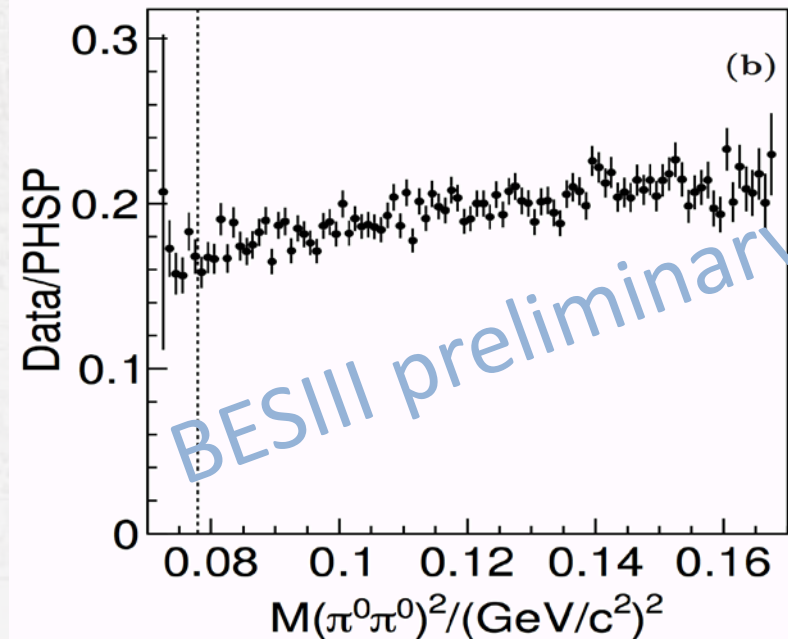
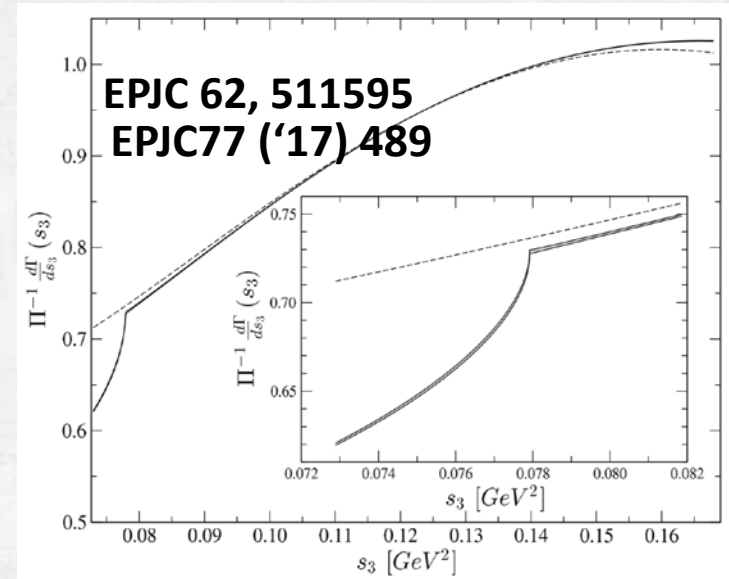
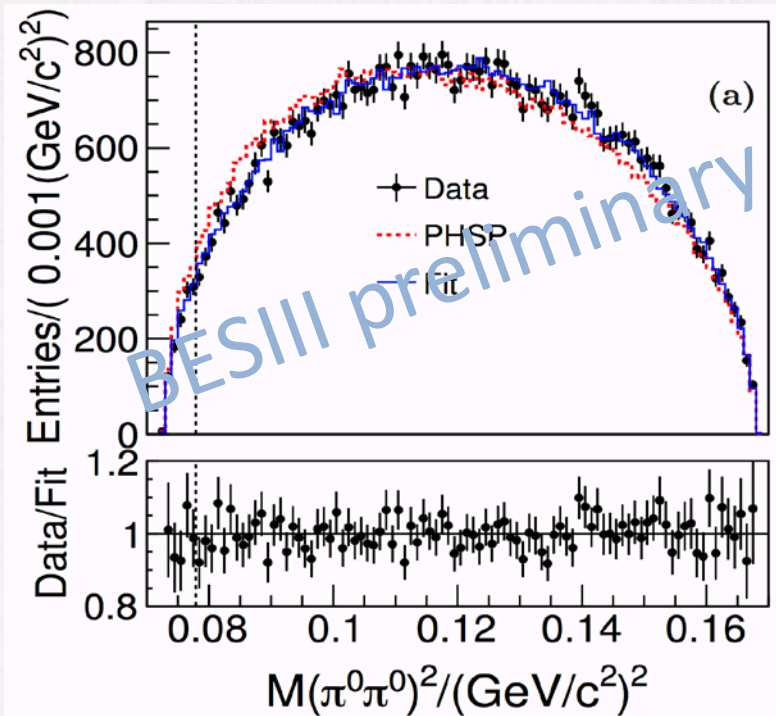
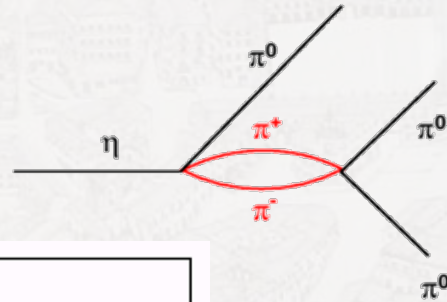
- $b < 0$ (4.9σ) \Rightarrow linear parameterization do not describe the data
- 2.6σ deviation for a between $\eta' \rightarrow \pi^+ \pi^- \eta$ and $\eta' \rightarrow \pi^0 \pi^0 \eta$ processes. Radiative corrections for $\eta' \rightarrow \pi^+ \pi^- \eta$...



Consistent with GAMS- 4π , while better precision.
A2 recent result: arXiv:1709.04230... $1.241(4)(8) \times 10^5$

Search for cusp in $\eta' \rightarrow \pi^0 \pi^0 \eta$

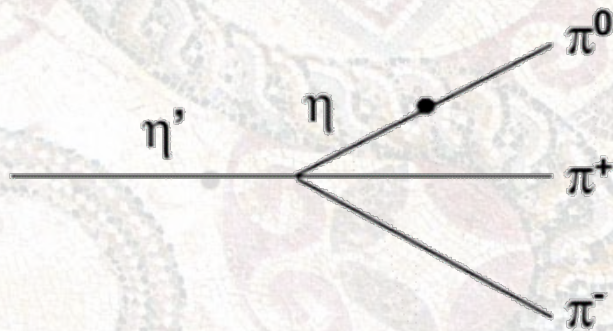
NRFT: cusp $\sim 8\%$ in $\pi^0 \pi^0$ mass spectrum at $\pi^0 \pi^0 \rightarrow \pi^+ \pi^-$ threshold



No statistically significant structure near the $\pi^+ \pi^-$ threshold

$\eta' \rightarrow \pi\pi\pi$

d-u quark masses



$$\frac{BR(\eta' \rightarrow \pi^+ \pi^- \pi^0)}{BR(\eta' \rightarrow \pi^+ \pi^- \eta)} \quad \text{and} \quad \frac{BR(\eta' \rightarrow \pi^0 \pi^0 \pi^0)}{BR(\eta' \rightarrow \pi^0 \pi^0 \eta)}$$

Gross, Treiman, Wilczek PRD19('79)2188

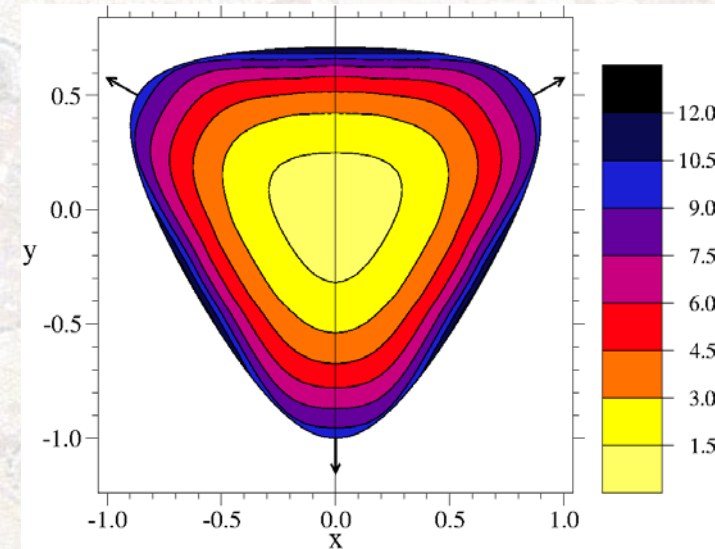
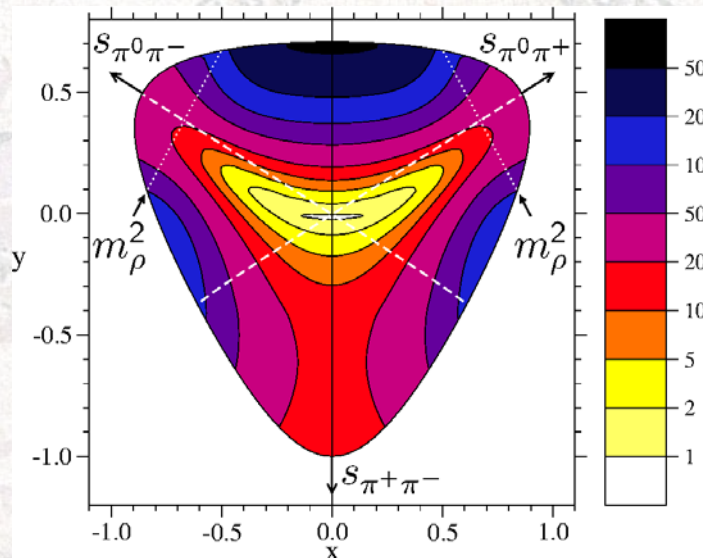
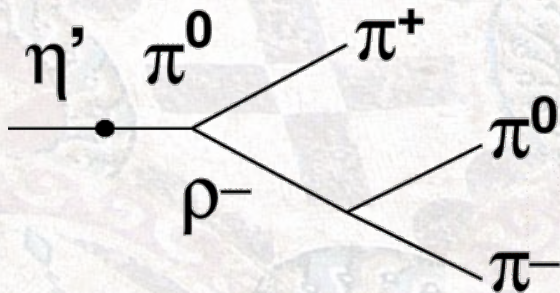
Difficult/dubious:

- other tree diagrams
- rescattering

Borasoy, Nißler, Meißner 06

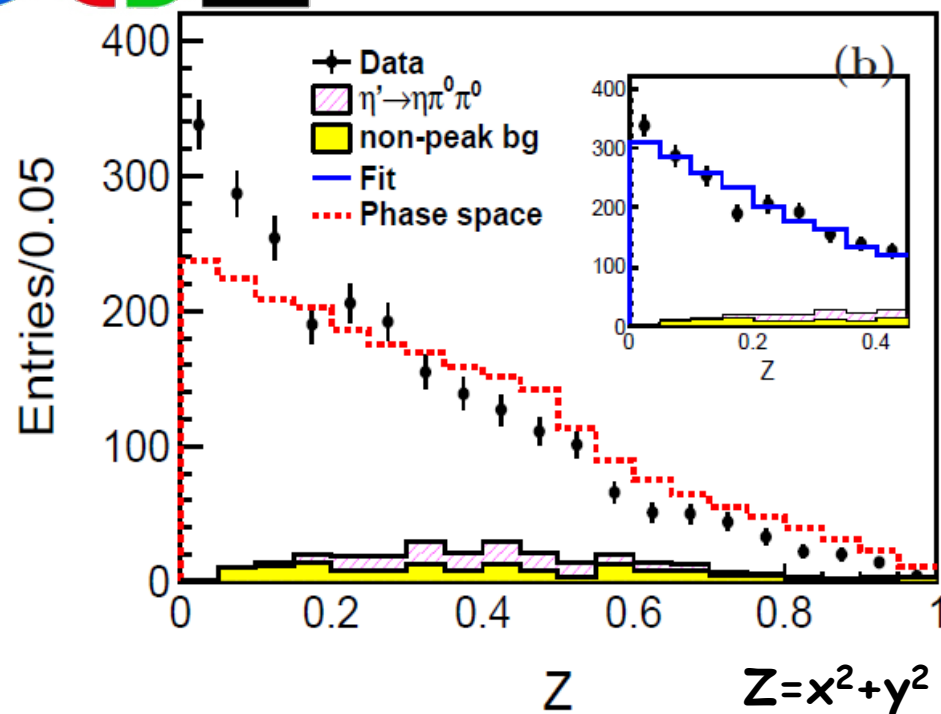
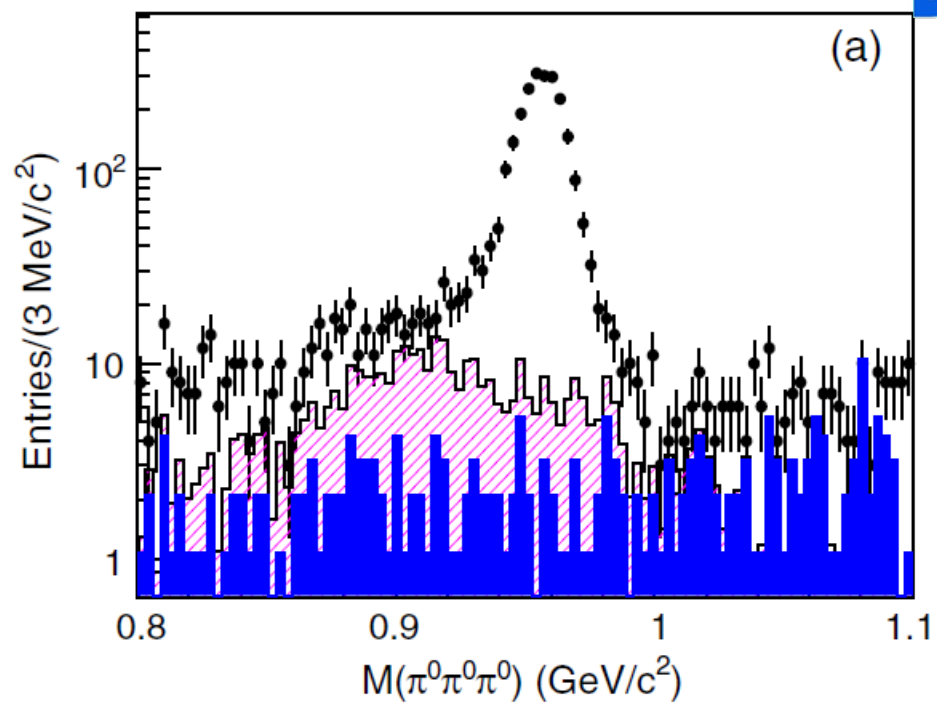
U(3) CHPT, Borasoy, Nißler 2005:

$BR(\eta \rightarrow \pi^+ \pi^- \pi^0) \approx 1.8\%$ large $\rho^+ \pi^- + cc$





BES III

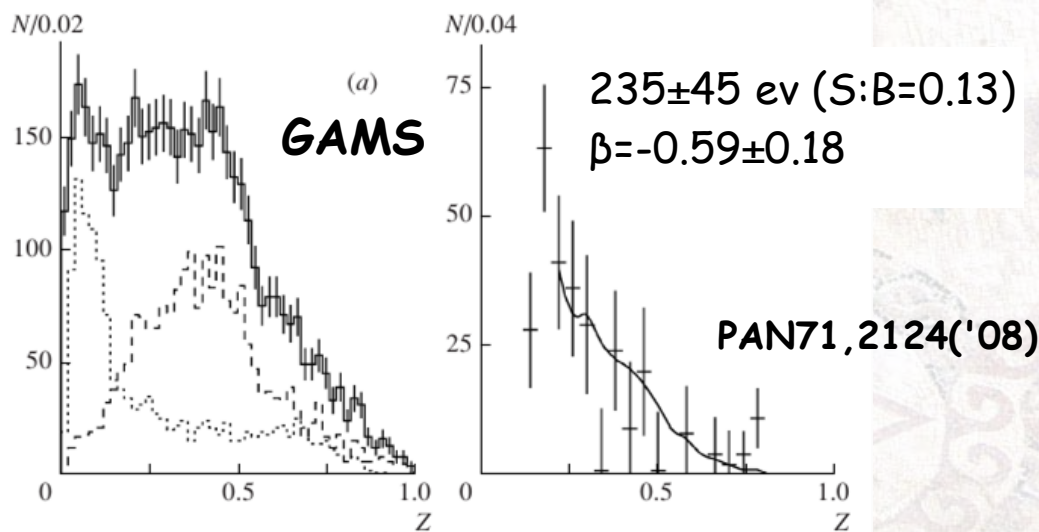


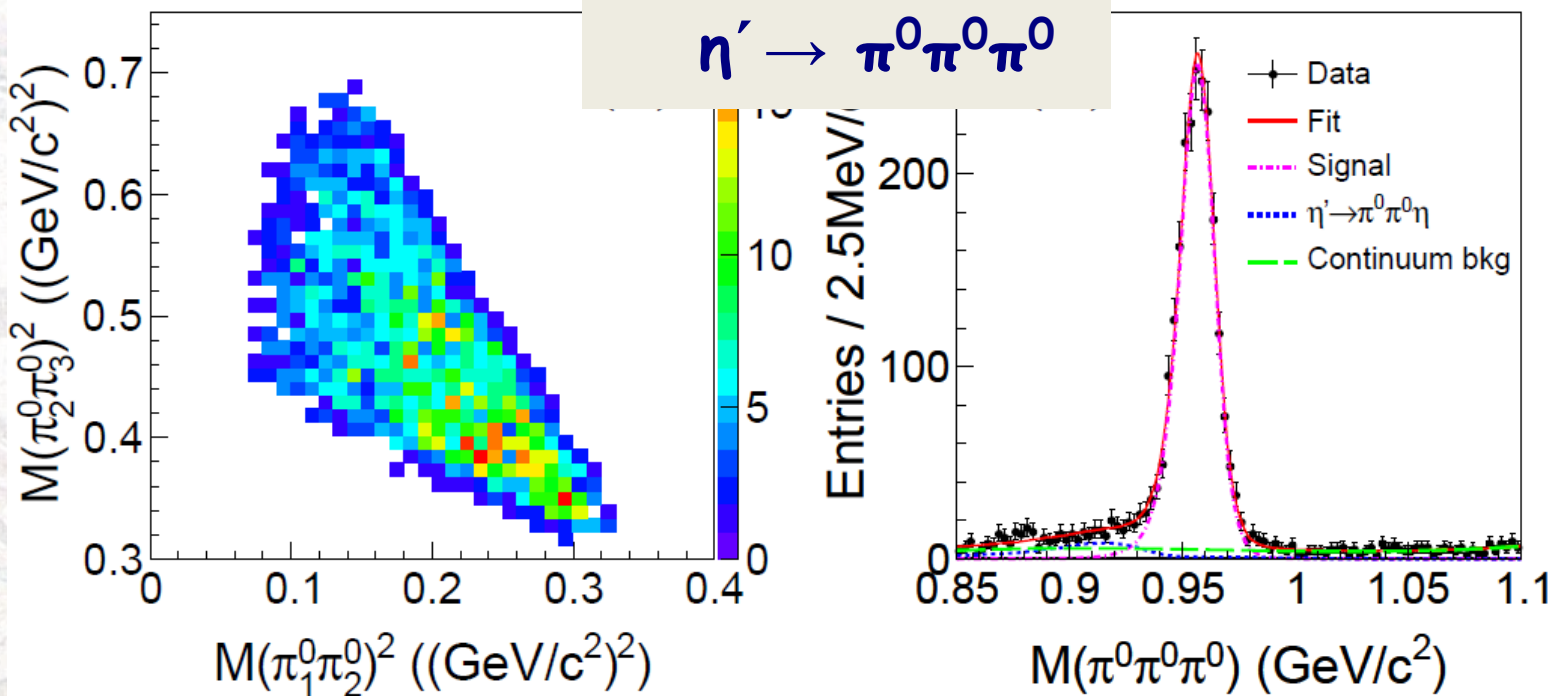
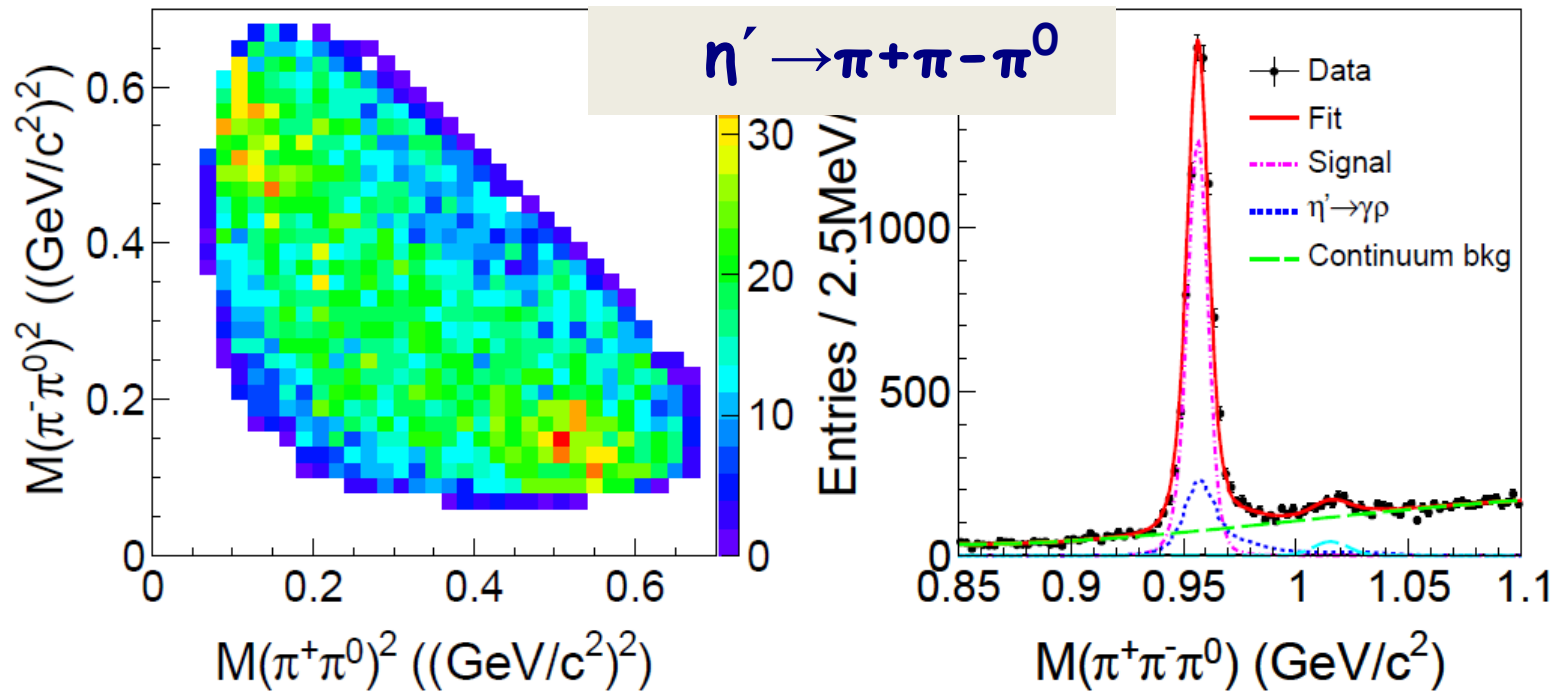
1900 ev

PRD92 ('15) 012014

$$\beta = -0.640 \pm 0.046 \pm 0.047$$

$$|M|^2 \propto 1 + 2\beta Z$$

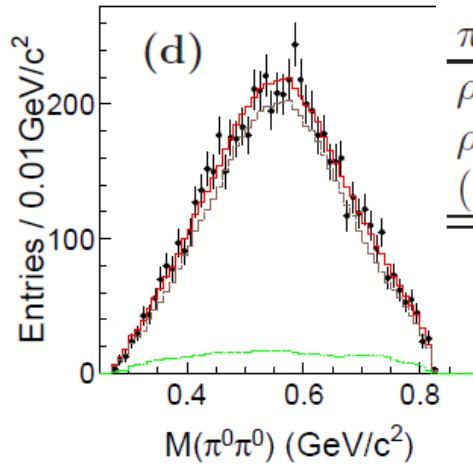
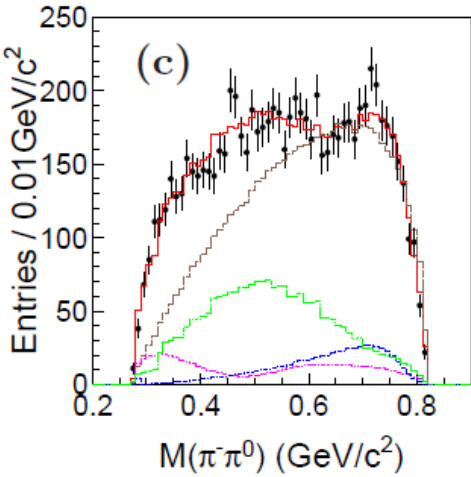
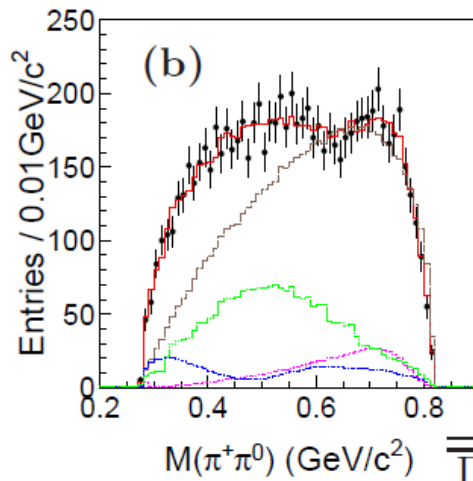
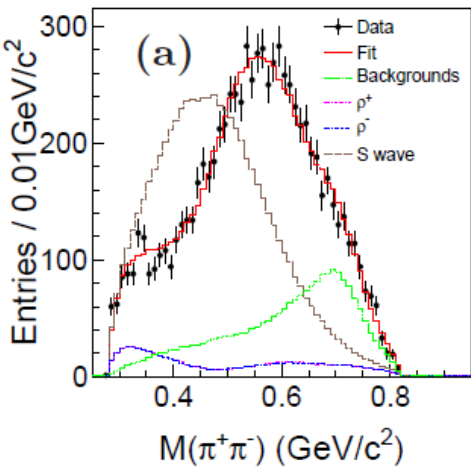




PWA $\eta' \rightarrow \pi\pi\pi$

BES III

PRL118 ('17) 012001



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	$37.63 \pm 0.77 \pm 2.22 \pm 4.48$

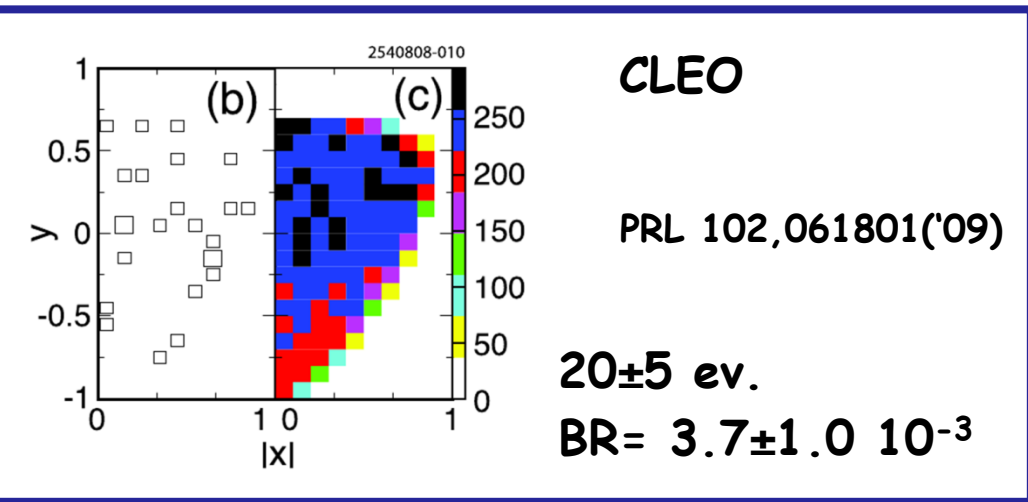
$$\mathcal{B}(\eta' \rightarrow \rho^+\pi^- + cc) = (7.44 \pm 0.60 \pm 1.26 \pm 1.84) \times 10^{-4}$$

$\mathcal{B}(\eta' \rightarrow \pi^0\pi^0\pi^0)$ puzzle

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

vs

BESIII $(159 \pm 12) \times 10^{-4}$



BESIII as η' factory

Decay Mode	Yield	ϵ (%)	\mathcal{B} ($\times 10^{-4}$)	Comment
$\eta' \rightarrow \pi^+\pi^-\pi^0$	6067 \pm 91	25.3	35.91 \pm 0.54 \pm 1.74	previously 20 evts.
$(\pi^+\pi^-\pi^0)_S$	6580 \pm 130	26.2	37.63 \pm 0.77 \pm 2.22 \pm 4.48	first measurement
$\eta' \rightarrow \pi^0\pi^0\pi^0$	2015 \pm 47	8.8	35.22 \pm 0.82 \pm 2.60	previously 235 evts.
$\eta' \rightarrow e^+e^-\gamma$	864 \pm 36	24.5	4.69 \pm 0.20 \pm 0.23	first measurement
$\eta' \rightarrow e^+e^-\omega$	66 \pm 11	5.45	1.97 \pm 0.34 \pm 0.17	first measurement
$\eta' \rightarrow \gamma\gamma\pi^0$	655 \pm 68	15.9	6.16 \pm 0.64 \pm 0.67	first measurement
$\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$	199 \pm 16	34.5	0.853 \pm 0.069 \pm 0.069	first measurement
$\eta' \rightarrow \pi^+\pi^-\pi^0\pi^0$	84 \pm 16	7.0	1.82 \pm 0.35 \pm 0.18	first measurement

BESIII: 1.31×10^9 J/ Ψ \rightarrow 6×10^6 η'

- ca 100x world stat.
- low background

Goal: 10^{10} J/ Ψ