η_c Decays at BESIII

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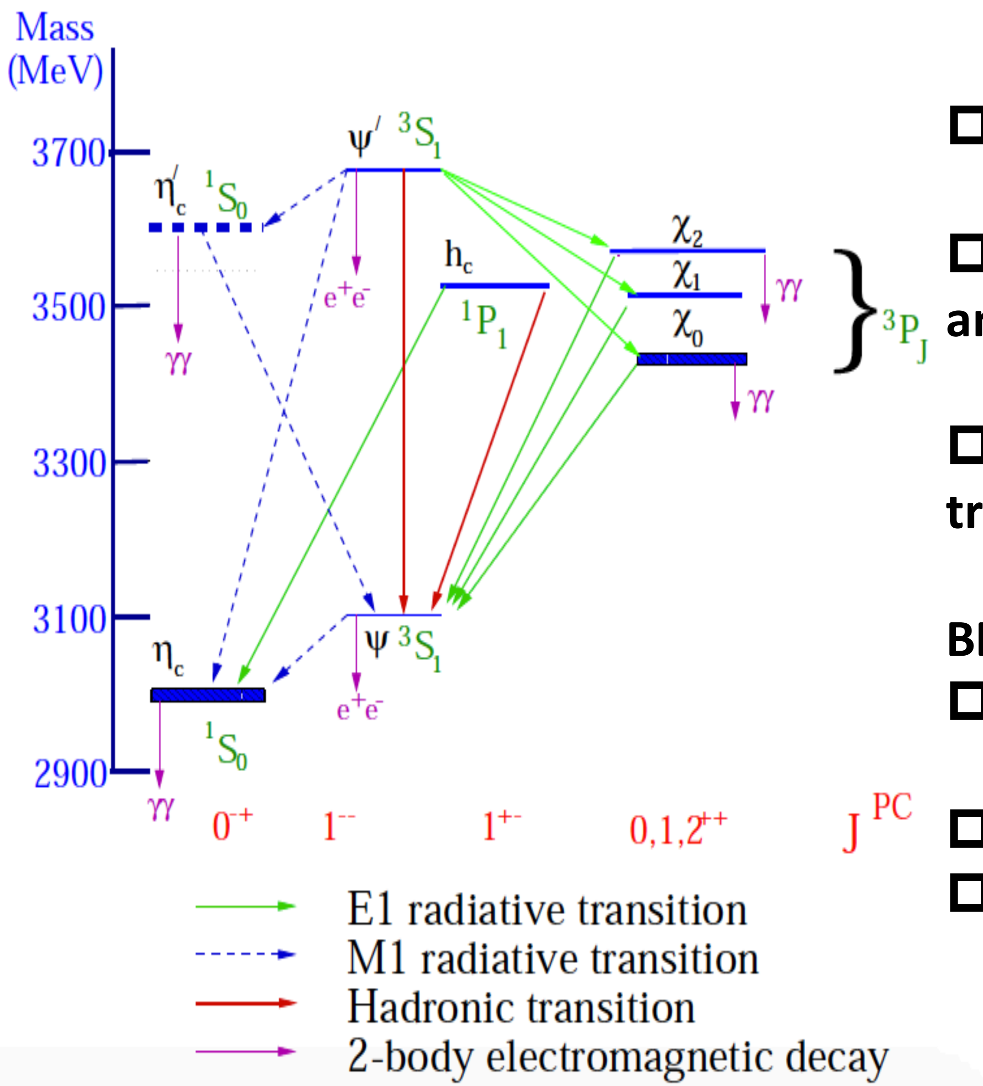
Outline

- Introduction
- $Br(\eta_c \rightarrow VV)$
  - $\eta_c \rightarrow \phi\phi, \omega\phi$
  - $\eta_c \rightarrow \omega\omega$
- Search for $\psi(3686) \rightarrow \gamma\eta_c \rightarrow \gamma\pi^+\pi^-\pi^0$
- $e^+e^- \rightarrow \pi^+\pi^- h_c, h_c \rightarrow \gamma\eta_c, \eta_c \rightarrow hadrons$ with XYZ data
- Summary

Introduction

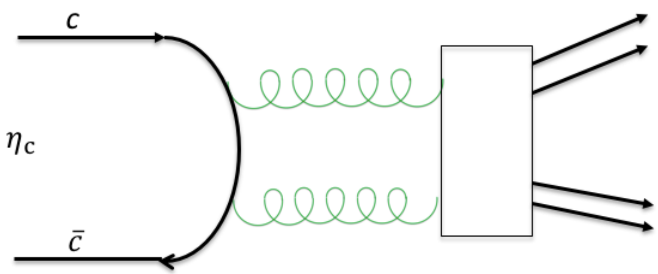


- ☐ η_c is the lowest lying charmonium state
- ☐ η_c can't be generated directly from e^+e^- annihilation
- ☐ η_c can be generated from the radiative transition of J/ψ, ψ' or h_c

BESIII data samples:

- ☐ J/ψ: 0.225Billion(2009), 1.09B(2012), 8.5B(2018)
- ☐ $\psi(3686)$: 106M(2009), 341M(2012)
- ☐ XYZ: 12fb^{-1} (Ecms> 3.8 GeV)

Introduction



- η_c mainly decay through the 2 gluons.
- η_c→VV is suppressed(forbidden) by pQCD at the leading-twist order because it violate the Helicity Selection Rule(HSR)

$$\mathrm{BR}_{J_{c\bar{c}}(\lambda)\to h_1(\lambda_1)h_2(\lambda_2)} \sim \left(\frac{\Lambda_{\mathrm{QCD}}^2}{m_c^2}\right)^{|\lambda_1+\lambda_2|+2},$$

PRD 81, 014017 (2010)

Or $\sigma_c \neq \sigma_1\sigma_2$, where $\sigma = P(-1)^J$ is the naturalness of the particle

- When higher order correction is taken into consideration in pQCD, the decay branching fraction can become significant

$$Br(\eta_c \to VV) \approx 10^{-4}$$

PLB 702 (2011) 49–54

Introduction

- **The experimental result for $Br(\eta_c \to VV) \approx 10^{-2}, 10^{-3}$ which is 1 or 2 orders larger than pQCD predication.**

- **Some non-perturbative mechanism is proposed to explain this, such as**
  - **The intermediate meson loop(IML)** PLB 711 (2012) 364–370
  - **The charmonium light fork component admixture model (η_c, η, η')**

    PLB 702 (2011) 49–54
  - **The $^3P_0$ quark creation mechanism $(\eta_c \to (\eta, \eta') \to VV)$**

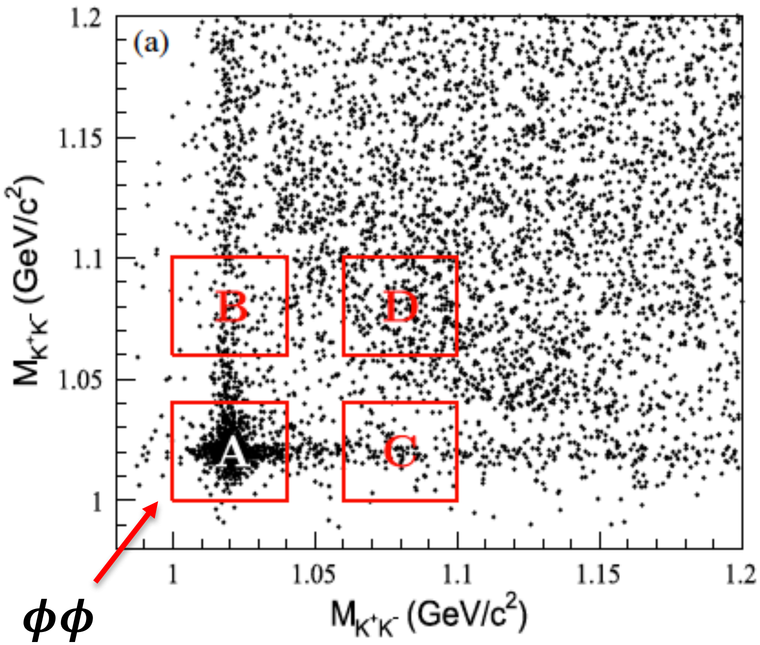
    PRD71, 114002 (2005)

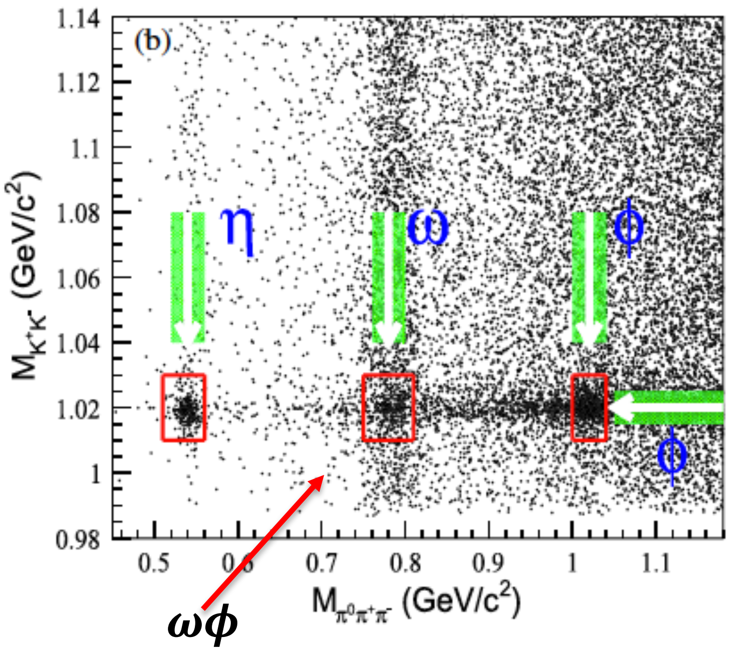
They can give predicated $Br(\eta_c \to VV)$ closer to experimental result.

Branching fractions for $\eta_c \to \phi\phi, \omega\phi$

PRD95, 092004 (2017)

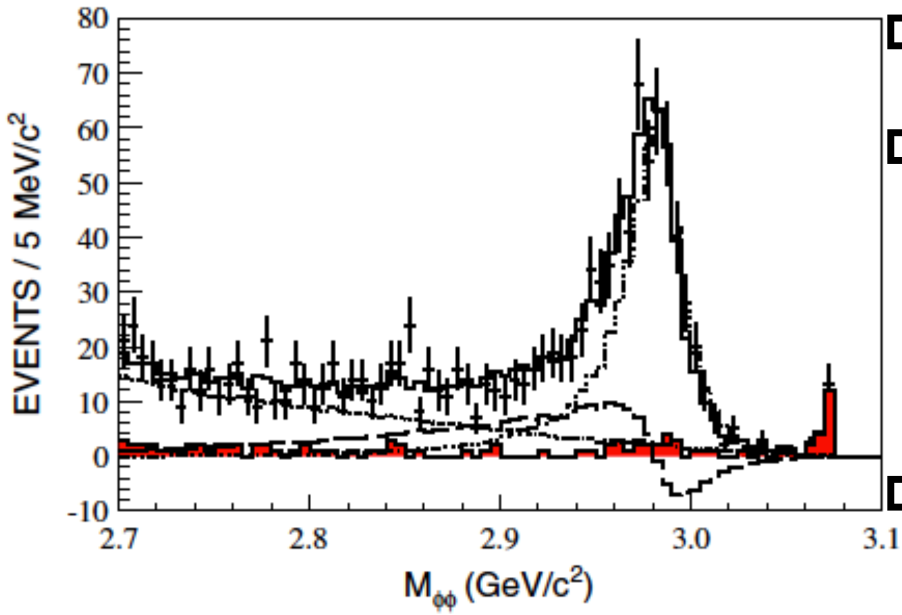
- **Based on $(223.7 \pm 1.4)\times10^6$ J/ψ events.**
- **$J/\psi \to \gamma\eta_c$, $\eta_c \to \phi\phi, \omega\phi$ signal are selected**





- **Clear $\phi\phi$ and $\omega\phi$ clusters can be seen**

PWA for $J/\psi \to \gamma\eta_c$, $\eta_c \to \phi\phi$



- PWA with helicity-covariant formalism is performed.
- η_c is parameterized with the following formula,

$$f(s) = \frac{1}{M^2 - s - iM\Gamma} \frac{\mathcal{F}(E_\gamma)}{\mathcal{F}(E_\gamma^0)},$$

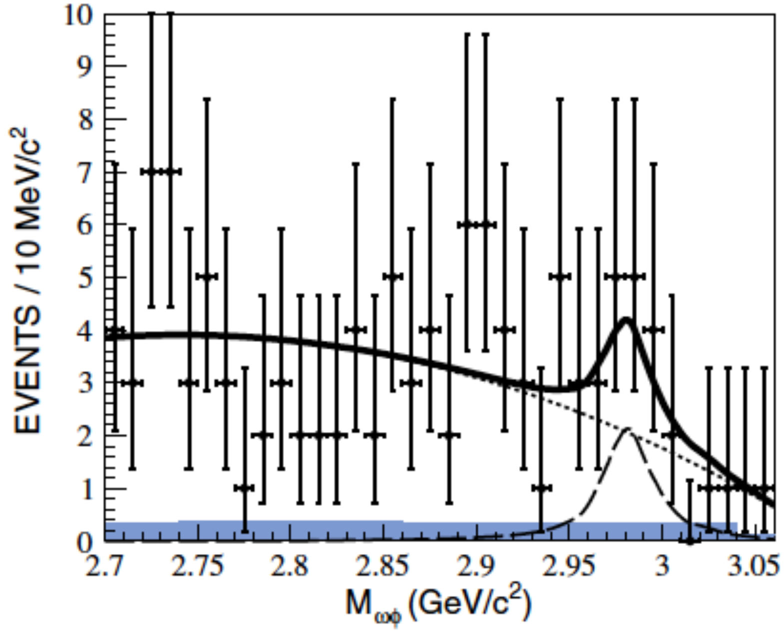
$$\mathcal{F}(E_\gamma) = \exp(-\frac{E_\gamma^2}{16\beta^2}) \text{ with } \beta = 0.065 \text{ GeV}$$

- And the mass and width are fixed to previous BESIII measurement, M=2.984GeV, Γ=0.032GeV

Experiment	$\mathrm{Br}(J/\psi \to \gamma\eta_c)$ $\mathrm{Br}(\eta_c \to \phi\phi)(\times 10^{-5})$	$\mathrm{Br}(\eta_c \to \phi\phi)(\times 10^{-3})$
BESIII	$4.3 \pm 0.5^{+0.5}_{-1.2}$	$2.5 \pm 0.3^{+0.3}_{-0.7} \pm 0.6$
BESII [5]	3.3 ± 0.8	1.9 ± 0.6
DM2 [30]	3.9 ± 1.1	2.3 ± 0.8
Theoretical	Prediction	$\mathrm{Br}(\eta_c \to \phi\phi)$ $(\times 10^{-3})$
	pQCD [10]	(0.7–0.8)
	$^3P_0$ quark model [13]	(1.9–2.0)
	Charm meson loop [14]	2.0

- The interference is considered, however PWA also bring larger uncertainty.
- The result is much larger than pQCD, and agree better with several non-perturbative model.

Branching fractions for $\eta_c \rightarrow \omega\phi$



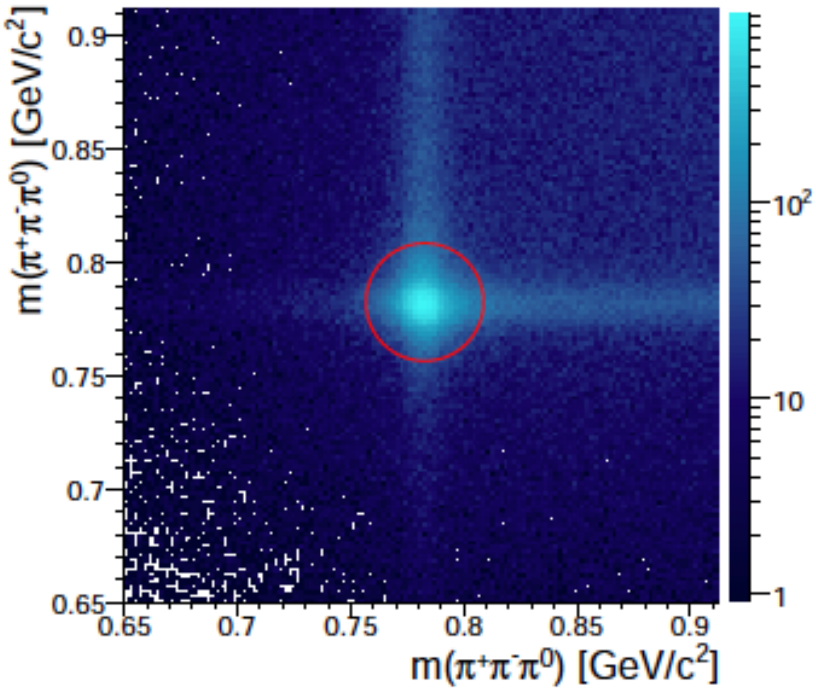
No significant $\eta_c \rightarrow \omega\phi$ events are observed， the uplimit at 90% C.L is given

$$\mathrm{Br}(\eta_c \to \omega\phi) < \frac{N_{\mathrm{up}}}{N_{J/\psi}\epsilon \mathrm{Br}(1-\sigma_{\mathrm{sys}})} = 2.5 \times 10^{-4},$$

Observation of $\eta_c \to \omega\omega$

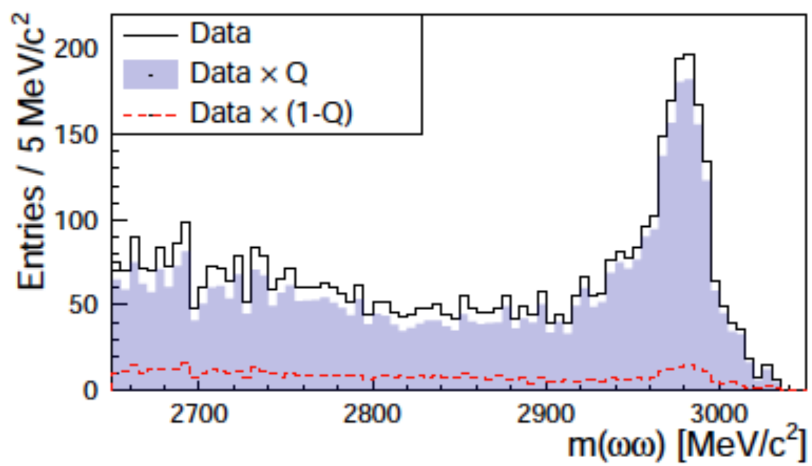
BESIII Preliminary

- **Based on $(1310.6 \pm 7.0)\times 10^6\ J/\psi$ events**

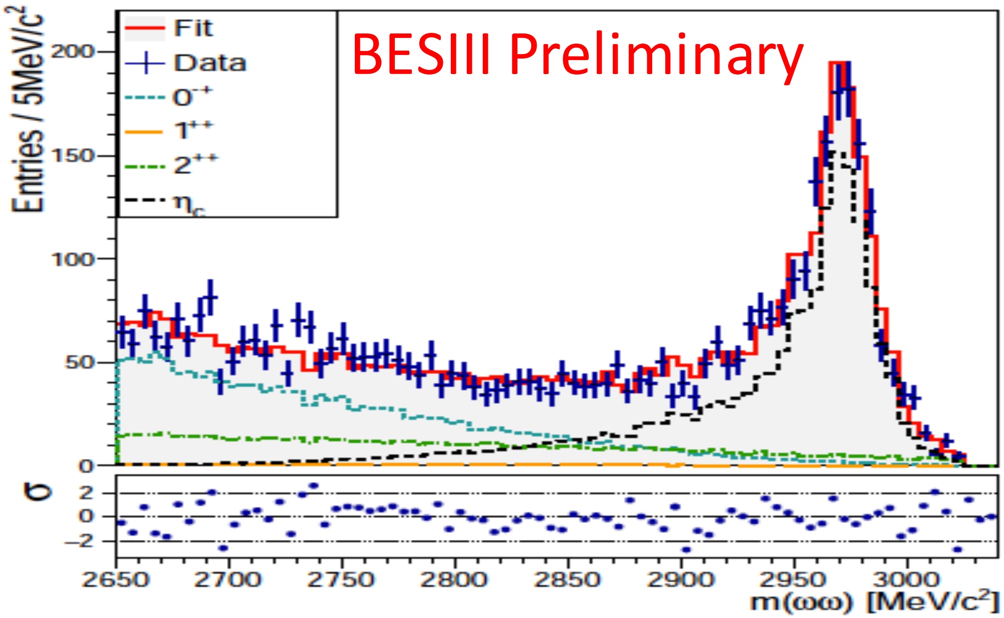


Clear cluster of signal can be seen

- **Remove all non-$\omega\omega$ background using Q-factor method. Based on probabilistic event weights.**
- **4900 $\omega\omega$ events after background subtracted.**



PWA of $J/\psi \to \gamma\eta_c, \eta_c \to \omega\omega$

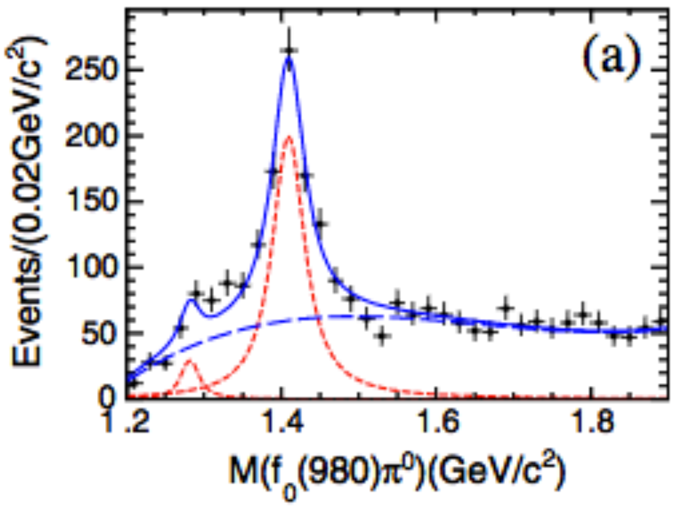


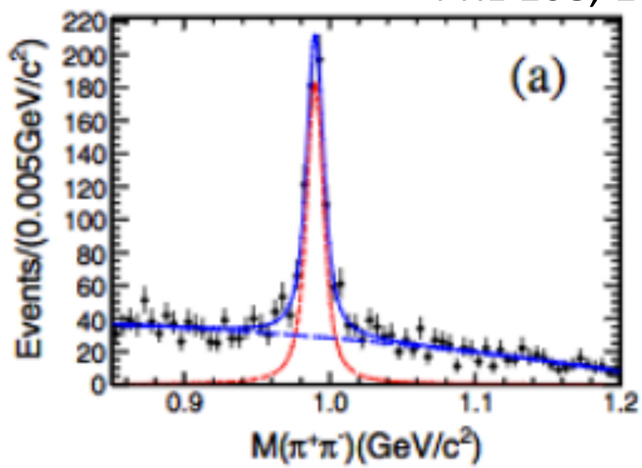
A similar PWA as in $\phi\phi$ channels are also performed

	$Br(\eta_c \to \omega\omega)$
This measurement	$(2.88 \pm 0.1 \pm 0.46 \pm 0.68)\times 10^{-3}$
PDG	$< 3.1\times 10^{-3}$
pQCD (PLB 702 (2011) 49–54)	1.3×10^{-4}
Meson loop (PLB 711 (2012) 364–370)	1.76×10^{-3}
Light fork states mixing	5.2×10^{-3}

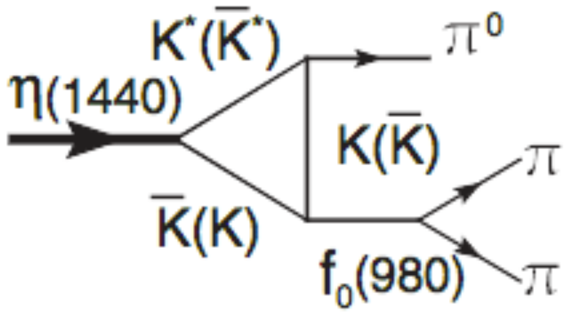
Isospin violated process $\eta(1405) \rightarrow \pi^+\pi^-\pi^0$ was observed, what about $\eta_c \rightarrow \pi^+\pi^-\pi^0$

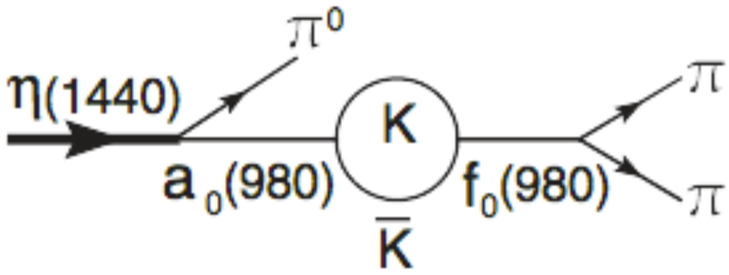
PRL 108, 182001 (2012)





BESIII has observed the $\eta(1405) \rightarrow f_0(980)\pi^0$ which is iso-spin violated process, And the width of f0(980) is very narrow Γ=9.5± 1.1 MeV.





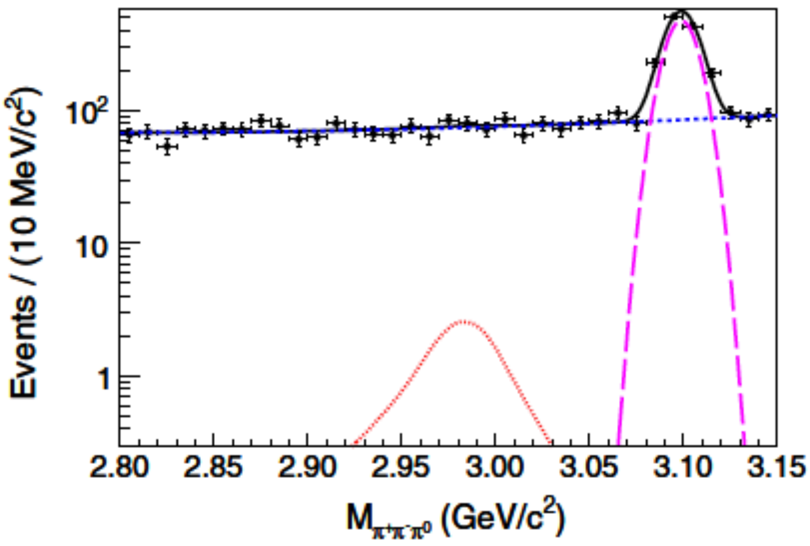
PRL108,081803(2012)

This can be explained dominantly by the Triangle Singularity , the f0-a0 mixing's contribution is small

Search for $\psi(3686) \rightarrow \gamma\eta_c \rightarrow \gamma\pi^+\pi^-\pi^0$

PRD96, 112008(2017)

- Based on 448.1×10^6 $\psi(3686)$ events
- Isospin violating(G Parity)



Uplimit at 90% C.L.

$$Br(\psi(3686) \rightarrow \gamma\eta_c)\times Br(\eta_c \rightarrow \pi^+\pi^-\pi^0) < 1.6\times10^{-6}$$

$e^+e^- \rightarrow \pi^+\pi^- h_c, h_c \rightarrow \gamma\eta_c, \eta_c \rightarrow$ *exclusive channels*

arXiv: 1903.05375

- Using XYZ data at Ecms=4.23, 4.26, 4.36 and 4.42GeV
- **Why use $h_c \rightarrow \gamma\eta_c$?**

✓ Br($h_c \rightarrow \gamma\eta_c$) ≈50% is much larger than Br(ψ′ → $\gamma\eta_c$) ≈ 0.3%.

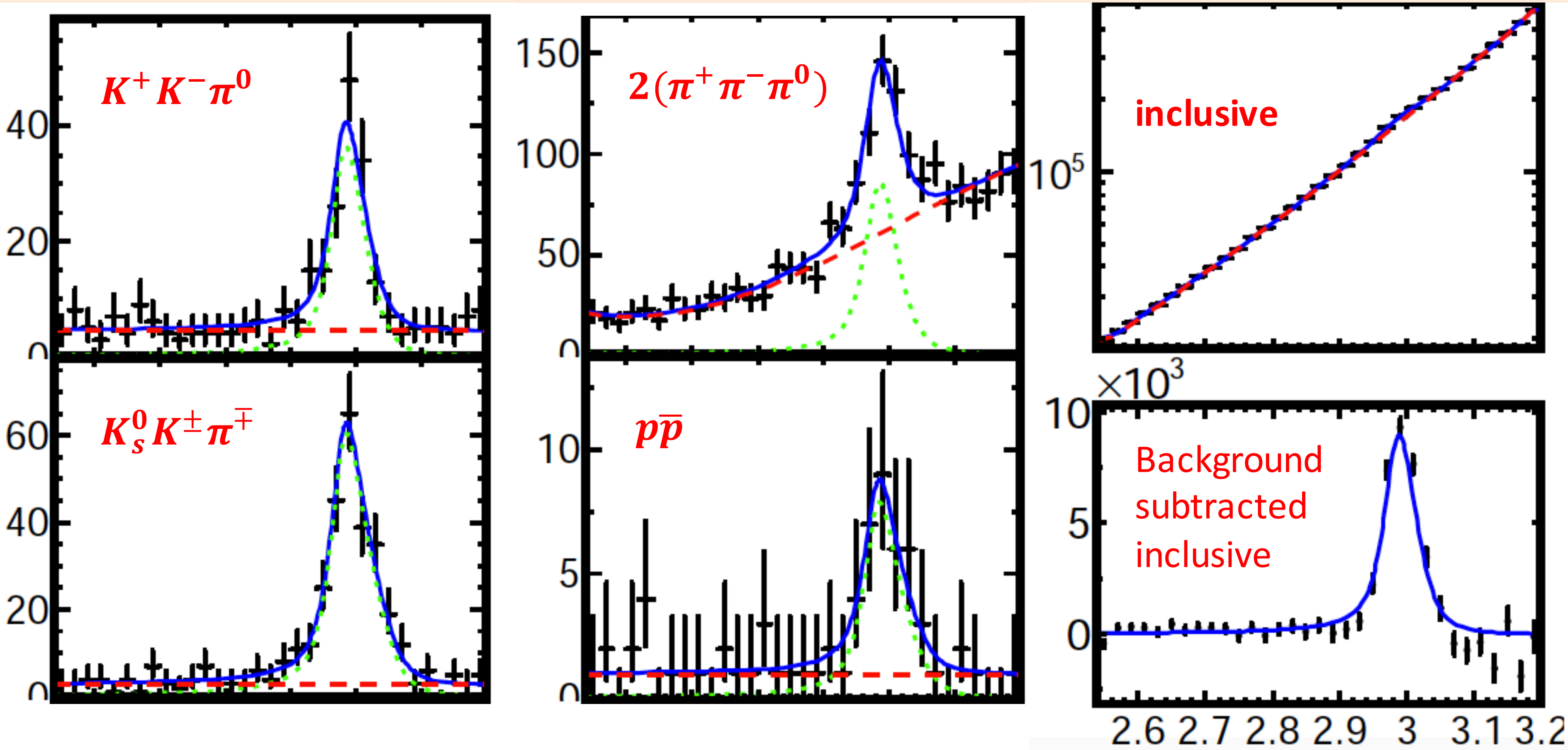
✓ If we assume the non-η_c radiative decay rate of h_c and ψ' is at the same level, then the interference between $h_c \rightarrow \gamma\eta_c$ and non-η_c process $h_c \rightarrow \gamma + hadrons$ should be much smaller than ψ' or J/ ψ decay.

method

- The η_c is reconstructed inclusively by the recoiled mass of $(\gamma\pi^+\pi^-)$.
- η_c is also reconstructed exclusively for four channels $\eta_c \to K^+K^-\pi^0, K_S^0K^\pm\pi^\mp, 2(\pi^+\pi^-\pi^0), p\bar{p}$.
- Then the branching fraction of four exclusive channels can be measured to be

$$\mathrm{BF}(\eta_c \to X) = \frac{N^i_{\mathrm{exclusive}} / \left(\mathrm{BF}(X \to Y) \times \epsilon^i_{\mathrm{exclusive}}\right)}{N^i_{\mathrm{inclusive}} / \epsilon^i_{\mathrm{inclusive}}}.$$

Simultaneous fit



The plots here are the sum of four energy points.
A simultaneous fit is performed to all four channels and inclusive result from all four energy points

Branching fraction result

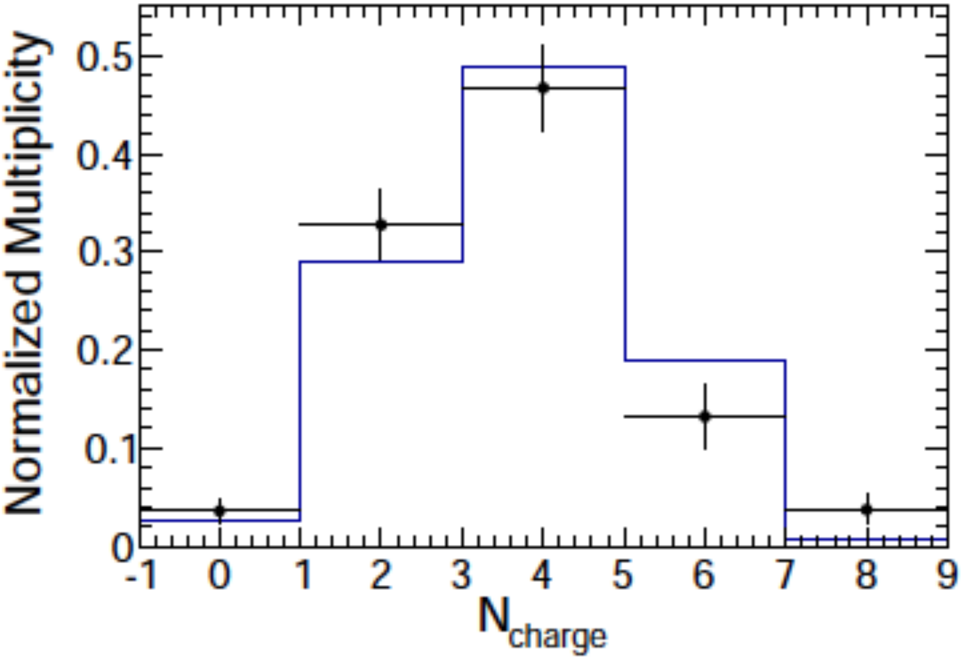
Final states	BF (%)	BF (%) from Ref. [6]	BF (%) from PDG [7]
$K^+K^-\pi^0$	$1.15 \pm 0.12 \pm 0.10$	$1.04 \pm 0.17 \pm 0.11 \pm 0.10$	$7.3 \pm 0.5\ (K\bar{K}\pi)$
$K_S^0K^\pm\pi^\mp$	$2.60 \pm 0.21 \pm 0.20$	$2.60 \pm 0.29 \pm 0.34 \pm 0.25$	
$2(\pi^+\pi^-\pi^0)$	$15.3 \pm 1.8 \pm 1.8$	$17.23 \pm 1.70 \pm 2.29 \pm 1.66$	17.4 ± 3.3
$p\bar{p}$	$0.120 \pm 0.026 \pm 0.015$	$0.15 \pm 0.04 \pm 0.02 \pm 0.01$	0.152 ± 0.016

Previous BESIII measurement with $\psi(3686) \rightarrow \pi^0 h_c, h_c \rightarrow \gamma\eta_c$

Result of this measurement

The result agree pretty well with previous measurement, with more and more XYZ Data that BESIII is still taking, better result can be expected.

The multiplicity of charged tracks from η_c decay



Normalized multiplicity

N_{charge}	Normalized values
0	$0.036 \pm 0.011 \pm 0.007$
2	$0.328 \pm 0.035 \pm 0.043$
4	$0.467 \pm 0.044 \pm 0.064$
6	$0.132 \pm 0.033 \pm 0.022$
≥ 8	$0.037 \pm 0.015 \pm 0.009$

The multiplicity is measured using unfolding method

$$\chi^2 = \sum_{i=1}^{8} \frac{(N_i^{\text{obs}} - \sum_{j=0}^{8} \epsilon_{ij} \cdot N_j)^2}{(\sigma_i^{\text{obs}})^2},$$

Summary

- $\eta_c \to \phi\phi, \omega\phi, \omega\omega$ are measured. Br($\eta_c \to VV$) is larger than pQCD prediction, the non-perturbative effect might be needed.
- The isospin violated process $\eta_c \to \pi^+\pi^-\pi^0$ is searched and no significant signal observed.
- $e^+e^- \to \pi^+\pi^- h_c, h_c \to \gamma\eta_c, \eta_c \to hadrons$ are measured with XYZ data
- The charged track multiplicity of η_c is measured.

SU(3) symmetry

- By SU(3) symmetry, the branching ration between the four VV channels of η_c decay is

$$\phi\phi : \omega\omega : \rho^0\rho^0 : K^{*0}\overline{K}^{*0} = 1:1:1:2$$

channel	Br (10^{-3})	
$\phi\phi$	$2.5 \pm 0.3^{+0.3}_{-0.7} \pm 0.6$	BESIII
$\omega\omega$	$2.88 \pm 0.1 \pm 0.46 \pm 0.68$	BESIII
$\rho^0\rho^0$	6 ± 1.7	PDG
$K^{*0}\overline{K}^{*0}$	4.55 ± 1.3	PDG