PROCEEDINGS OF SCIENCE

Radiative J/Ψ Decays at BESIII

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Search of hadrons besides meson and baryon is an important topic in particle physics and one of the main goals of the BESIII experiment. In 2009, BESIII collected 2.25×10^8 J/Ψ events, which provide a great opportunity for seach of new hadrons with mass below 3 GeV/c^2 with its radiative decays. In this talk, we present some latest results on this subject at BESIII.

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1. Introduction

In Constituent Quark Model (CQM), there're two types of hadrons: meson and baryon; however, QCD allows existence of hadrons of other types, such as multiquark states, hybrids, glueballs, etc. Up to now, none of these new hadrons has ever been established experimentlly. Therefore, search of new hadrons remains as an important topic in particle physics.

J/Ψ was first discovered almost simultaneously by BNL and SLAC in 1974. Due to its special properties, radiative J/Ψ decays are ideally suitable for search of new hadrons. At BESIII[1], we collected 2.25×10^8 J/Ψ events in 2009, many new particles were observed or confirmed since then.

2. Recent Results at BESIII

2.1 Threshold Enhancement in $J/\Psi \to \gamma p\bar{p}$[2]

A $p\bar{p}$ threshold enhancement structure was first observed at BESII in $J/\Psi \to \gamma p\bar{p}$[3] and named $X(p\bar{p})$. Later in 2010, both CLEO[4] and BESIII[5] confirmed $X(p\bar{p})$ in $\Psi \to \pi^+\pi^- J/\Psi, J/\Psi \to \gamma p\bar{p}$. Similar structure's not seen in $J/\Psi \to \omega p\bar{p}$[6] indicates that $X(p\bar{p})$ is not simply from FSI effect. With 2.25×10^8 J/Ψ events, BESIII again confirmed $X(p\bar{p})$ in $J/\Psi \to \gamma p\bar{p}$. A partial wave analysis (PWA) was then performed. Solution of PWA shows that up to 2.2 GeV/c^2 there are $X(p\bar{p})$, $f_2(1910)$, $f_2(1910)$ and 0^{++} phase contribution in $J/\Psi \to \gamma p\bar{p}$. For $X(p\bar{p})$: it was described with a Breit-Wigner formula with FSI factor included; the J^{PC} is determinated to be 0^{-+}; the mass is $1832^{+10}_{-5}(stat.)^{+18}_{-17}(syst.)^{+19}_{-19}(mod.)$ MeV/c^2; the width is $13^{+39}_{-39}(stat.)^{+10}_{-13}(syst.)^{+4}_{-4}(mod.)$ MeV/c^2, smaller than 76 MeV/c^2 at 90% C.L.; the branch ratio is $9.0^{+0.4}_{-1.1}(stat.)^{+1.5}_{-5.0}(syst.)^{+2.3}_{-2.3}(mod.) \times 10^{-5}$; the significance is much larger than 30σ.

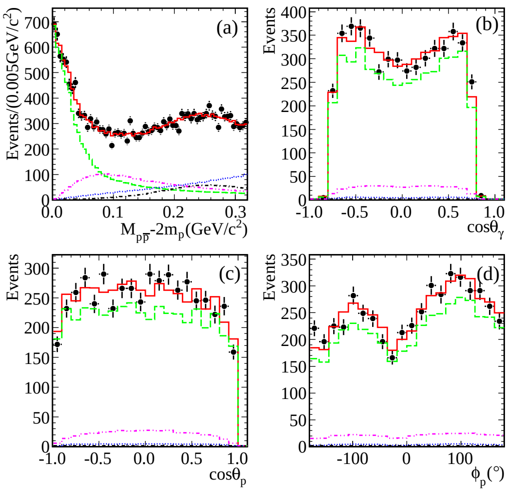

Figure 1: Comparisons between data and PWA fit projection: (a) the $p\bar{p}$ invariant mass; (b)-(d) the polar angle θ_γ of the radiative photon in the J/Ψ center of mass system, the polar angle θ_p and the azimuthal angle ϕ_p of the proton in the $p\bar{p}$ center of mass system with $M_{p\bar{p}} - 2m_p < 50$ MeV/c^2, respectively.

In order to get more information about $X(p\bar{p})$, we also performed PWA on $\Psi' \to \gamma p\bar{p}$ (base on 106 million Ψ' events collected at BESIII). Enhancement at threshold is also seen but has much different shape. Due to the low statics of $\Psi' \to \gamma p\bar{p}$, parameters of $X(p\bar{p})$ are fixed to values got from $J/\Psi \to \gamma p\bar{p}$. Result shows that significance of $X(p\bar{p})$ in $\Psi' \to \gamma p\bar{p}$ is 6.9σ; ratio of production rate of $X(p\bar{p})$ between J/Ψ decay and Ψ' decay is $5.08^{+0.71}_{-0.45}(stat.)^{+0.67}_{-3.58}(syst.)^{+0.12}_{-0.12}(mod.)\%$, smaller than the well known 12% rule.

2.2 $X(1840)$ in $J/\Psi \to \gamma 3(\pi^+\pi^-)$[7]

$X(1835)$ was first discovered at BESII in $J/\Psi \to \gamma\eta'\pi^+\pi^-$[8]. Ever since $X(1835)$'s discovery, people have been guessing its nature. Two possible interpretation are an η' excitation and a glueball, therefore $X(1835)$ may have similar properties as η_c do. $3(\pi^+\pi^-)$ is one of the main decay modes of η_c, so we can try to find $X(1835)$ in this channel.

As excepted, a distinct enhancement on mass spectrum of $3(\pi^+\pi^-)$ is seen. Analysis shows that this enhancement is not from background processes such as $J/\Psi \to \pi^0 3(\pi^+\pi^-)$. Assuming the enhancement is a resonance, fit to mass spectrum shows that the resonance has mass of $1842^{+4.2}_{-4.2}(stat.)^{+7.1}_{-2.6}(syst.)$ MeV/c^2 and width of $83^{+14}_{-14}(stat.)^{+11}_{-11}(syst.)$ MeV/c^2.

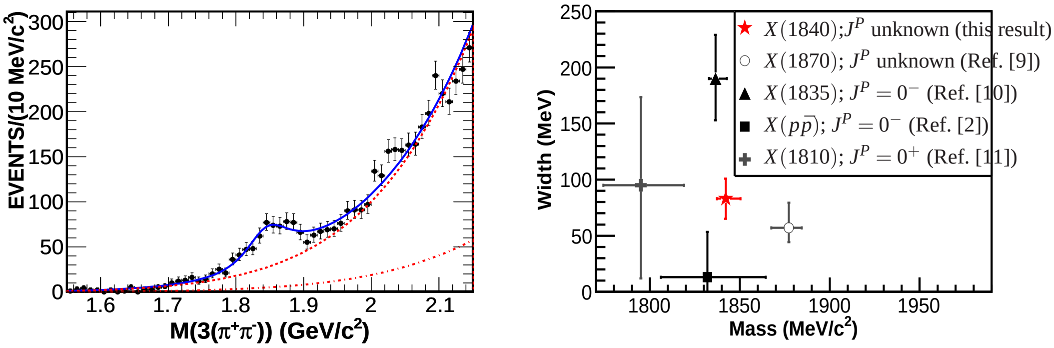

Figure 2: Figure on the left shows fit to mass spectrum of $3(\pi^+\pi^-)$: dashed line represents all the backgrounds, including the background events from $J/\Psi \to \pi^0 3(\pi^+\pi^-)$ (dash-dotted line, fixed in the fit) and a third-order polynomial representing other backgrounds. Figure on the right shows comparison of mass and width of five particles observed at BESIII.

Between 1.8 GeV/c^2 and 1.9 GeV/c^2, the BES experiment has already found $X(p\bar{p})$, $X(1835)$, $X(1870)$ and $X(1840)$, all of which are (or likely to be) pseudoscalar particles. Although their widths are much different from each other, the same J^{PC} and similar masses still make people guessing these particles are different manifestations of one the same particle. We need more studies on these particles to understand their nature.

2.3 Study of $J/\Psi \to \gamma 3\pi$[12]

In $J/\Psi \to \gamma 3\pi$, we obeserved an isospin-violating decay mode of $\eta(1405)$ for the first time: $\eta(1405) \to f_0(980)\pi^0$. Since $\eta(1405) \to a_0(980)\pi^0$ is a main decay mode of $\eta(1405)$, this isospin-violating decay process may take place from $a_0 - f_0$ mixing. However, comparison of two production rates shows that the ratio between these two modes is 17.9%, which is much bigger than the $a_0 - f_0$ mixing rate (<1%) measured at BESIII[13]. Besides the unusual large production rate, we also found that the width of $f_0(980)$ is very narrow: for $f_0(980) \to \pi^+\pi^-$ it's $9.5^{+1.1}_{-1.1}$

MeV/c^2; for $f_0(980) \to \pi^0\pi^0$ it's $4.6^{+5.1}_{-5.1}$ MeV/c^2. One possible explaination for these abnormal phenomena is triangle singularity[14].

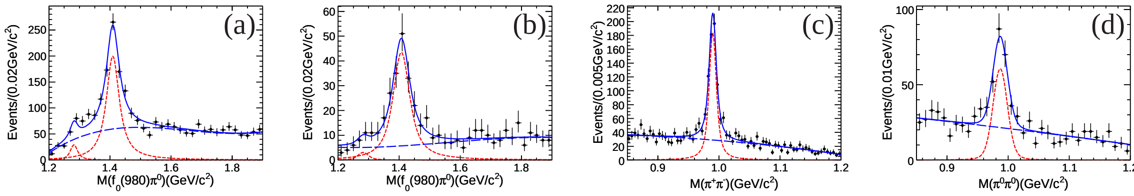

Figure 3: (a)$\eta(1405) \to \pi^+\pi^-\pi^0$. (b)$\eta(1405) \to \pi^0\pi^0\pi^0$. (c)$f_0(980) \to \pi^+\pi^-$. (d)$f_0(980) \to \pi^0\pi^0$.

2.4 Partial Wave Analysis of $J/\Psi \to \gamma\eta\eta$[16]

LQCD predicts the lowest lying 0^{++} glueball between 1.5 GeV/c^2 and 1.7 GeV/c^2; the lowest lying 2^{++} glueball around 2.2 GeV/c^2[15]. In $J/\Psi \to \gamma\eta\eta$, the $\eta\eta$ forms mainly 0^{++} and 2^{++} states, and the background is rather low. Thus this process is quite suitable for search of 0^{++} and 2^{++} glueballs.

At BESIII, we performed PWA to this process. Solution of PWA shows there are $f_0(1500)$, $f_2'(1525)$, $f_0(1710)$, $f_2(1810)$, $f_0(2100)$, $f_2(2340)$ and 0^{++} phase space contribution in $J/\Psi \to \gamma\eta\eta$. PWA also shows that the production rate of $f_0(1500)$ is approximately one order smaller than that of $f_0(1710)$ and $f_0(2100)$, and what's more, the production rate of $f_0(1710)$ is compatible with LQCD's prediction on that of a pure gauge scalar glueball. This may indicate that there's a large overlap between $f_0(1710)$ and a glueball.

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathscr{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081\pm13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2'(1525)$	$1513\pm5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ

Table 1: PWA solutions of $J/\Psi \to \gamma\eta\eta$.

2.5 Threshold Enhancement in $J/\Psi \to \gamma\omega\phi$[11]

An $\omega\phi$ threshold enhancement structure was first observed at BESII in $J/\Psi \to \gamma\omega\phi$[17] and named $X(1810)$. BESIII confirmed it's existence in the same process and performed PWA. Solutions of PWA shows there are $X(1810)$, $f_2(1950)$, $f_0(2020)$, $\eta(2025)$ and 0^{-+} phase space contribution in $J/\Psi \to \gamma\omega\phi$.

$J/\Psi \to \gamma\omega\phi$ is a DOZI process, while its production rate is similar to that of $J/\Psi \to \gamma\omega\omega$ which is an OZI process. Explainations of this include interpreting $X(1810)$ as dynamical effect from intermediate meson re-scattering, or a manifestation of $f_0(1710)$, or hadron of new types, etc., while making conclusion needs further study.

Resonance	J^{PC}	M(MeV$/c^2$)	Γ(MeV$/c^2$)	Events	$\Delta\mathscr{S}$	Δndf	Significance
$X(1810)$	0^{++}	1795 ± 7	95 ± 10	1319 ± 52	783	4	$> 30\sigma$
$f_2(1950)$	2^{++}	1944	472	665 ± 40	211	2	20.4σ
$f_0(2020)$	0^{++}	1992	442	715 ± 45	100	2	13.9σ
$\eta(2225)$	0^{-+}	2226	185	70 ± 30	23	2	6.4σ
phase space	0^{-+}	—	—	319 ± 24	45	2	9.1σ

Table 2: PWA solution of $J/\Psi \to \gamma\omega\phi$.

3. Summary

Over the past few years, the BESIII experiment has got many important results ($X(p\bar{p})$, $X(1835)$, etc.) through radiative J/Ψ decays. Last year, BESIII collected more than 1 billion J/Ψ events during a new run period, which is almost 5 times as large as the previous sample. With such high statics, it's excited to expect more and more interesting discoveries from radiative J/Ψ decays at BESIII.

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PoS(Hadron 2013)101