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Partial Wave Analysis at BESIII

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The BESIII experiment in Beijing takes data in τ -charm domain since 2009. For the moment the world largest samples of J/ψ , $\psi(3686)$, $\psi(3770)$ and $\psi(4040)$ data have been collected. Hadron spectroscopy is a unique way to access QCD, which is one of the most important physics goals of BESIII. Experimental search of new forms of hadrons and subsequent investigation of their properties would provide validation of and valuable input to the quantitative understanding of QCD. The key to success lies in high levels of precision during the measurement and high statistics in the recorded data set complemented with sophisticated analysis methods. Partial wave analysis (PWA) is a powerful tool to study the hadron spectroscopy, that allows one to extract the resonance's spin-parity, mass, width and decay properties with high sensitivity and accuracy. In this poster, we present the working PWA framework of BESIII – GPUPWA and the recent results of PWA of $J/\psi \rightarrow \gamma\eta\eta$. GPUPWA is a PWA framework for high statistics partial wave analyses harnessing the GPU parallel computing.

Keywords: hadron spectroscopy, partial wave analysis, BESIII

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1. Introduction

Hadron spectroscopy is a unique way to access QCD. This theory predicts that there should exist new forms of matter, such as glueballs (pure-gluon objects) and hybrids ($q\bar{q}$ states with explicit gluon) ^{1–5}. Experimental search of these predictions and subsequent investigation of their properties would provide validation of and valuable input to the quantitative understanding of QCD. From the experimental side, the basic task is to systematically map out all the resonances with the determination of their properties like mass, width, spin-parity as well as partial decays widths.

BESIII (Beijing Spectrometer) is a new state-of-the-art 4π detector at the upgraded BEPCII (Beijing Electron and Positron Collider) that operated in the τ -charm threshold energy region⁶. Since 2009, it has collected the worlds largest data samples of J/ψ , $\psi(3686)$, $\psi(3770)$ and $\psi(4040)$ decays. These data are being used to make a variety of interesting and unique studies of light hadron spectroscopy precision charmonium physics and high-statistics measurements of D meson decays⁷.

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The study of radiative decays of J/ψ is considered most suggestive in the glueball search. After photon emission, the $c\bar{c}$ annihilation can go through C -even gg states, and hence may have a strong coupling to the low-lying glueballs¹⁻⁵.

2. Partial wave analysis method

Extracting resonance properties from experimental data is however far from straightforward; resonances tend to be broad and plentiful, leading to intricate interference patterns. In such an environment, simple fitting of mass spectra is usually not sufficient and a partial wave analysis (PWA) is required to disentangle interference effects and to extract resonance properties. In the cases discussed here, the full kinematic information is used and fitted to a model of the amplitude in a partial wave decomposition. The partial wave amplitude is constructed with an angular part and a dynamical part. The model parameters are determined by an unbinned likelihood fit to the data, while the event-wise efficiency correction is included. In a typical PWA (we use the radiative decay $J/\psi \rightarrow \gamma\eta\eta^8$ as an example), the quasi two-body decay amplitudes (isobar model) in the sequential decay process $J/\psi \rightarrow \gamma X, X \rightarrow \eta\eta$ are constructed using covariant tensor amplitudes described in Ref.9.

The probability to observe the event characterized by the measurement ξ is

$$P(\xi) = \frac{\omega(\xi)\epsilon(\xi)}{\int d\xi \omega(\xi)\epsilon(\xi)}, \quad (1)$$

where $\epsilon(\xi)$ is the detection efficiency and $\omega(\xi) \equiv \frac{d\sigma}{d\Phi}$ is the differential cross section, and $d\Phi$ is the standard element of phase space.

$$\frac{d\sigma}{d\Phi} = \left| \sum_j^{wave} \Lambda_j A_j \right|^2, \quad (2)$$

where A_j is the partial wave amplitude with coupling strength determined by a complex coefficient Λ_j . The normalization integral is performed numerically by Monte Carlo techniques. The likelihood for a particular model is

$$\mathcal{L} = \prod_{i=1}^{N_{data}} P(\xi_i). \quad (3)$$

A series of likelihood fits are performed for parameter estimation and model evaluation. In the log likelihood calculation, the likelihood value of background events are given negative weights, and are removed from data since the log likelihood value of data is the sum of signal and background.

As this involves the computation of the amplitude for every event in every iteration of a fit, this becomes computationally very expensive for large data samples. As events are independent and the amplitude calculation does not vary from event to event, this task is trivially parallelizable. This and the floating point intensity predestine PWA for implementation on graphics processing units (GPUs). GPUPWA

⁷¹³ has been developed as the working framework of BESIII, harnessing GPU parallel acceleration. The framework now provides facilities for amplitude calculation, minimization and plotting and is widely used for analyses at BESIII.

GPUPWA ¹⁰ has been developed as the working framework of BESIII, harnessing GPU parallel acceleration. GPUPWA is now developed with *OpenCL* ¹¹ as described in ¹². The framework now provides facilities for amplitude calculation, minimization and plotting and is widely used for analyses at BES III. It continues to be developed and is available at ¹³.

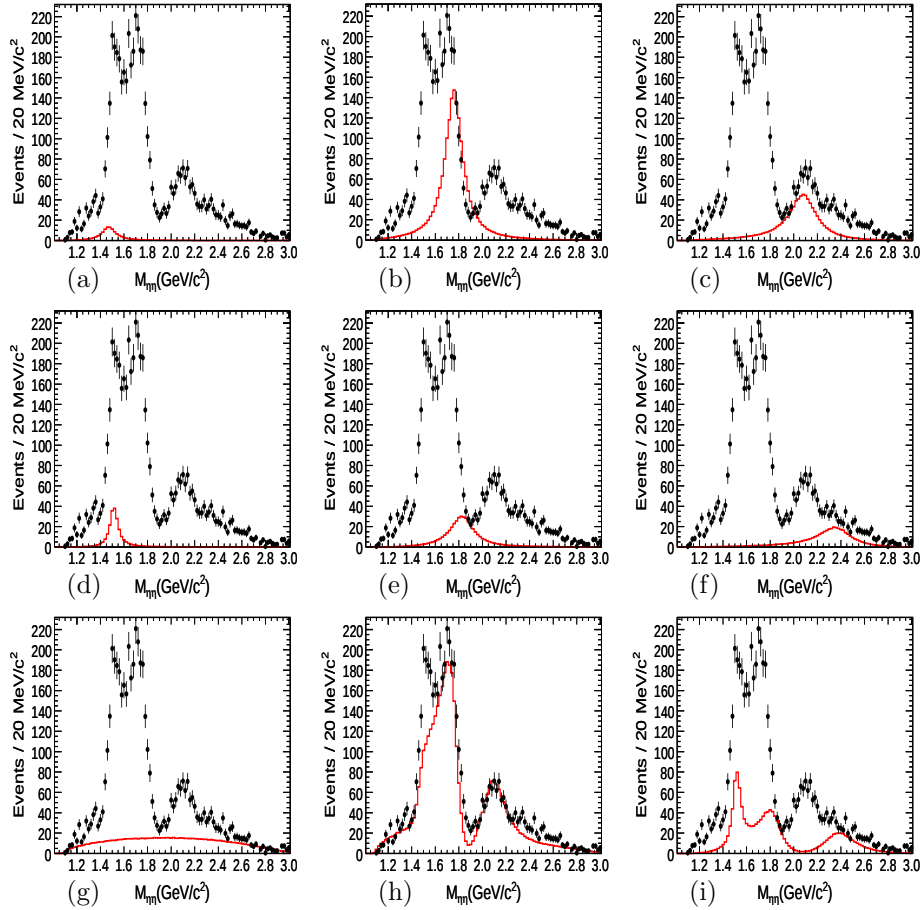


Fig. 1. Contribution of the components. (a) $f_0(1500)$, (b) $f_0(1710)$, (c) $f_0(2100)$, (d) $f'_2(1525)$, (e) $f_2(1810)$, (f) $f_2(2340)$, (g) 0^{++} phase space, (h) total 0^{++} component, and (i) total 2^{++} component. The dots with error bars are data with background subtracted, and the solid histograms are the projection of the PWA results⁸.

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3. PWA results of $J/\psi \rightarrow \gamma\eta\eta$

For a J/ψ radiative decay to two pseudoscalar mesons, it offers a very clean laboratory to search for scalar and tensor glueballs because only intermediate states with $J^{PC} = \text{even}^{++}$ are possible. An early study of $J/\psi \rightarrow \gamma\eta\eta$ was made by the Crystal Ball Collaboration with the first observation of $f_0(1710)$, but the study suffered from low statistics. The results of partial wave analysis (PWA) on $J/\psi \rightarrow \gamma\eta\eta$ (Fig. 1) are presented based on a sample of 2.25×10^8 J/ψ events collected with BESIII⁸.

4. Summary and outlook

A full partial wave analysis was performed to disentangle the structures present in $J/\psi \rightarrow \gamma\eta\eta$ decays. The scalar contributions are mainly from $f_0(1500)$, $f_0(1710)$ and $f_0(2100)$, while no evident contributions from $f_0(1370)$ and $f_0(1790)$ are seen. Recently, the production rate of the pure gauge scalar glueball in J/ψ radiative decays predicted by the lattice QCD¹⁴ was found to be compatible with the production rate of J/ψ radiative decays to $f_0(1710)$; this suggests that $f_0(1710)$ has a larger overlap with the glueball compared to other glueball candidates (eg. $f_0(1500)$). In this analysis, the production rate of $f_0(1710)$ and $f_0(2100)$ are both about one order of magnitude larger than that of the $f_0(1500)$, which are both consistent with, at least not contrary to, lattice QCD predictions¹⁴.

Now five years from our first collisions, BESIII has established a broad and successful program in charm physics. Recently, in 2012, even larger samples have been accumulated at the J/ψ and $\psi(3686)$; total samples are now about 1.2 billion and 0.35 billion decays, respectively. Furthermore, our 2013 dataset includes more data near 4260 MeV, and also a large sample at the $Y(4360)$. With the excellent performance of the accelerator and detector, more interesting results are expected.

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