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Results from BESII and prospects at BESIII

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We reported the observation of $Y(2175)$ in $\phi f_0(980)$ mass spectrum from $J/\psi \to \eta\phi f_0(980)$ and $f_0(980) \to \pi^+\pi^-$, the search for $Y(2175)$ in $K^*\bar{K}^*$ from $J/\psi \to \eta K^*\bar{K}^*$, the partial wave analysis of $J/\psi \to p\bar{p}\pi^0$, based on 5.8×10^7 J/ψ events collected at BESII. We also reported the precision R values at the energy points of 2.6, 3.05 and 3.65 GeV/c^2 and the measurement of the line shape for the cross sections of $e^+e^- \to hadrons$ in the energy range of 3.650 - 3.872 GeV/c^2. The status of BESIII running, as well as the preliminary results from BES3 are also presented.

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1. Introduction

The Standard Model (SM), regarded as the theory of the elementary particle physics, has been very successful in describing all the relevant physics phenomena. However, there are still many unanswered questions remained. The QCD, as a fundamental theory of the strong interaction, has been well tested at high energies, but is not well understood due to its non-perturbative features. The Beijing Electron Positron Collider (BEPC)/Beijing Electromagnetic Spectrometer (BES) is a facility running at the energy region of 2-4.6 GeV/c^2, in which many of the charmonium states and charm mesons, as well as the τ lepton can be produced. The physics program of BES covers the spectroscopy of light hadrons, charmonium physics, $D(Ds)$ physics, τ physics and precision measurement of R values. It also allows the searches for possible new physics.

The BESI started running in 1989. In 1997, the BESI detector was upgraded to BESII detector. With BESII detector, the R values at 91 energy points in the energy region of 2-5 GeV were measured with a factor of 2-3 improvement of the errors. In addition, the $5.8\times10^7 J/\psi$ events, $1.4\times10^7\,\psi(2S)$ events and 33 pb^{-1} $\psi(3770)$ data were accumulated.

There have been many discussions on the future of BEPC/BES since 1995. The project of BEPCII/BESIII was approved officially in 2003. BEPCII is a major upgrade of the previous collider BEPC. In BEPC, the electrons and positrons shared the same vacuum tube in a single ring of magnets, and this arrangement limited the rate at which interesting particles are produced. The major change of BEPCII is the installation of a second ring of magnets that allows the electron and positron beams to be stored separately, and therefore leads to the designed peak luminosity of 10^{33}, an order of two to that of BEPC. BESIII detector is completely new with a number of major improvements. These include the superconducting magnet, which produces a magnetic field of 1 Tesla throughout the detector. BESIII detector consists of a drift chamber (MDC) which has a small cell structure filled with a helium-based gas, an electromagnetic calorimeter (EMC) made of CsI(Tl) crystals, time-of-flight counters (TOF) for particle identification made of plastic scintillators, a muon system made of Resistive Plate Chambers (RPC) and a super conducting magnet. The designed single wire spatial resolution, the resolutions of dE/dx and momentum for the MDC are 130μm, 6% and 0.5 % $\sqrt{1+p^2}$ (p in GeV/c), respectively. The time resolution for TOF is $\sigma_{TOF}=100$ ps for Bhabha events and the energy resolution for photons is $\sigma_E/E\simeq 2.5$ % /$\sqrt{E}$ (E in GeV) in EMC. To handle the huge data rates expected in the BESIII detector, a specialized state-of-the-art high speed data communication system has been developed and implemented.

In this talk, the recent results from BESII are presented. The status of BESIII running and some preliminary results at BESIII are reported as well.

2. Study of $Y(2175)$ in J/ψ decays

A new 1^{--} structure, denoted as $Y(2175)$ and with the mass and width of $2.175\pm0.010\pm0.015$ GeV/c^2 and $58\pm16\pm20$ MeV/c^2, was observed by the BABAR experiment in the $e^+e^-\to\gamma_{ISR}\phi f_0(980)$ initial-state radiation(ISR) process [1], [2]. This observation stimulated some theoretical speculation that this state may be an s-quark version of the $Y(4260)$ since both of them are produced in e^+e^- annihilation and decay to similar final states [3]. The $Y(2175)$ has correspondingly been interpreted as a $s\bar{s}g$ [4], a 2^3D_1 $s\bar{s}$ state [5] or a tetraquark $s\bar{s}s\bar{s}$ state [6]. As of now, none of these interpretations have either been established or ruled out by experiment.

The decays of $J/\psi \to \eta\phi f_0(980)$, with $\eta \to \gamma\gamma$, $\phi \to K^+K^-$, $f_0(980) \to \pi^+\pi^-$ are analyzed at BESII [7]. After the final events selection, an η signal is evident in the $\gamma\gamma$ invariant mass spectrum (Fig. 1(a)); $\eta \to \gamma\gamma$ candidates are defined as γ-pairs with $|M_{\gamma\gamma} - 0.547| < 0.037$ GeV/c^2. A ϕ signal is distinct in the K^+K^- invariant mass spectrum (Fig. 1(b)) and for these candidates we require $|m_{K^+K^-} - 1.02| < 0.019$ GeV/c^2. In the $\pi^+\pi^-$ invariant mass spectrum, candidate $f_0(980)$ mesons are defined by $|m_{\pi^+\pi^-} - 0.980| < 0.060$ GeV/c^2 (Fig. 1(c)). The $\phi f_0(980)$ invariant mass spectrum for the selected events is shown as points with error bars in Fig. 2, where a clear enhancement is seen around 2.18 GeV/c^2.

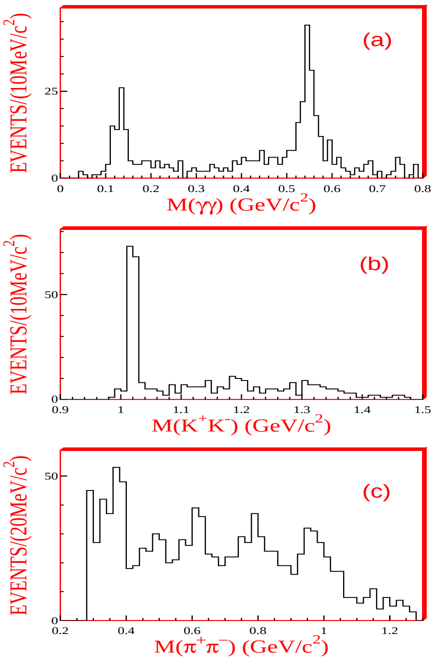

Figure 1: (a)The $\gamma\gamma$ invariant mass spectrum. (b) The K^+K^- invariant mass spectrum. (c) The $\pi^+\pi^-$ invariant mass spectrum.

We fit the $\phi f_0(980)$ invariant mass spectrum and the total sidebands simultaneously. The statistical significance of the signal is 5.5 σ. The mass and width obtained from the fit (shown as smooth curves in Fig. 2) are $M = 2.186 \pm 0.010(stat) \pm 0.006(syst)$ GeV/c^2 and $\Gamma = 0.065 \pm 0.023(stat) \pm 0.017(syst)$ GeV/c^2, and the product branching ratio is measured to be $Br(J/\psi \to \eta Y(2175)) \cdot Br(Y(2175) \to \phi f_0(980)) \cdot Br(f_0(980) \to \pi^+\pi^-) = (3.23 \pm 0.75(stat) \pm 0.73(syst)) \times 10^{-4}$.

We also studied the decays of $J/\psi \to \eta K^{*0}\bar{K}^{*0}$, with $K^{*0} \to K^{\pm}\pi^{\mp}$ in a J/ψ sample of 58 million events collected with the BESII detector. No evidence of $Y(2175) \to K^{*0}\bar{K}^{*0}$ is seen. Fig. 3 is the invariant mass spectrum of $K^{*0}\bar{K}^{*0}$ recoiling against η. An upper limit of $Br(J/\psi \to \eta Y(2175))Br(Y(2175) \to K^{*0}\bar{K}^{*0}) < 2.52 \times 10^{-4}$ is set at the 90% confidence level.

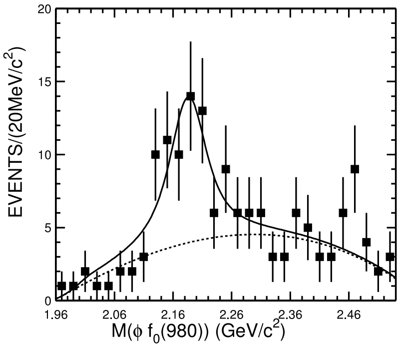

Figure 2: The solid curve is the fit to the data (points with error bars).

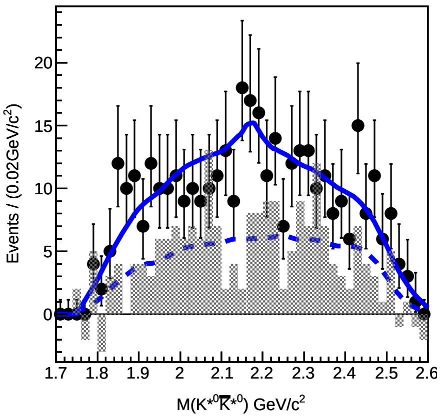

Figure 3: The $K^{*0}\bar{K}^{*0}$ invariant mass spectrum, where points with error bars are candidate events, the dashed histogram is from MC phase space for $J/\psi \to \eta K^{*0}\bar{K}^{*0}$, the shaded histogram is from side-band events, and the solid curve is the fitting result, where the Y(2175) shape used is from MC simulation.

3. Partial wave analysis of $J/\psi \to p\bar{p}\pi^0$

J/ψ decays provide a good laboratory for studying excited baryon states. For $J/\psi \to N\bar{N}\pi$ and $N\bar{N}\pi\pi$ decays, the $N\pi(\bar{N}\pi)$ and $N\pi\pi(\bar{N}\pi\pi)$ systems are expected to be dominantly isospin 1/2 due to that the isospin conserving three-gluon annihilation of the constituent c-quarks dominates over the isospin violating decays via intermediate photon for the baronic final states. This makes the study of N^* resonances from J/ψ decays less complicated, compared with πN and γN experiments which have states that are a mixture of isospin 1/2 and 3/2. In a recent analysis of $J/\psi \to p\bar{n}\pi^- + c.c.$ [8], a 'missing' N^* at around 2.0 GeV/c^2 named $N_x(2065)$ was observed, based on $5.8 \times 10^7 J/\psi$ events collected with BESII. The mass and width for this state are determined to be $2065 \pm 3^{+15}_{-30}$ MeV/c^2 and $175 \pm 12 \pm 40$ MeV/c^2, respectively, from a simple Breit-Wigner fit.

We analyzed $J/\psi \to p\bar{p}\pi^0$ from BESII J/ψ data [11]. The Dalitz plot of this decay is shown in Fig. 4, and some N^* bands are evident. The Dalitz plot exhibits an asymmetry for $m_{p\pi^0}$ and $m_{\bar{p}\pi^0}$, which is mainly caused by different detection efficiencies for the proton and antiproton.

A partial wave analysis (PWA) is performed to study the N^* states in this decay. The sequential decay process can be described by $J/\psi \to \bar{p}N^*(p\bar{N}^*)$, $N^*(\bar{N}^*) \to p\pi^0(\bar{p}\pi^0)$. The amplitudes are

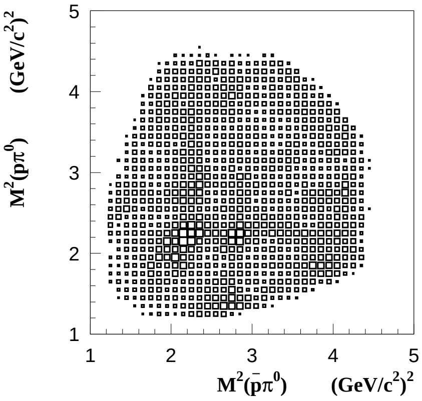

Figure 4: The Dalitz plot of $J/\psi \to p\bar{p}\pi^0$.

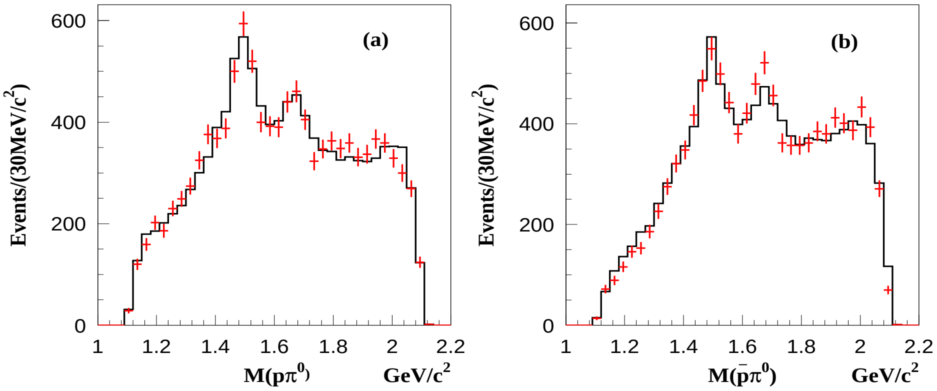

Figure 5: The $p\pi^0$ and $\bar{p}\pi^0$ invariant mass spectra after optimization of masses and widths. Plot (a) is $M_{p\pi^0}$, and plot (b) is $M_{\bar{p}\pi^0}$, where the crosses are data and histograms are fit results.

constructed using the relativistic covariant tensor amplitude formalism [9, 10], and the maximum likelihood method is used in the fit. In the analysis, the well established N^* states, such as $N(1440)$, $N(1520)$, $N(1535)$, $N(1650)$, $N(1675)$ and $N(1680)$ are included. In addition, $N_x(2065)$, a long-sought 'missing' N^* which was observed recently by BES [8], is also included. We find that the $N_x(2065)$ is definitely needed in all fits, and its spin-parity favors $\frac{3}{2}^+$. The mass and width are determined to be $2040^{+3}_{-4} \pm 25$ MeV/c^2 and $230^{+8}_{-8} \pm 52$ MeV/c^2, respectively, which are consistent with those from $J/\psi \to p\bar{n}\pi^- + c.c.$ within errors. We also obtain the masses and widths of other N^* resonances in the low mass region. Figs. 5(a) and (b) show the comparison of data and PWA fit, in which the agreement is reasonable.

4. R measurement

The R ratio is defined as the lowest level hadronic cross section normalized by the theoretical $\mu^+\mu^-$ production cross section in e^+e^- annihilation

$$R = \frac{\sigma^0_{had}(e^+e^- \to \gamma^* \to \text{hadrons})}{\sigma^0_{\mu\mu}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}, \tag{4.1}$$

and it is an important input parameter for precision tests of the Standard Model (SM). The errors on R value measurements below 5 GeV have a strong influence on the uncertainties of the calculated QED running electromagnetic coupling constant $\alpha(s)$, the muon anomalous magnetic moment $(g-2)$ and global SM fits for the Higgs mass [12, 13, 14].

In 1998 and 1999, R value measurements were made at 91 energy points between 2 and 5 GeV by the BESII experiment[15, 16]. The average statistical errors of the R values are $2-4\%$, and the systematical errors are $5-8\%$ depending on the energy point. In 2003, the R values at 68 energy points in 3.650-3.872 GeV energy region were measured from a dedicated $\psi(3770)$ scan data, with the statistical errors of 3-4% and systimatic errors of about 4% [17].

In this talk, the R measurements at center-of-mass energies of 2.60, 3.07 and 3.65 GeV are reported. The data were taken in 2004 and have a total integrated luminosity of 10.0 pb^{-1}. An additional 65.2 nb^{-1} was accumulated at 2.2 GeV for the purpose of tuning the parameters of the hadronic event generator. Improvements in the event selection, tuning of generator parameters and luminosity measurement have been made in order to decrease the systematic errors. The results are shown in Fig. 6, together with previous measurements. The errors on the R values reported here are about 3.5%. The R values are consistent within errors with the prediction of perturbative QCD [19].

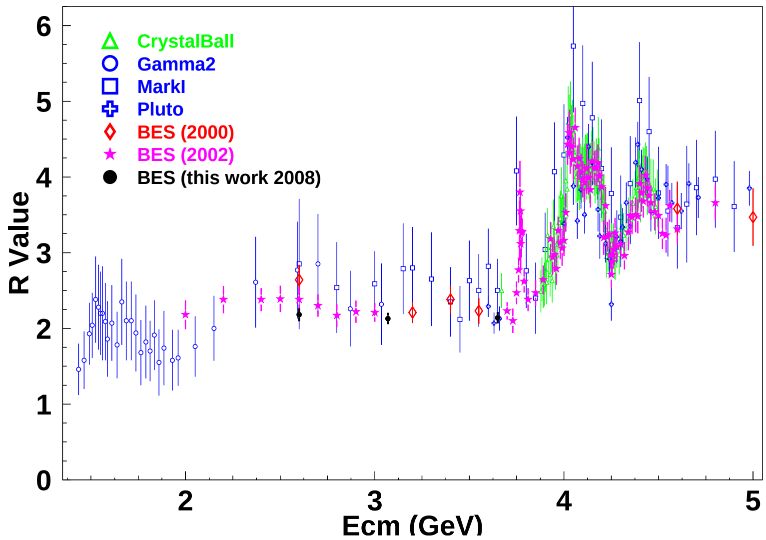

Figure 6: R values reported here together with prevous measurements below 5 GeV.

5. Anomalous Line-Shape of Cross Sections for $e^+e^- \to$ Hadrons in the Center-of-Mass Energy Region between 3.650 and 3.872 GeV

In the energy range from 3.700 to 3.872 GeV, the well established $\psi(3770)$ resonance is believed to be the only observed structure, and has been identified to be a mixture of D-wave and S-wave of angular momentum eigenstates of the $c\bar{c}$ system. In addition, the $\psi(3770)$ resonance is expected to decay into $D\bar{D}$ meson pairs with a branching fraction greater than 98%. However, there is a long-standing puzzle in the existing measurements of $\psi(3770)$ production and decays.

BES experiment measured the branching fraction of $\psi(3770)$ decays to $D\bar{D}$ to be $B[\psi(3770) \to D\bar{D}] = (85 \pm 5)\%$ and directly measured the non-$D\bar{D}$ branching fraction of $\psi(3770)$ decay to be around 15% under the assumption of only one simple $\psi(3770)$ resonance in the energy region between 3.700 and 3.872 GeV [20, 21, 22, 23].

BES measured the $e^+e^- \to$ hadrons total cross sections in the energy region between 3.700 and 3.872 GeV from the data samples taken with the BESII detector at the BEPC Collider. The observed inclusive hadronic cross sections obtained from the cross section scan data taken in March 2003 and in December 2003 are shown in Fig. 7. The line shape of the observed inclusive hadronic cross sections shows that the slopes on the two sides of the peak are quite different: the slope of the high energy side of the peak is substantially larger than that of the low energy side. It conflicts with the expectations for only one resonance in this energy region.

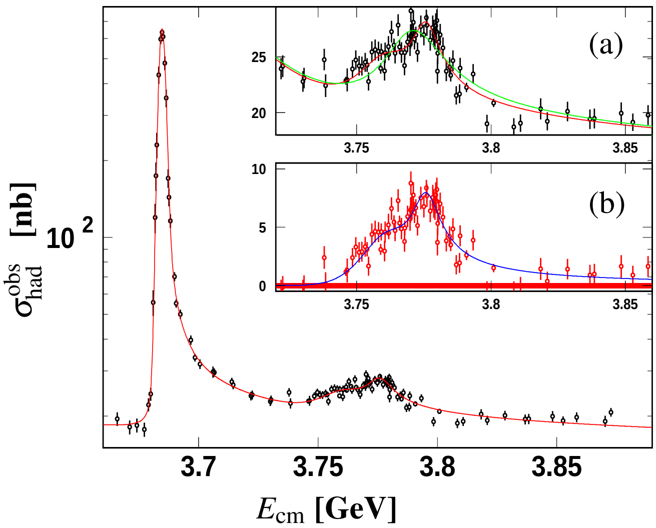

Figure 7: The measured inclusive hadronic cross sections versus the c.m. energy for the two data sets taken in March and December 2003; the fit is done with two incoherent amplitudes.

we tried to fit the 3.770 GeV energy region with two pure P-wave Breit-Wigner amplitudes with energy-dependent total widths or one amplitude, respectively. The curves in Fig. 7 are the fits with two incoherent amplitudes. The analysis shows that the fit is inconsistent with the explanation for only one simple $\psi(3770)$ resonance at 7σ statistical significance, which indicates either there is likely a new structure in addition to the $\psi(3770)$ resonance around 3.773 GeV, or there are some physics effects reflecting the $D\bar{D}$ production dynamics. A fine scan in this energy region is needed to further clarify the line shape of the inclusive hadronic cross section.

6. Status of BESIII

The construction of BESIII detector started in 2003. By the end of 2007, the construction and installation of BESIII was accomplished. Cosmic ray experiments were then started and continued till March of 2008 to test each parts, including detectors, electronics, trigger, data acquisition and slow control system. In early May of 2008, BESIII was pushed into the collision point, and the precise regulation was finished at the point. The measurement showed that the location accuracy was better than the design requirements. Joint commissioning of BESIII and the accelerator began in June. On July 19, 2008, the first physics event produced by the electron-positron collision was observed, as shown in Fig. 8. In Nov. of 2008, about 20 pb^{-1} $\psi(2S)$ events were accumulated for understanding the performance of both detector and software. The detectors worked properly and stably, and the performance has reached the design requirements. Fig.9 shows the performance of each sub-detectors.

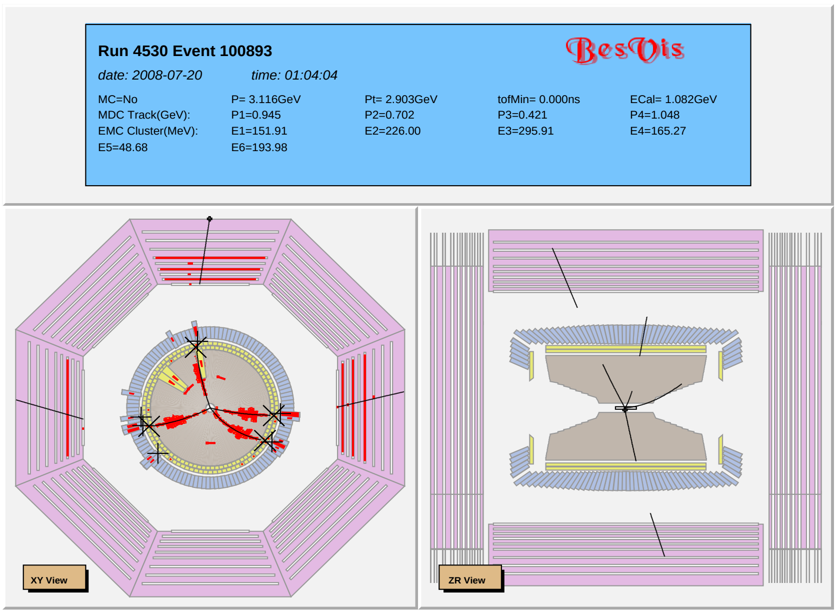

Figure 8: The first physics event recorded at BESIII.

On March 14, 2009, BESIII finished accumulating her first large data set of over 100M $\psi(2S)$ events. This is the world's largest $\psi(2S)$ data set. Data taking started on March 6, 2009, after a scan of the $\psi(2S)$ peak. The J/ψ data taking started on June 12 and ended on July 28, with totally about 200M J/ψ events collected. Here are some preliminary results from BESIII 100M $\psi(2S)$ events.

The spin-singlet P wave charmonium state h_c was first observed by CLEOc experiment in $\psi(2S) \to \pi^0 h_c, h_c \to \gamma\eta_c$ decays. Using BESIII 100M $\psi(2S)$ events, the h_c state is confirmed. The width of h_c, the production rate $Br(\psi(2S) \to \pi^0 h_c$ and the decay branching ratio of $Br(h_c \to \gamma\eta_c)$ are measured for the first time. Fig. 10 shows the π^0 recoiling mass spectrum in $\psi(2S) \to \pi^0 h_c$ after the background subtraction, where the h_c signal is evident.

In 2003, an anomalous enhancement, $X(1860)$, near the mass threshold in the $p\bar{p}$ invariant mass spectrum from $J/\psi \to \gamma p\bar{p}$ decays was reported, with 58M J/ψ events at BESII. This resonance is not compatible with any known meson. The experimental observations stimulated a number of theoretical speculations, including the baryonium explanation. The confirmation of this state, the observation of more decay modes and the determination of the J^{PC}'s become crucial in clarifying its nature. With 100M $\psi(2S)$ events collected at BESIII, the $p\bar{p}$ threshold enhancement $X(1860)$ is confirmed in the decays of $\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to \gamma p\bar{p}$. The mass and width of

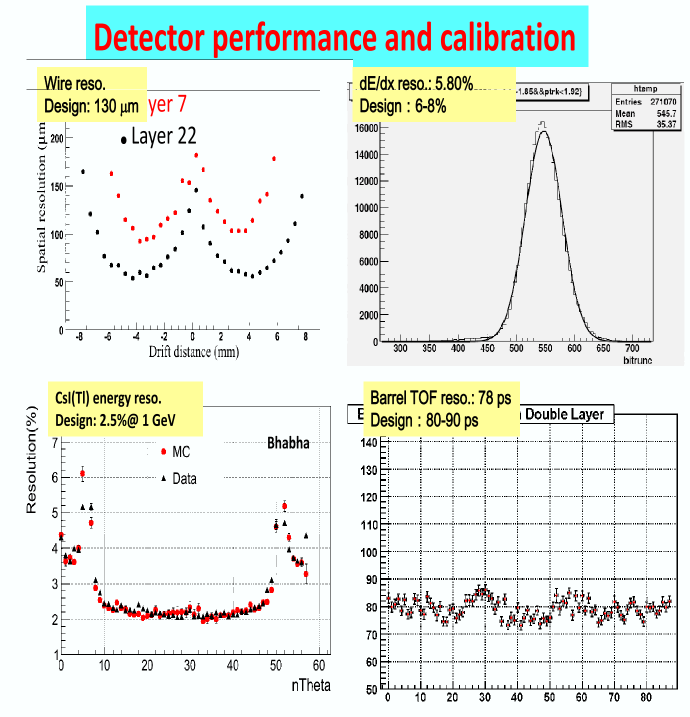

Figure 9: The performance of BESIII.

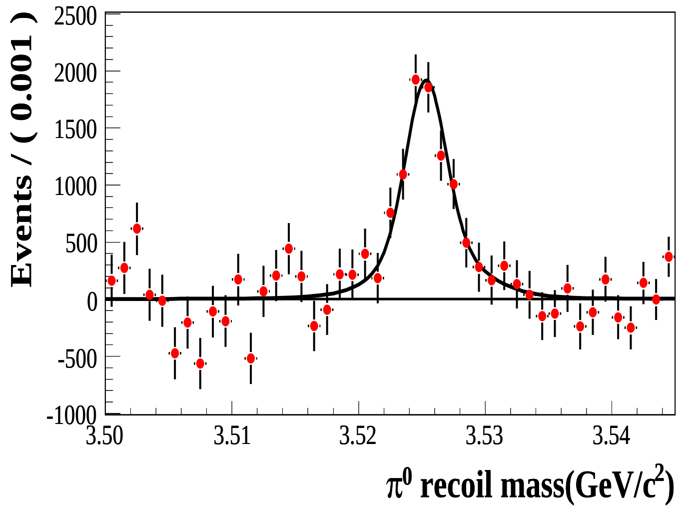

Figure 10: The π^0 recoiling mass spectrum in $\psi(2S) \to \pi^0 h_c$ after the background subtraction.

$X(1860)$ are consistent with those from BESII data. Fig. 11 shows the distribution of $M - M_{p\bar{p}}$ from $\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to \gamma p\bar{p}$. The solid curve is the fit.

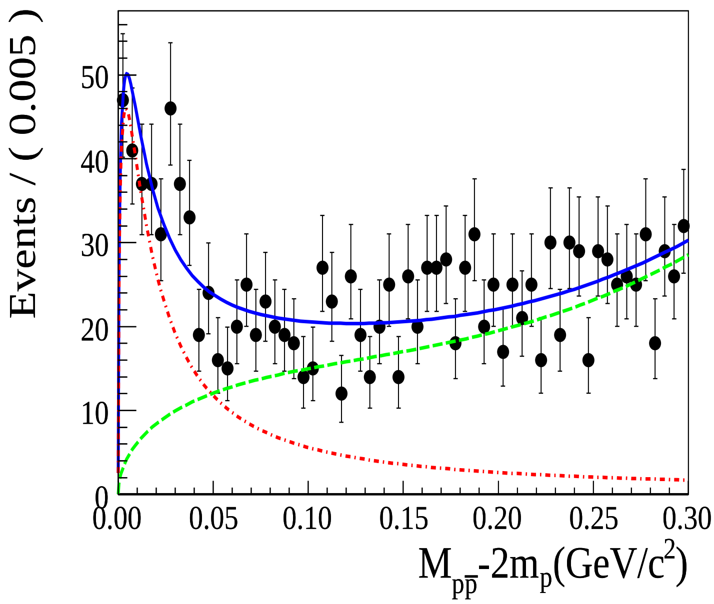

Figure 11: The confirmation of $p\bar{p}$ threshold enhancement at BESIII.

Acknowledgments

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