

# An Overview of BESIII recent results

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**Abstract.** Working in the center-of-mass energy region from 2 to 5 GeV, BESIII has published many interesting and important results in a broad range of physics topics, including charmonium and charm physics, hadron studies, determination of the tau mass, R measurements, and investigations of the still-mysterious XYZ particles. This paper reviews a selection of results from BESIII.

## 1. Introduction

The third generation of Beijing Spectrometer experiments (BESIII) operating at the second generation of Beijing Electron Positron Collider (BEPCII), has been run for eight years. The BESIII detector has consisted a single small-celled helium-based MDC, a plastic scintillator TOF system, a CsI(Tl) electromagnetic calorimeter, a 1.0 T superconducting magnet, and a muon counter with 9 resistive plate chamber (RPC) layers in the barrel part and 8 in the end-cap portions interleaved in the steel of the flux return yoke. More details of the BESIII detector can be found in Ref. [1].

From the first event in 2008, BESIII has data sets at many Center-of-mass (CM) energies between 2 to 5 GeV, and very large data sets at the  $J/\psi$  (1.3 billion events),  $\psi(2S)(2S)$  (0.45 billion), and  $\psi(3770)$  ( $2.9 \text{ fb}^{-1}$ ). These are the world's largest exclusive charmonium data sets and allow for many precision measurements. In the following, we reported the results from:  $D_{(s)}$ ,  $\Lambda_c$ , XYZ particles, light hadron progress, proton form factor and  $\tau$  mass measurement, new physics.

## 2. Charmed meson Physics

At the  $\psi(3770)$  resonance or 4.009 GeV,  $D\bar{D}$  or  $D_s D_s$  pairs are produced with no other accompanying particles. Thereby the data sets at  $\psi(3770)$  and 4.009 GeV can provide extremely clean and pure charmed-meson signals. The quantum coherence of the two produced  $D$  mesons provides opportunities to measure  $D^0 - \bar{D}^0$  mixing parameters, determine strong phases, and search for CP violation. In addition, two elements of Cabibbo-Kobayashi-Maskawa (CKM) matrix which parameterizes the mixing between the quark flavors in weak interaction can be precisely measured in  $D_{(s)}$  decays. Precise measurements of these elements are very important in testing the Standard Model (SM) and searching for New Physics (NP) beyond the SM. Any improved measurement of these elements would be the important input for precision test of the SM.

The following results in this section are based on the tagged technique and  $2.93 \text{ fb}^{-1}$  data at  $\sqrt{s} = 3.773$  and  $482 \text{ pb}^{-1}$  data at  $\sqrt{s} = 4.009$  GeV. (Throughout this paper, the inclusion of



charge conjugate channels is implied.) Since the  $D_{(s)}\bar{D}_{(s)}$  are pair produced just above threshold, the identification of one  $D_{(s)}$  meson from a subset of tracks in an event guarantees that the remaining tracks have originated from the decay of the recoiling  $\bar{D}_{(s)}$ . Once a tag is found, the recoil tracks can be examined for the decay mode of interest. Frequently two variables, beam-constrained mass  $M_{BC}$  and energy difference  $\Delta E$ , are used to identify the signals, defined as:  $M_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_{D_{(s)}}|^2}$  and  $\Delta E = E_{D_{(s)}} - E_{beam}$ , where  $E_{D_{(s)}}$  and  $\vec{p}_{D_{(s)}}$  are the energies and momenta of the  $D_{(s)}$  decay products in the center-of-mass system of the  $\psi(3770)$  or 4.009 GeV. For true  $D_{(s)}$  candidates,  $\Delta E$  will be consistent with zero, and  $M_{BC}$  will be consistent with the  $D_{(s)}$  mass.

### 2.1. Leptonic decays of $D_{(s)}^+$

The  $D_{(s)}^+$  meson can decay into  $l^+\nu_l$  (where  $l = e, \mu$  or  $\tau$ ) via annihilation mediated by a virtual  $W^+$  boson. In the SM, the decay width is given by

$$\Gamma(D_{(s)}^+ \rightarrow l^+\nu_l) = \frac{G_F^2}{8\pi} f_{D_{(s)}^+}^2 m_l^2 m_{D_{(s)}^+} \left(1 - \frac{m_l^2}{m_{D_{(s)}^+}^2}\right)^2 |V_{cd(s)}|^2, \quad (1)$$

where  $G_F$  is the Fermi coupling constant,  $V_{cd(s)}$  is the  $c \rightarrow d(s)$  Cabibbo-Kobayashi-Maskawa (CKM) matrix element,  $m_l$  is the lepton mass, and  $m_{D_{(s)}^+}$  is the mass of  $D_{(s)}^+$ . All of the strong interaction effects between the two initial-state quarks are absorbed into the decay constant  $f_{D_{(s)}^+}$ . The decay constant is a very fundamental parameter that can be used to test our knowledge of hadronic dynamics. Moreover, the precise measurement of  $f_{D^+}$  can validate theoretical calculations of  $f_B$ , which is a parameter of critical importance for B physics.

For the analysis of  $D^+ \rightarrow \mu^+\nu_\mu$ , nine hadronic modes  $K^+\pi^-\pi^-$ ,  $K_s^+\pi^-$ ,  $K_s^-$ ,  $K^+K^-\pi^-$ ,  $K^+\pi^-\pi^-\pi^0$ ,  $\pi^+\pi^-\pi^-$ ,  $K_s^+\pi^-\pi^0$ ,  $K^+\pi^-\pi^-\pi^-\pi^+$  and  $K_s^+\pi^-\pi^-\pi^+$  are used for tagging  $D^-$ . The signal of  $D^-$  is clearly observed in  $M_{BC}$  spectra. A maximum likelihood fit to the  $M_{BC}$  spectra gives the number of the observed  $D^-$  events. The  $D^+ \rightarrow \mu^+\nu_\mu$  decays are selected on the recoil side by requiring no extra tracks except a muon. The information of the neutrino is inferred from the variable of a missing mass. After subtracting the backgrounds and correcting for the reconstruction efficiency, the branching fraction is measured to be  $\mathcal{B}(D^+ \rightarrow \mu^+\nu_\mu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$ . With the PDG value of  $D^+$  lifetime,  $m_D$ ,  $m_\mu$  and  $|V_{cd}|$ ,  $f_D$  is determined to be  $(203.2 \pm 5.3 \pm 1.8)$  MeV. Alternatively, with the value of  $f_{D^+}$  from PDG, the  $|V_{cd}|$  is calculated to be  $(0.2210 \pm 0.0058 \pm 0.0047)$  [2].

For the  $D_s$  leptonic decays, nine hadronic modes of  $D_s^-$  to  $K_s^-$ ,  $K^+K^-$ ,  $K^+K^-\pi^-$ ,  $K_s^+K^+\pi^-\pi^-$ ,  $\pi^+\pi^-\pi^-$ ,  $\pi^-\eta$ ,  $\pi^-\pi^0\eta$ ,  $\pi^-\eta'(\eta' \rightarrow \pi^+\pi^-\eta)$  and  $\pi^-\eta'(\eta' \rightarrow \rho^0\gamma)$  are used. On the recoil side,  $D^- \rightarrow \mu^+\nu_{mu}$  and  $\tau^+\nu_\tau$  are selected by requiring there is only one charged track to be identified as  $\mu$  or  $\tau$ . Fitting on the missing mass distribution, the number of events are extracted and the corresponding branching fractions are calculated as  $\mathcal{B}(D_s^+ \rightarrow \mu^+\nu_{tau}) = (0.495 \pm 0.067 \pm 0.026)\%$ , and  $\mathcal{B}(D_s^+ \rightarrow \tau^+\nu_\tau) = (4.83 \pm 0.65 \pm 0.26)\%$ . The decay constant is then extracted as  $241.0 \pm 16.3 \pm 6.5$  MeV [3].

### 2.2. Semileptonic decays of $D$

The semileptonic charm meson decay process is a good laboratory for both studying the quark-mixing mechanism and testing theoretical techniques developed for calculating the hadronic matrix element. In the SM, neglecting the lepton mass, the differential decay rate for  $D^+ \rightarrow Pe^+\nu_e$  ( $P = K^-, \pi^-, \bar{K}^0$  or  $\pi^0$ ) is given by

$$\frac{d\Gamma}{dq^2} = X \frac{G_F^2}{24\pi^3} |V_{cd(s)}|^2 p^3 |f_+(q^2)|^2, \quad (2)$$

where  $p$  is the momentum of the pseudoscalar meson  $P$  in the rest frame of the  $D$  meson, and  $f_+(q^2)$  is the form factor representing the hadronic form factors of the hadronic weak current that depends on the square of the four-momentum transfer  $q = p_{D(s)} - p_P$ . In Eq. 2,  $X$  is a factor due to isospin, which equals to 1 for  $D^0 \rightarrow K^- e^+ \mu_e$ ,  $D^0 \rightarrow \pi^- e^+ \mu_e$ ,  $D^+ \rightarrow \bar{K}^0 e^+ \mu_e$  and  $1/2$  for  $D^+ \rightarrow \pi^0 e^+ \mu_e$ .

By tagging  $\bar{D}^0$  decays to  $K^+ \pi^-$ ,  $K^+ \pi^- \pi^0$ ,  $K^+ \pi^+ \pi^- \pi^-$ ,  $K^+ \pi^+ \pi^- \pi^- \pi^0$  and  $K^+ \pi^- \pi^0 \pi^0$ , the events of  $D^0$  decays  $K^- e^+ \mu_e$  and  $\pi^- e^+ \mu_e$  are selected on the recoil side. By analyzing these events, the branching fraction are measured to be  $\mathcal{B}(D^0 \rightarrow K^- e^+ \mu_e) = (3.505 \pm 0.14 \pm 0.033)\%$  and  $\mathcal{B}(D^0 \rightarrow \pi^- e^+ \mu_e) = (0.295 \pm 0.004 \pm 0.003)\%$ . The differential decay rates are measured in  $q^2$  bins precisely. The product  $f_+(0)|V_{cs(d)}|$  are extracted from the fit to the differential decay rates with different models. In conjunction with the values of  $|V_{cs(d)}|$  determined from a global SM fit, the form factor is determined as  $f_+^{D \rightarrow K}(0) = 0.7368 \pm 0.0026 \pm 0.0036$ ,  $f_+^{D \rightarrow \pi}(0) = 0.6372 \pm 0.0080 \pm 0.0044$ . Alternatively, the  $|V_{cs(d)}|$  is extracted using the recent lattice QCD results of form factors:  $V_{cs} = 0.9601 \pm 0.0033 \pm 0.0047 \pm 0.0239_{\text{LQCD}}$  and  $|V_{cd}| = 0.2155 \pm 0.0027 \pm 0.0014 \pm 0.0094_{\text{LQCD}}$  [4]. With these precise results, the PDG group issued a new world weighted average value for  $|V_{cd}|$  which is  $\sim 48\%$  improved in precision. The PDG checked the unitarity of the CKM matrix, and indeed found about  $2\sigma$  tension with three-generation unitarity [5, 6]. Similarly,  $D^+ \rightarrow K^0 e^+ \nu_e$  and  $D^+ \rightarrow \pi^0 e^+ \nu_e$  are analyzed. The numerical results are consistent with the charged decay modes.

### 3. Charmed baryon physics

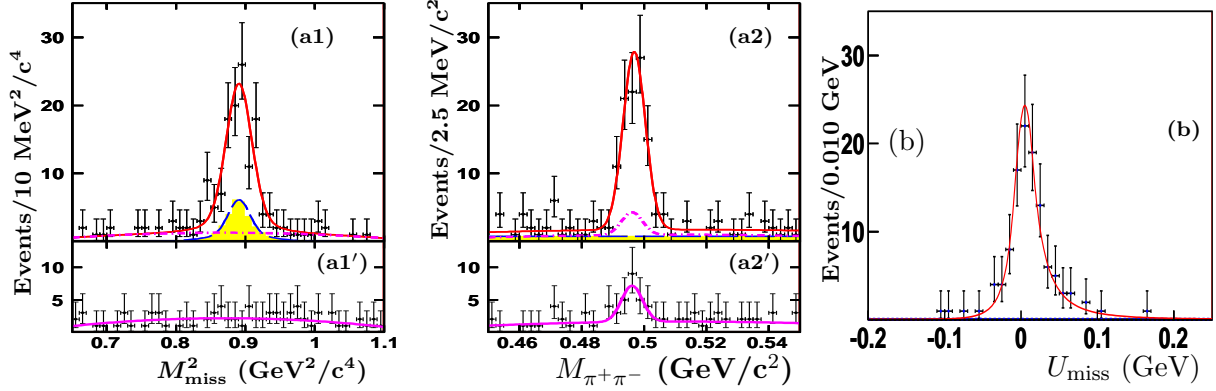
Unlike the charmed meson decays, charmed baryon decays suffer from great uncertainties experimentally. Thus, the improved measurement of the charmed baryon  $\Lambda_c$  decays is of crucial importance for that they could both provide plentiful information for the dynamics in the charm sector and improved input for beauty physics. Utilizing the  $567 \text{ pb}^{-1}$  data at  $\sqrt{s} = 4.599 \text{ GeV}$  which is just above the  $\Lambda_c^+ \bar{\Lambda}_c^-$  threshold, BESIII performed a measurement of the absolute branching fraction for 12 Cabibbo-favored  $\Lambda_c^+$  hadronic decay modes [7]. With the single tag and double tag technique, the absolute branching fractions of  $\Lambda_c$  have been measured with 3-6 times better precision than the world average values. For the golden mode  $\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)$ , our result is about  $2\sigma$  lower than Belle result.

The measurement of  $\Lambda_c$  decaying to neutron involved final states is very rare. It has been argued that the isospin symmetry works well in the charged baryon section. The relative branching fraction of the neutron-involving decay to the proton-involving decay provides an important observable in testing isospin symmetry in  $\Lambda_c$  decays. It will also help to explore the final state interactions. A measurement of  $\Lambda_c \rightarrow n \bar{K}_0 \pi^+$  is finished at BESIII. With 11 single tag modes, a clean  $\Lambda_c^+$  sample is selected. The signal of  $\Lambda_c^+ \rightarrow n K_s \pi^+$  is get by a simultaneous fit on the mass spectrum of  $M_{miss}^2$  (the mass of neutron) and  $M_{\pi^+ \pi^-}$  (the mass of  $K_s$ ) and the mass spectrums from events of  $\Lambda_c^-$  sideband, shown in Fig. 1 (the left four plots). The branching fraction is measured as  $\mathcal{B}(\Lambda_c^+ \rightarrow n K_s \pi^+) = (1.82 \pm 0.23 \pm 0.11)\%$ .

The branching fraction for  $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$  is the benchmark for those of other  $\Lambda_c$  semileptonic channels. The absolute branching fraction of it is measured in 11 tag modes. From the  $U_{miss}$  distribution of neutrino which is shown in Fig. 1 (b), the number of events are extracted and the branching fraction is then determined as  $(3.63 \pm 0.38 \pm 0.20)\%$  which improves the precision of the world average value by more than twofold [8].

### 4. XYZ particles

From 2013, many fruitful results from BESIII about the XYZ have extracted the most interest in particle physics. Up to now, four charged  $Z_c$  states with probable the corresponding neutral states have been found. Their masses, widths, and original decay channels are listed in Table 1.



**Figure 1.** (a) For the  $\Lambda_c \rightarrow nK_s\pi$  analysis: the simultaneous fit to  $M_{\text{miss}}^2$  and  $M_{\pi^+\pi^-}$  of events in (a1, a2) the  $\Lambda_c^-$  signal region and (a1', a2') sideband regions. (b) For the  $\Lambda_c \rightarrow \Lambda e\nu_e$  analysis: fit to the  $U_{\text{miss}}$  distribution within the  $\Lambda$  signal region.

**Table 1.** The summary of the found  $Z_c$  states.

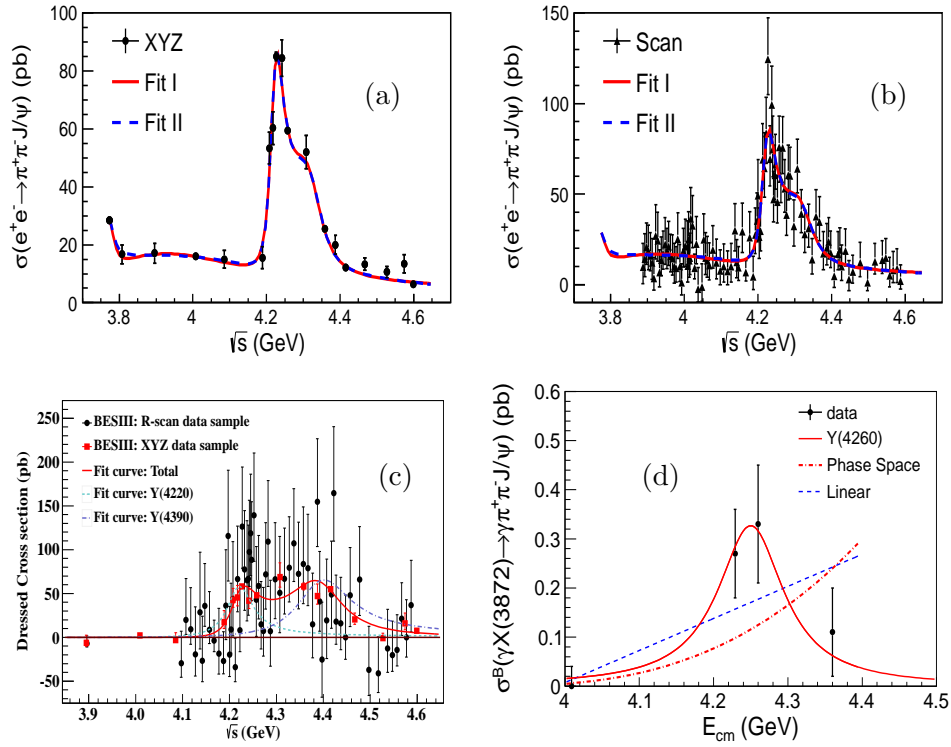
Particles	channel	Mass (MeV/ $c^2$ )	Width (MeV)
$Z_c^\pm(3900)$	$e^+e^- \rightarrow \pi^+\pi^- J/\psi$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
$Z_c^0(3900)$	$e^+e^- \rightarrow \pi^0\pi^0 J/\psi$	$3894.8 \pm 2.3$	$29.6 \pm 8.2$
$Z_c^\pm(3885)$	$e^+e^- \rightarrow \pi(D^*D)^\pm$	$3882.2 \pm 1.1 \pm 1.5$	$26.5 \pm 1.7 \pm 2.1$
$Z_c^0(3885)$	$e^+e^- \rightarrow \pi(D^*D)^0$	$3885.7 \pm 5.7 \pm 8.4$	$35 \pm 12 \pm 15$
$Z_c^\pm(4020)$	$e^+e^- \rightarrow \pi^+\pi^- h_c$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
$Z_c^0(4020)$	$e^+e^- \rightarrow \pi^0\pi^0 h_c$	$4023.9 \pm 2.2 \pm 3.8$	Fixed at $Z_c^\pm(4020)$
$Z_c^\pm(4025)$	$e^+e^- \rightarrow \pi(D^*D^*)^\pm$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
$Z_c^0(4025)$	$e^+e^- \rightarrow \pi(D^*D^*)^0$	$4025.5 \pm 4.7 \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$

For the  $Y$  state, the first to be discovered is  $Y(4260)$ , which is originally seen as a peak in the  $e^+e^- \rightarrow \pi^+\pi^- J/\psi$  cross section. New results from BESIII, however, show that the  $Y(4260)$  is not a simple peak. Using both a small number of high-statistics data points and a large number of low-statistics data points, the cross section of  $e^+e^- \rightarrow \pi^+\pi^- J/\psi$  is renewed, shown in Fig. 2 (a,b). The peak that was formerly known as the  $Y(4260)$  can be better described as a combination of two peaks, one with a mass of  $4220.0 \pm 3.1 \pm 1.4$  MeV/ $c^2$  and width of  $44.1 \pm 4.1 \pm 2.0$  MeV and one with a mass of  $4320.0 \pm 10.4 \pm 7.0$  MeV/ $c^2$  and width of  $101.4^{+25.3}_{-19.7} \pm 10.2$  MeV [9].

Similarly, the  $e^+e^- \rightarrow \pi^+\pi^- h_c$  cross section is much more complex than previously suspected [10]. The cross section can also be described as two peaks, shown in Fig. 2 (c), one with a mass of  $4218.4 \pm 4.0 \pm 0.9$  MeV/ $c^2$  and width of  $66.0 \pm 9.0 \pm 0.4$  MeV and one with a mass of  $4391.6 \pm 6.3 \pm 1.0$  MeV/ $c^2$  and width of  $139.5 \pm 16.1 \pm 0.6$  MeV. The parameters of the lighter peak agree with the parameters of the lighter peak in  $\pi^+\pi^- J/\psi$ .

An analysis with preliminary result on the cross section of  $e^+e^- \rightarrow \pi^+\pi^- \psi(2S)$  is also made. The new measurements are in agreement with those from Belle and BaBar, which were used to determine the parameters of the  $Y(4360)$ .

Another well-known mystery in the charmonium spectrum is the nature of the  $X(3872)$ . Using high-statistics data above 4.0 GeV, BESIII observed the process  $e^+e^- \rightarrow \gamma X(3872)$ ,  $X(3872) \rightarrow$



**Figure 2.** The (a) and (b) plots are for the measured cross section of  $e^+e^- \rightarrow \pi^+\pi^- J/\psi$  using high-statistics data point (left) and a larger number of low-statistics data points. The plot of (c) is the measured cross section of  $e^+e^- \rightarrow \pi^+\pi^- h_c$ . The plot of (d) is the measured cross section of  $e^+e^- \gamma X(3872) \rightarrow \gamma \pi^+\pi^- J/\psi$ .

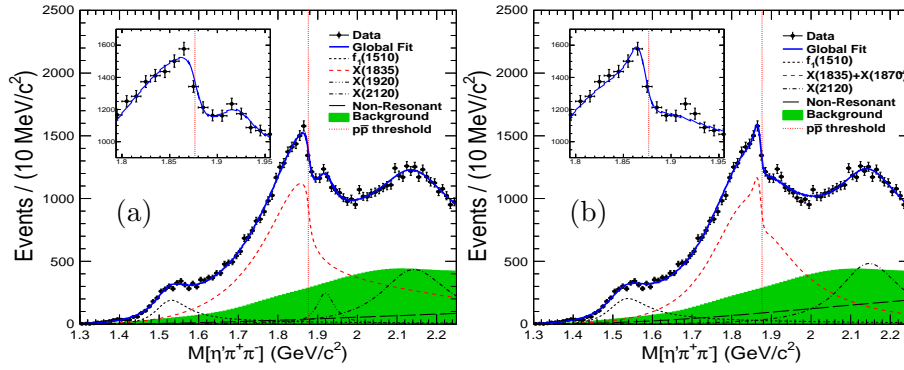
$\pi^+\pi^- J/\psi$  [11]. The cross section shows a shape that is consistent with a peak between 4.2 and 4.3 GeV, shown in Fig. 2 (d), which may indicate a connection between the  $X$ (3872) and the  $Y$  states. More data is needed to resolve this issue, and find more connections among  $X$ ,  $Y$  and  $Z$  states.

## 5. The $X$ (1835)

Since its discovery, the  $X$ (1835) was subject of different speculations about its nature. The possible interpretations include  $p\bar{p}$  bound state, glueball, radia excitation of  $\eta'$  meason, and so on. The lowest lying pseudoscalar glueball meson predicted by the Lattice QCD is expected to have a mass around  $2.3 \text{ GeV}/c^2$ . Its decay dynamics suggests that it may have properties in common with the  $\eta_c$ , of which one of the strongest decay channel is  $\pi^+\pi^-\eta'$ . The  $X$ (1835) was found in the  $\pi^+\pi^-\eta'$  mass distribution at BESII, and confirmed at BESIII. The  $X$ (1835) is also observed in the  $\eta K_s K_s$  channel in  $J/\psi$  radiative decays, where its spin parity was determined as  $J^P = 0^-$  by a partial wave analysis [12]. At the same time, an anomalously strong enhancement at the  $p\bar{p}$  mass threshold, dubbed as  $X(p\bar{p})$ , was first observed by BESII in  $J/\psi \rightarrow \gamma p\bar{p}$ , and then confirmed at BESIII and CLEO. The quantum numbers were subsequently determined as  $J^P = 0^-$  by BESIII.

With the 1.3 billion data of  $J/\psi$ , a significant abrupt change in slope of the  $X(1835) \rightarrow \pi^+\pi^-\eta'$  line shape is observed. This indicates a connection between  $X(1835)$  and  $X(p\bar{p})$ . The invariant mass spectrum lineshape around  $1.85 \text{ GeV}/c^2$  might be characterized by two models.

The first one takes the advantage of the Flatté formula to describe the opening of an additional decay mode, and a resonance at  $X(1920)$  with a significance of  $5.7\sigma$  has been included, shown in Fig. 3 (a). The second model is based on the coherent sum of two Breit-Wigner amplitudes, the  $X(1835)$  and a narrow  $X(1870)$ , and the fit plot is shown in Fig. 3 (b). Both models support the existence of a  $p\bar{p}$  moleculelike or bound state. More data are needed to further study the structure around  $1.85 \text{ GeV}/c^2$ , and the line shapes from other decay modes are also needed.



**Figure 3.** Fit results of the mass spectrum of  $\pi^+\pi^-\eta'$  from  $J/\psi$  radiative decay with (a) the Flatté formula and the  $X(1920)$  resonance and (b) a coherent sum of two Breit-Wigner amplitudes.

## 6. Baryon form factors

The baryon form factors (FFs) provide fundamental information on the baryon structure, giving crucial tests also to models of hadron internal structure in general. It describes the modifications of the point-like photon-hadron vertex due to the internal structure and dynamic of hadrons. Taking into account the symmetry properties of the EM interaction under Charge (C), Parity (P) and Time (T) transformations, the structure of any non-point-like particle of spin  $S$  is parameterized in terms of  $(2S+1)$  FFs. For baryons with  $\frac{1}{2}$  spin are described by electro FF ( $G_E$ ) and magnetic FF ( $G_M$ ). In the time-like region, like  $e^+e^- \rightarrow p\bar{p}$  process, the  $G_E$  and  $G_M$ , or  $R = \frac{G_E}{G_M}$  and  $G_M$  can be measured from the differential born cross section:

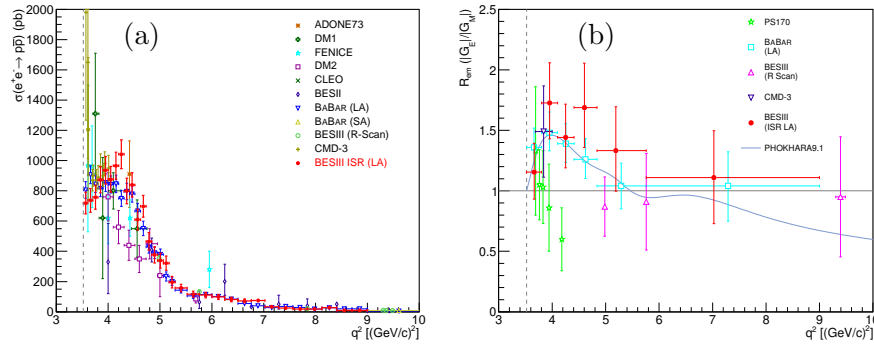
$$\frac{d\sigma_{Born}}{d\Omega} = \frac{\alpha^2 \beta \mathcal{C}}{4q^2} \left[ (1 + \cos^2 \theta) |G_M|^2 + \frac{1}{\tau} \sin^2 \theta |G_E|^2 \right] \quad (3)$$

The Born cross section can be written as:

$$\sigma_{Born} = \frac{4\pi \alpha^2 \beta \mathcal{C}}{3q^2} \left[ |G_M|^2 + \frac{1}{2\tau} |G_E|^2 \right] \quad (4)$$

The factor  $\mathcal{C}$  is a correction factor to take into account the coulomb interaction between the outgoing charged baryons.

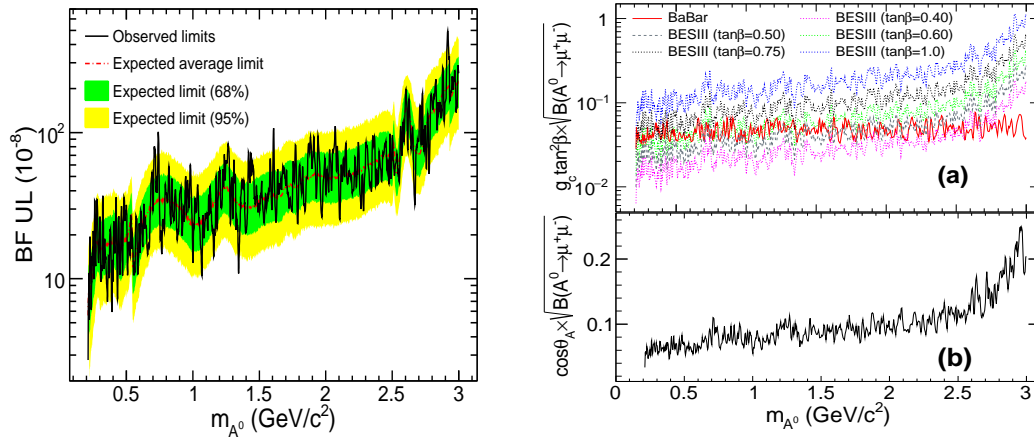
For the proton FFs, the direct production of  $p\bar{p}$  from  $e^+e^-$  annihilation or the production from ISR events from  $e^+e^-$  can both serve for the measurement. With the data collected at 2012, the proton FFs have been measured, and the cross section of  $e^+e^- \rightarrow p\bar{p}$  and  $R$  were both consistent with Babar result. Recently, by means of ISR technique, the cross section and FFs are measured in a continuous  $q^2$  region from the  $p\bar{p}$  threshold with the large XYZ data sets. The



**Figure 4.** Preliminary results of the cross section of  $e^+e^- \rightarrow p\bar{p}$  (a) and the  $R$  of proton (b) from ISR analysis.

dressed cross section and  $R$  are shown in Fig. 4. Obviously, the precisions in cross section and  $R$  are comparable with BaBar results.

In 2014 and 2015, an unprecedented amount of off-resonance data have been taken within the CMS energy range 2-3 GeV and above the threshold of the  $\Lambda_c \bar{\Lambda}_c$ . These data enable a great leap forward regarding baryon structure. The precision of proton form factors will reach 10% level, and the precision of  $R$  and  $G_M$  will be similar as that in the space-like region. For the other baryons ( $n$ ,  $\Lambda$ ,  $\Sigma$ ,  $\Lambda_c$ ), their form factors will be measured for the first time and the result is promising.



**Figure 5.** (Left) Upper limit of the branching fraction  $\mathcal{B}((J/\psi \rightarrow \gamma A^0)) \times \mathcal{B}(A^0 \rightarrow \mu^+ \mu^-)$ . (Right) [top] The 90% C.L. upper limit of  $g_b (= g_c \tan^2 \beta) \times \sqrt{\mathcal{B}(A^0 \rightarrow \mu^+ \mu^-)}$  and [bottom]  $\cos \theta_A (= |sqr{t} g_b g_c| \times \sqrt{\mathcal{B}(A^0 \rightarrow \mu^+ \mu^-)})$ .

## 7. New physics

It is a very important part of BESIII project to search for new physics which can explain many unsolved mysteries or puzzles. New physics ideas or theories, even some of which are against with traditional SM, are put forward as the extensions of SM. The next-to-minimal supersymmetric Standard Model (NMSSM) has a rich Higgs sector containing three CP-even, two CP-odd, and

two charge Higgs bosons. The mass of the lightest CP-odd Higgs boson,  $A^0$ , maybe less than twice the mass of the charmed quark, and can decay to a muon pair from charmonium radiative decay.

BESIII has searched the light Higgs boson firstly through 106 million  $\psi(2S)$  event. Non-resonant background can be reduced very effectively due to the intermediate production of  $J/\psi$ . Upper limit of number of  $A^0$  signal is set at the 90% confidence level and corresponded upper limit of the branching fraction of  $\mathcal{B}(\psi(2S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \mu^+\mu^-)$  is from  $4 \times 10^{-7}$  to  $2.1 \times 10^{-5}$  [13]. With 225 million  $J/\psi$  data,  $A^0$  is searched for again directly from  $J/\psi$  radiative decay [14]. This analysis gives a factor of five times improvement result for the upper limit of  $\mathcal{B}(J/\psi \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \mu^+\mu^-)$  ranging between  $2.8 \times 10^{-8}$  and  $4.953 \times 10^{-6}$ , shown in Fig. 5 (left). In this work, the coupling parameter  $g_b$  is also computed, shown in Fig. 5 (right). The new result is complementary and better than BaBar in the low mass region for  $\tan\beta \leq 0.6$ . Combining BaBar results, the measured  $\cos\theta_A \times \mathcal{B}(A^0 \rightarrow \mu^+\mu^-)$  result constrains the  $A^0$  is mostly a singlet.

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