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Recent BESIII results

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The BESIII detector, built at the Beijing Electron Positron Collider II (BEPC-II), is a powerful facility to study physics in the energy range up to 4.6 GeV, with a broad research program covering charmonium physics, D-physics, spectroscopy of light hadrons and tau-physics. BESIII has started to take data in 2008 and it has already collected a statistics of $225*10^6$ J/ψ and $106*10^6$ ψ' events, the world largest data samples on these charmonium states. Based on these data, recent results will be here presented.

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1. Introduction

The Beijing Spectrometer BESIII is a major upgrade of the BESII detector and aims to study electron positron collisions in the charm energy range. The physics program is quite broad and foresees an intensive study of charmonium physics, charmonium decays, open charm and tau physics, and also spectroscopy of light hadrons.

1.1 The Beijing Electron Positron Collider BEPC-II

BESIII is built in the Beijing Electron Positron Collider BEPC-II, a two rings $e^+ e^-$ collider with a circumference of 273 m, operating in a center of mass energy range from 2 GeV to 4.6 GeV. The design peak luminosity of the collider is 10^{33} cm^{-2}s^{-1} at a beam current of 0.93 A and an energy spread of 5.16×10^{-4}, and its optimum energy is 1.89 GeV corresponding to the $\psi(3770)$ mass. The two bunches of electron and positron collide in the BESIII interaction point with an angle of 22 mrad.
The physics data taking has started in March 2009, and up to now BESIII has collected 225 M events of J/ψ data, 106 M events of ψ', 2.9 fb^{-1} of ψ(3770), which are the world largest data samples, and an unique sample of 0.5 fb^{-1} at 4010 MeV. A luminosity of 0.65×10^{33} cm^{-2}s^{-1} has been achieved up to now.

1.2 The BESIII detector

The BESIII detector[1] has a geometrical acceptance of 93% of the full solid angle. Tracking is performed by a small-celled, helium-based main drift chamber with 43 layers, placed inside a 1 T superconducting solenoid; the average single wire position resolution is 135 μm and the momentum resolution at 1 GeV/c is 0.5%. An electromagnetic calorimeter (EMC) consists of 6240 CsI(Tl) crystals arranged in a cylindrical shape (barrel) plus two end caps. The energy resolution for 1 GeV photons is 2.5% in the barrel and 5% in the end caps, and the position resolution is 6 mm in the barrel and 9 mm in the end caps. A time-of-flight system for particle identification is present, composed of a barrel part made of two layers with 88 pieces of 5 cm thick, 2.4 m long plastic scintillators in each layer, and two end caps with 96 fan-shaped, 5 cm thick plastic scintillators in each end cap. The time resolution is 80 ps in the barrel and 110 ps in the end caps, corresponding to better than a 2 sigma K/π separation for momenta below 1 GeV/c. Muon detection is performed by a chamber system made of 1000 m^2 of resistive plate chambers arranged in 9 layers in the barrel and 8 layers in the end caps, incorporated in the return iron of the superconducting magnet. The position resolution is about 2 cm. The last comer is the Zero Degree Detector (ZDD), a lead-scintillating fiber calorimeter placed in the very forward and in the very backward region (few milliradians) to detect the Initial State Radation photons; the first of the two detectors has just been installed and it will be used for the first time with the incoming beamtime period.

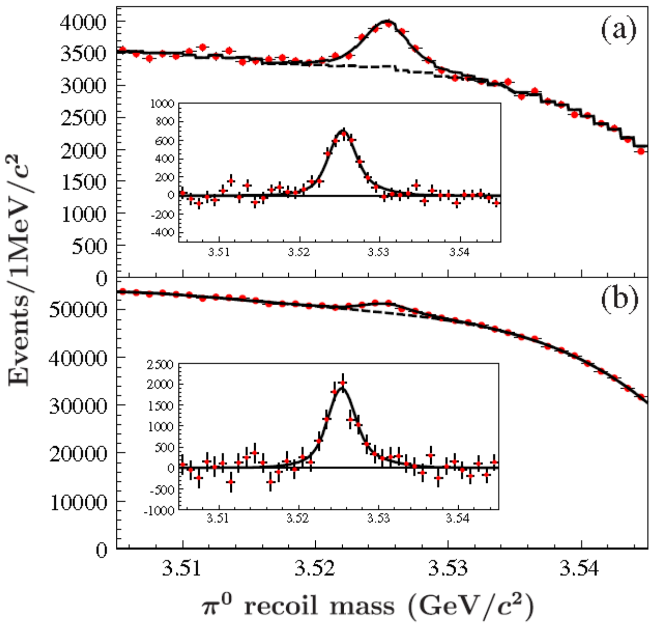

Figure 1: The π° recoil mass spectrum for a) E1-tagged and 2) untagged analysis of $\psi' \to \pi^\circ h_c$, $h_c \to \gamma\eta_c$.

2. Charmonium spectroscopy

2.1 Measurements of $h_c(^1P_1)$ in ψ' decays

In the charmonium family the $h_c(^1P_1)$ singlet state has not being studies intensively so far; it was seen only in the $\psi' \to \pi^\circ h_c$ production mode, whose branching ratio has not been previously measured. A very precise measurement of the h_c mass allows to study the strenght of the spin-spin interaction in the charmonium potential model, by calculating the $1P$ hyperfine splitting $\Delta M_{hf} =< M(^3P_J) > -M(^1P_1)$, where $< M(^3P_J) >$ is the spin-weighted centroid of the χ_{cJ} mass and $M(^1P_1)$ is the mass of the h_c state.
In BESIII the h_c production is studied in the $\psi' \to \pi^\circ h_c$ isospin violating decay, separately by detecting the E1 photon from the $h_c \to \gamma\eta_c$ decay and by performing inclusive measurement. Fig.1 shows the π° recoil mass distribution for the inclusive and the E1-tagged channel, where a clear h_c signal is present. By means of a combined analysis of the inclusive and the exclusive channel BESIII has measured the mass of the h_c state $M(h_c) = 3525.40 \pm 0.13 \pm 0.18$ MeV/c^2, for the first time its decay width $\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28$ MeV/c^2, and for the first time the branching ratios $Br(\psi' \to \pi^\circ h_c) = 8.4 \pm 1.3 \pm 1.0 \times 10^{-4}$ and $Br(h_c \to \gamma\eta_c) = 54.3 \pm 6.7 \pm 5.2\%$[2]. The mass value is consistent with no strong spin-spin interaction. Currently a more precise determination of the h_c properties is ongoing by a combined measurement of different exclusive η_c decay modes.

2.2 Measurements of η_c resonance parameters

The η_c meson is the ground state of the charmonium and it is known since ling time; nevertheless its properties are known with a worse resolution than the other main charmonium states

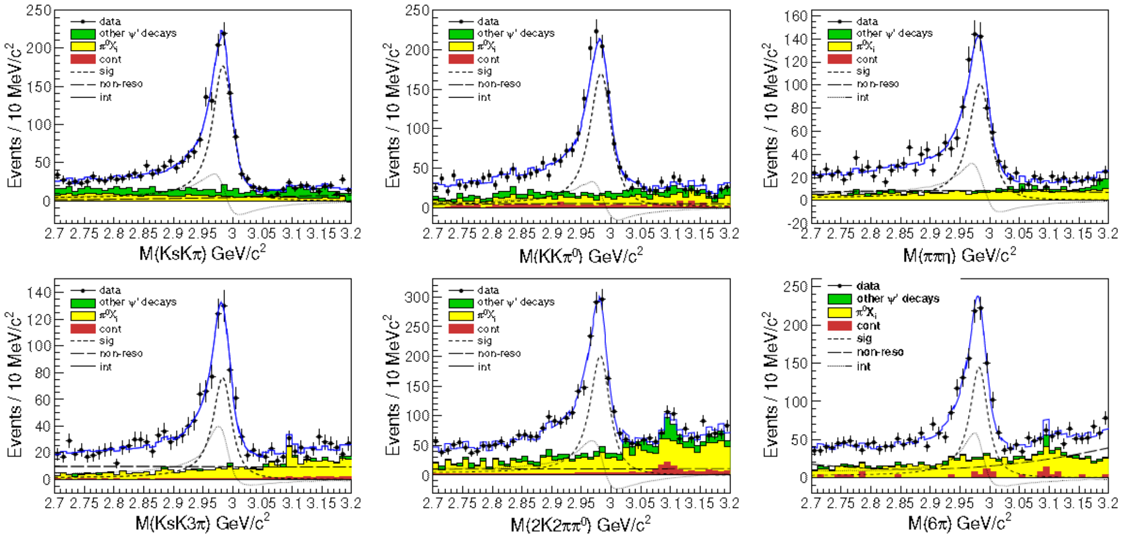

Figure 2: The preliminary invariant mass distributions for the decays $K_S K\pi$, $K^+K^-\pi^\circ$, $\pi^+\pi^-\eta$, $K_S K3\pi$, $2K2\pi\pi^\circ$, 6π, superimposing the fit results.

(J/ψ, ψ', χ_{cJ}) and recent results from B-factories have shown discrepancies with the earlier measurements.
In BESIII we have studied the η_c produced in the $\psi' \to \gamma\eta_c$ channel and its decay into six hadron modes (i.e. $K_S K\pi$, $K^+K^-\pi^\circ$, $\pi^+\pi^-\eta$, $K_S K3\pi$, $2K2\pi\pi^\circ$, 6π)[3]. As shown in fig.2, all the modes were fitted simultaneusly by a modified Breit-Wigner, weighted by the M1-transition, by adding also an interference term between the η_c signal and the non-η_c decays in order to reproduce the asymmetric shape of the signal peaks. The η_c mass and widths values were constrained to be the same for all the modes, and we obtain $M(\eta_c) = 2984.3 \pm 0.6 \pm 0.6$ MeV/c^2, $\Gamma(\eta_c) = 32.0 \pm 1.2 \pm 1.0$ MeV/c^2 with the relative phases of each mode consistent within 3σ. A fit with a common phase for all the modes describes better the data, with as results $M(\eta_c) = 2983.9 \pm 0.6 \pm 0.6$ MeV/c^2, $\Gamma(\eta_c) = 31.3 \pm 1.2 \pm 0.9$ MeV/c^2, and $\phi = 2.40 \pm 0.07 \pm 0.08$ rad (constructive) or $\phi = 4.19 \pm 0.03 \pm 0.09$ rad (destructive). The obtained mass and width values are consistent with CLEO-C results and they are currently the world best measurements. The physics behind the observation of a relative phase value has to be understood, and this could partially explain the discrepancies in the measurements of the previous years.

2.3 Measurements of M1 transitions in $J/\psi \to \gamma\eta_c$(2S)

The $\eta_c(2S)$ is the first η_c excited state and previously has been measured in B decays or in two photon processes. The $\eta_c(2S)$ can be produced also by the decay $\psi' \to \gamma\eta_c(2S)$, but this measurement is experimentally challenging because a low energy photon of around 50 MeV has to be reconstructed. BESIII has studied the reaction $\psi' \to \gamma\eta_c(2S)$, $\eta_c(2S) \to K_S K\pi$ with the 106M ψ' data sample, as shown in fig.3. From a preliminary analysis, fitting the distribution with a $\eta_c(2S)$ modified (M1) Breit-Wigner, the two χ_{cJ} signal peaks and the background (from data measurements), 50.6 ± 9.7 $\eta_c(2S)$ mesons were counted, with a pure statistical significance larger

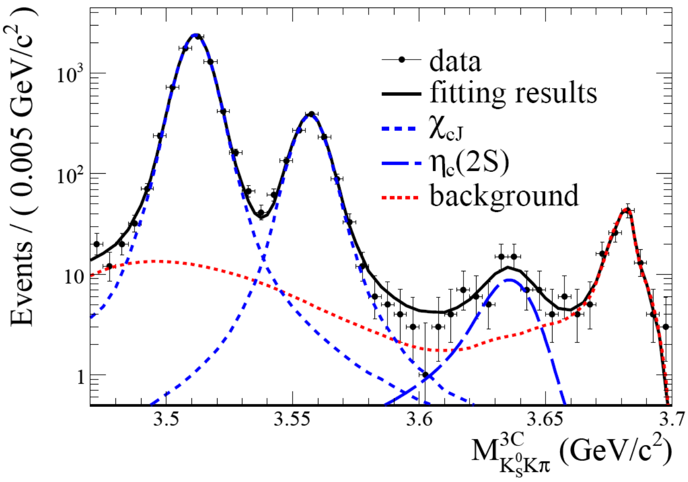

Figure 3: Preliminary distribution of the $K_S K\pi$ invariant mass, where the $\eta_c(2S)$ peak is evident.

than 6σ. The obtained mass value is $M(\eta_c(2S)) = 3638.5 \pm 2.3 \pm 1.0$ MeV/c^2, and the branching ratio $Br(\psi' \to \gamma\eta_c(2S) \to \gamma K_S^\circ K\pi) = (2.98 \pm 0.57 \pm 0.48) \times 10^{-6}$, which combined with previous measurements provides $Br(\psi' \to \gamma\eta_c(2S)) = (4.7 \pm 0.9 \pm 3.0) \times 10^{-4}$, in agreement with CLEO-C upper limits[4]. The analysis has still to be finalized and with the incoming data the statistics will be increased.

3. Light hadron spectroscopy

3.1 $p\bar{p}$ mass threshold enhancement in $J/\psi \to \gamma p\bar{p}$ decay

The BESII collaboration has seen a strong enhancement in the $p\bar{p}$ invariant mass close to threshold studying $J/\psi \to \gamma p\bar{p}$ decays[5], while this effect has not been observed in other channels such as $\psi(2S) \to \gamma p\bar{p}$, $\Upsilon \to \gamma p\bar{p}$ and $J/\psi \to \omega p\bar{p}$. This could be interpreted as a $p\bar{p}$ bound state, or pure effect of final state interaction (FSI), even if the latter is disfavored by the missing observances of the other channels.
BESIII has accumulated a huge statistics of J/ψ and ψ' data, allowing a detailed study of such structure. An analysis of $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma p\bar{p}$ has confirmed BESII data; the data were fitted (fig.4) by a S-wave Breit-Wigner resonance function, obtaining $M = 1861^{+6}_{-13}(stat)^{+7}_{-26}(syst)$[6]. Recently $J/\psi \to \gamma p\bar{p}$ data were studied, and from a preliminary partial wave analysis the quantum numbers 0^{-+} seem preferable; an inclusion of the FSI improve the data dscription, and from the fit results we obtain $M = 1832 \pm 5(stat)^{+15}_{-17}(syst) \pm 19(mod)$, with $\Gamma < 48$ MeV at 90% CL.

3.2 Confirmation of the X(1835) and observation of the new resonances X(2120) and X(2370) in $J/\psi \to \gamma\pi^+\pi^-\eta'$

The state X(1835) was firstly seen by the BESII collaboration[7] in J/ψ radiative decays $J/\psi \to \gamma\pi^+\pi^-\eta'$. This could be intepreted as $p\bar{p}$ bound state, as a candidate glueball state, as a radial excitation of η', etc. With higher statistics and higher precision BESIII has not only

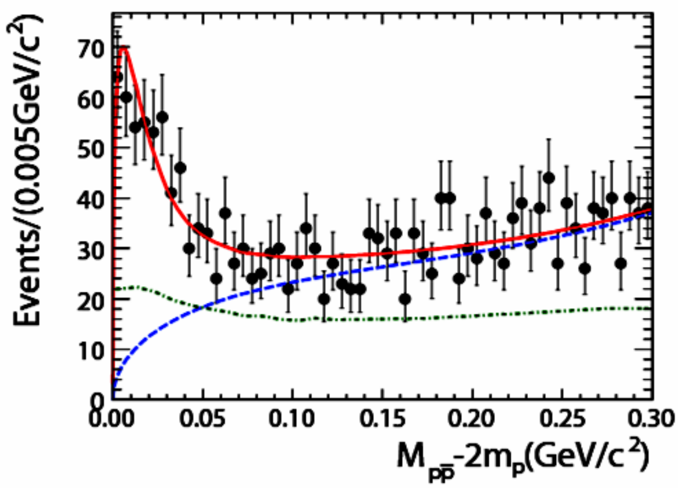

Figure 4: The $p\bar{p}$ invariant mass spectrum for the $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma p\bar{p}$ channel. The curves show: solid $\to$ the fit result; dashed $\to$ the fitted background; dash-dotted $\to$ acceptance variations.

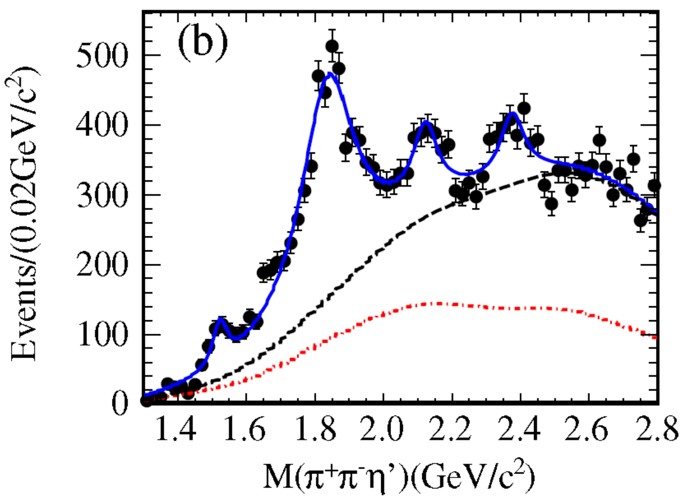

Figure 5: Distribution of $\pi^+\pi^-\eta'$ for the selected events, where the continuous line is the four resonances fit and the dashed line is the contribution of the total background and nonresonant $\pi^+\pi^-\eta'$ processes.

confirmed the BESII results, but also seen the $f_1(1510)$ peak and two new states X(2120) and X(2370) as shown in fig.5[8]. The results from the fit are for X(1835) $M = 1836.5 \pm 3.0(stat) \pm^{+5.5}_{-2.1} (syst)$ and $\Gamma = 190 \pm 9(stat) \pm^{+38}_{-36} (syst)$, for X(2120) $M = 2122.4 \pm 6.7(stat) \pm^{+4.7}_{-2.7} (syst)$ and $\Gamma = 83 \pm 16(stat) \pm^{+31}_{-11} (syst)$, and for X(2370) $M = 2376.3 \pm 8.7(stat) \pm^{+3.2}_{-4.3} (syst)$ and $\Gamma = 83 \pm 17(stat) \pm^{+44}_{-6} (syst)$. The X(1835) angular distribution favors a 0^{-+} state, but in order to have a more precise measurements of spin, parity, mass and width of these three states, and to understand their nature, a partial wave analysis must be performed with the much higher J/ψ data sample planned for the next years.

3.3 $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$ measurements

The decay process $J/\psi \to N\bar{N}$ should be a good laboratory to test perturbative QCD, considering that the three gluons match the three $q\bar{q}$ pairs inside the nucleons in the J/ψ OZI-violating strong decays. In particular, the ratio between the $n\bar{n}$ and the $p\bar{p}$ branching ratios can be used to evaluate the phase angle between the strong and the electromagnetic amplitudes[9]. Indeed, in the two processes the strong amplitudes are the same (the J/ψ is isoscalar), while the electromagnetic amplitudes have the opposite signs like the magnetic moments. If pQCD holds, the two amplitudes should be real and the interference between the two amplitudes should decrease the branching ratio of the neutron channel compared to the proton one. On the contrary, if the two amplitudes are orthogonal, no interference should be present and the two branching ratios should be similar. While $J/\psi \to p\bar{p}$ has been measured accurately, for the $J/\psi \to n\bar{n}$ we have large incertainty in literature[10].
With the 225M J/ψ data sample BESIII has measured both the branching ratios. As preliminary results we obtained $Br(J/\psi \to p\bar{p}) = (2.112 \pm 0.004 \pm 0.027) \times 10^{-3}$ and $Br(J/\psi \to n\bar{n}) = (2.07 \pm 0.01 \pm 0.17) \times 10^{-3}$, consistent with earlier measurements and with much better errors in the neutron channel. These results seem to favor an orthogonality between the strong and the electromagnetic phase, which has to be understood in the theory.

4. Charm physics at threshold

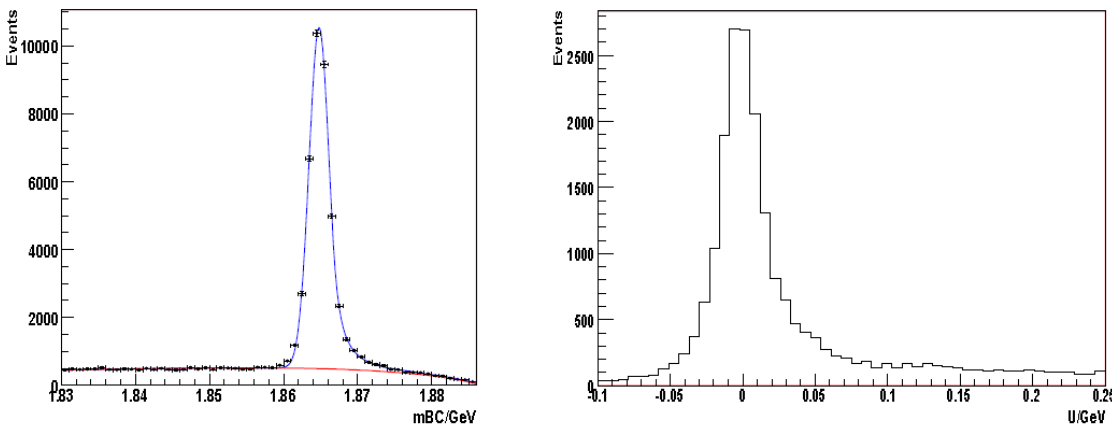

Figure 6: Distribution of beam constrained mass (left) for the $D^\circ \to K^-\pi^+\pi^-\pi^+$ decays, and (right) U distribution of $D^\circ \to K^-e^+\nu$ events (see the text).

One of the most important topic in flavour physics is the high precision measurement of the CKM matrix elements, whose available contraints are mainly dominated by theoretical errors. An analysis of D semileptonic decays can provide precise measurements of the $|V_{cs}|$ and $|V_{cd}|$ CKM elements and form factors, or from pure D leptonic decays the decay constants can be extracted. Moreover, at charm energies the Standard Model background is reduced, and CP and T violating processes can be searched as hints of new physics in the weak sector.
The open charm physics is broad, and e^+e^- collisions are very suitable for such studies because

the initial momentum and quantum numbers are known. In e^+e^- collisions at threshold pairs of D mesons are produced, quantum correlated and almost at rest; by reconstructing both particles absolute branching ratios can be measured, and with the reconstruction of only one of the mesons it is possible to analyze the properties of the other one. In such a way the background is suppressed, the signal is very clean and it is possible to infer the properties of the missing particles in the untagged D meson decays.
Fig.6(left) shows the beam constrained mass $m_{BC} = \sqrt{E^2_{beam} - p^2_{cand}}$ of the $D^\circ \to K^-\pi^+\pi^-\pi^+$ decays for part of the $\psi(3770)$ data, where E_{beam} is the beam energy and p_{cand} is the candidate momentum, and the very clean peak is evident. From a preliminary analysis we obtain a mass resolution of $\approx$ 1.3 MeV/c^2 for pure charged tagging modes, and $\approx$ 1.9 MeV/c^2 for π° modes.
In fig.6(right) an example of recontruction of a semi-leptonic decays is shown, with the $U = E_{miss} - P_{miss}$ distribution of $D^\circ \to K^-e^+\nu$ events, where E_{miss} is the energy and P_{miss} is the momentum of the missing neutrino; even in this case the signal is very clean.
At present charm analysis of the 2.9 fb^{-1} $\psi(3770)$ data sample are ongoing, and of the 0.5 fb^{-1} at 4010 MeV. Preliminary results will be released soon.

5. Summary

With the largest data sample of J/ψ and ψ' mesons reconstructed by the BESIII spectrometer, many measurements have been performed improving our knowledge of the charmonium as well as the light hadron states, while open charm analyses are still ongoing. This report could show only a small part of the BESIII results. In the next future many physics issues will be addressed, increasing the statistics at low energies and taking new data in the higher energy range, in order to perform also τ physics studies, the R scan, to study the production of the D_s mesons and also of the new XYZ charmonium resonances. Moreover, new prospects are open for baryon form factors, and the new ZDD detector will increase the performances for the ISR physics.
We expect then for the incoming years that BESIII will continue bringing us new high precision results and most probably new surprises.

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