Recent Results from BESIII experiment

F. De Mori([1])
on behalf of the BESIII Collaboration (*)
([1]) *Dip. di Fisica, Università degli Studi di Torino and INFN sez. di Torino, Torino,Italy*

Summary. — In this contribution we review recent results from the BESIII experiment. We focus on two very different main topics. Firstly we report the investigation of XYZ states and the discovery of new charged and neutral charmonium-like structures and then we will present recent BESIII results on studies related to the Collins asymmetries measurement.

PACS 14.40.Pq, 13.66.Bc, 14.40.Rt – .

1. – Introduction

The BESIII experiment is installed at the BEPCII double-ring electron-positron collider at the Institute of High Energy Physics (IHEP, Beijing, PRC), with a beam energy tunable from 1.0 to 2.3 GeV. The BESIII detector is a magnetic spectrometer composed by a helium gas based Main Drift Chamber (MDC), a plastic scintillator Time-Of-Flight (TOF) system, a CSI(Tl) ElectroMagnetic Calorimeter (EMC) and a muon detector (MUC) based on Resistive Plate Chambers, immersed in a 1.0 T magnetic field provided by a super-conducting solenoidal magnet. Further details can be found in Ref.[1]. Since 2009 the BESIII experiment has already collected large data samples of e^+e^- annihilations at center-of-mass energies corresponding to the J/ψ, $\psi(3686)$ and $\psi(3770)$ resonances. Recently, a dedicated data-taking was performed for XYZ studies up to about 4.4 GeV collecting the world's largest samples of Y(4260) and Y(4360).

2. – Charged and neutral charmonium-like Zc

Most states in the charmonium region can be successfully described as a simple charm quark and anti-charm quark bound system. In the past decade, many new states (named the XYZ states), which do not fit this model, were discovered. They point towards more complex explanations. In December of 2012 BESIII started a dedicated program to study XYZ states by directly producing Y(4260) and Y(4360) in e^+e^- collisions. In 2013, the

(*) demori@to.infn.it

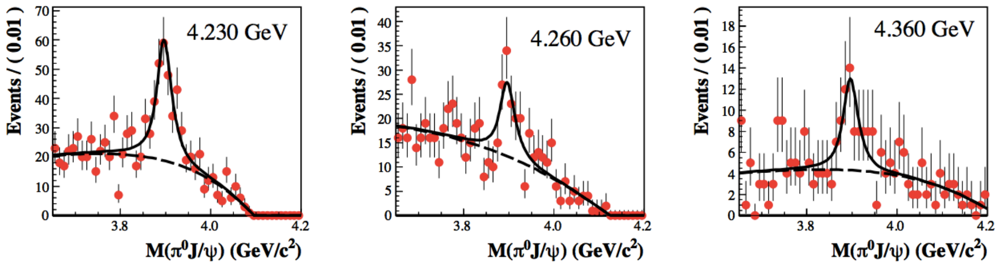

Fig. 1. – $J/\psi\pi^0$ invariant mass distributions for the analyzed samples at 4.23, 4.26, and 4.36 GeV. At the data-point it is superimosed the signal fitting result.

BESIII Collaboration observed a new charged charmonium-like state [2], referred to as $Z_c(3900)$, that was also observed by the Belle Collaboration in e^+e^- annihilations with radiative return to the Y(4260) [3] and was shortly afterwards confirmed in direct e^+e^- annihilations at 4.17 GeV in CLEO-c data [4]. At center-of-mass (c.m.) energies around 4.26 GeV, the signal was found in the invariant $J/\psi\pi^+$ mass distribution [2] in the study of the process $e^+e^- \rightarrow J/\psi\pi^-\pi^+$ with a mass of (3899.0 ± 3.6 ± 4.9) MeV/c^2 and a width of (46 ± 10 ± 20) MeV and a significance larger than 5σ. This $Z_c(3900)$ couples strongly to charmonium and carries electric charge, so it should be at least a four-quark combination. Furthermore it is close to the $D\overline{D^*}$ threshold. Various interpretation were given about its nature e.g. a tetraquark, a hadronic molecule, or a hadrocharmonium. An evidence for a structure in the $J/\psi\pi^0$ invariant mass distribution in the isospin-related channel $e^+e^- \rightarrow J/\psi\pi^0\pi^0$ was reported in CLEO-c data[4], opening the question whether a neutral isospin=0 patner of the charged $Z_c(3900)$ exists. To answer this BESIII investigated the same reaction at center-of-mass energies close to Y(4260) and Y(4360) masses. Preliminary results of this analysis are reported here. At c.m. energes of 4.23, 4.26 and 4.36 GeV, a significant structure in the $J/\psi\pi^0$ invariant mass distribution is observed as shown in Fig. 1, in which the fitting result are also reported. For all of the three data samples common fit parameters for the BreitWigner function were used to describe the signal. A mass of (3894.8 ± 2.3) MeV/c^2 and a width of (29.6 ± 8.2) MeV are obtained, where the errors are statistical only, with a statistical significance of 10.4σ. The results are consistent with those obtained for the charged $Z_c(3900)$ and with those reported for $Z_c(3900)^0$ in Ref. [4]. It is necessary to determine the spin-parity of $Z_c(3900)^+$ and $Z_c(3900)^0$ to establish them as an isospin triplet. Searching for other decay modes of $Z_c(3900)^+$, BESIII investigated the $e^+e^- \rightarrow h_c\pi^+\pi^-$[5]. The h_c is reconstructed via its radiative decay to η_c , that is fully reconstructed in 16 hadronic final states. At c.m. energies between 3.90 and 4.42 GeV the $h_c\pi^+$ invariant mass spectrum shows a narrow structure at about 4.02 GeV/c^2, very close to the $D^*\overline{D^*}$ threshold, referred to as $Z_c(4020)^+$. A fit to the spectrum, neglecting possible interferences, results in a mass of (4022.9 ± 0.8 ± 2.7) MeV/c^2 and a width of (7.9 ± 2.7 ± 2.6) MeV. No significant $Z_c(3900)^+$ signal is observed and an upper limit of 11 pb at $90\% C.L.$ on the $Z_c(3900)^+$ production cross section was found at 4.26 GeV. A similar analysis was performed in the $e^+e^- \rightarrow h_c\pi^0\pi^0$ channel, with the observation of a significant signal in the invariant $h_c\pi^0$ mass distribution at about the same mass of $Z_c(4020)^+$. The fitting result is a mass of (4023.9 ± 2.2 ± 3.8) MeV/c^2 that is consistent with $Z_c(4020)^+$, using a width fixed to that of the charged $Z_c(4020)^+$ due to limited statistics. Being the

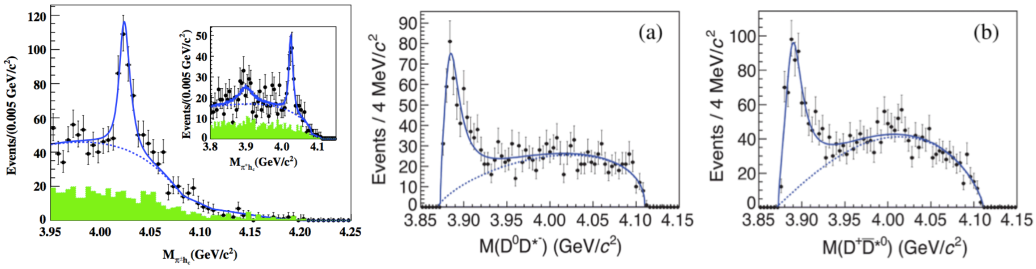

Fig. 2. – On the first plot on left the $h_c\pi^+$ invariant mass spectrum is shown with the fitting results superimposed. In the in-set the fit result adding a $Zc(3900)^+$ signal is shown. the other two plots are referred to $e^+e^-\pi^\pm(D\overline{D*})^\mp$ process, showing the enhancement found in the $(D\overline{D*})^\mp$ invariant mass for both channels, using the Single Tag tecnique

$Z_c(4020)^+$ and $Z_c(3900)^+$ so close to the $D\overline{D^*}$ and $D^*\overline{D^*}$ thresholds, BESIII performed a search for similar structures in the corresponding open-charm channels. The processes $e^+e^-\pi^\pm(D\overline{D^*})^\mp$ [6] and $e^+e^-\pi^\pm(D^*\overline{D^*})^\mp$ [7] were investigated at the c.m. energy of 4.26 GeV with a partial reconstruction technique. For the first one, using Single Tag method, a charged structure is observed in the $(D\overline{D^*})^\mp$ invariant mass distribution with a mass of $(3883.9\pm1.5(stat)\pm4.2(syst))$ MeV/c^2 and width $(24.8\pm3.3(stat)\pm11.0(syst))$ MeV, denoted as $Z_c(3885)^\pm$. Analysing the distribution of the π^- decay angle it was found that is consistent with a spin-parity assignment of $J^P = 1^+$. To understand if $Z_c(3885)^+$ and $Z_c(3900)^+$ are the same state it is necessary to determine the spin-parity of the latter. Recently a new analysis using Double Tag method was explored by BESIII with compatible results but improved statistics. For the second process a structure close to the $(D^*\overline{D^*})$ threshold was observed in the $\pi^\mp$ recoiling mass spectrum, referred to as $Z_c(4025)^\pm$, with a mass of $(4026.3\pm2.6\pm3.7)$ MeV/c^2 and a width of $(24.8\pm5.6\pm7.7)$ MeV. Its production ratio is determined to be $0.65\pm0.09\pm0.06$. The statistics do not allow for a spin-parity analysis of $Z_c(4025)^\pm$. The $\pi^0(D^*\overline{D^*})^0$ channel was studied at 4.23 and 4.26 GeV. We observe a new neutral structure close to $(D^*\overline{D^*})^0$ threshold in the π^0 recoil mass spectrum, called $Z_c(4025)^0$, with $(4025.5^{+2.0}_{-4.7}\pm3.1)$ MeV/c^2 and $(23.0\pm6.0\pm1.0)$ MeV with a significance of 7.4σ.

3. – Measurement of Collins Asymmetries

The Collins fragmentation function [8], which accounts for spin-dependent effects in fragmentation process, describes the distribution of final state hadrons with respect to the direction of the momentum of the transversely polarized fragmenting quark. Experimentally it can be accessed measuring the azimuthal modulation (the so-called Collins effect) of normalized distributions of hadronic fragments along the initial quark momentum. With unpolarized e^+e^- colliders it is impossible to measure the Collins effect in the fragmentation process of a single quark because its spin direction is unknown. Nethertheless the Collins asymmetries can be studied looking at two correlated Collins fragmentation functions in the inclusive production of two hadrons that are produced from the fragmentation of a q and a $\overline{q}$ ($q = u, d, s$) in opposite hemispheres of hadronic events. The cross section of this section can be written, in a simplified notation, as:

$$\sigma(e^+e^- \to h_1h_2X) \sim cos(2\phi_0)(H_1^\perp \otimes H_2^\perp) \tag{1}$$

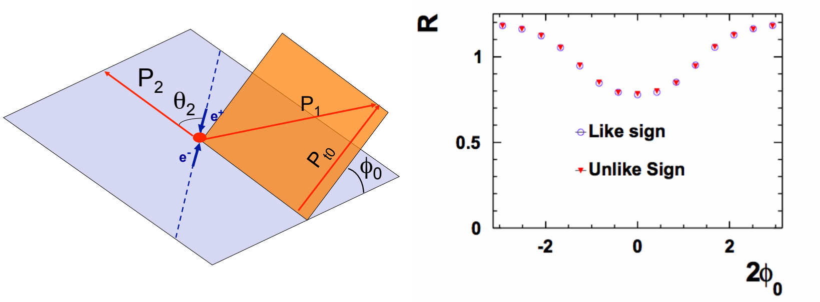

Fig. 3. – On the left the used reference system is sketched. ϕ is the azimuthal angle between the plane defined by the beam axis and P_2 and the transverse momentum p_{t0} of the first hadron. On the right the raw distribution of the Ratio R, as defined in the text, from MC data sample, is shown as a function of $2\phi_0$.

where the azimuthal modulation is introduced and two Collins functions($H^{\perp}$) are involved. We presented the preliminary results of the measurement of the Collins effect in the process $e^+e^- \rightarrow q\bar{q} \rightarrow \pi\pi X$, where a pair of correlated charged pions is detected. It is based on a data sample with about 62 pb^{-1} of integrated luminosity at a c.m. energy of 3.65 GeV. These results can be combined with Semi-Inclusive Deep Inelastic Scattering (SIDIS) data ($Q^2 \sim 3$ GeV^2) and with the ones obtained at the B-factories by BaBar and Belle ($Q^2 \sim 100$ GeV^2) to extract the transversity parton distribution function, which is the least known leading-twist component of the QCD description of the nucleon. Furthermore it can help to study the Q^2 evolution of Collins function. In the second hadron reference frame [9], shown in Fig. **3** on the left and chosen for this BESIII analysis, the azimuthal angle ϕ_0 is defined as the angle between the plane spanned by the beam axis and the second hadron P_2, and the first hadron transverse momentum p_t around the second hadron directions. The normalized distribution of pion pairs is defined as $R = N(2\phi_0)/ < N >$, where $N(2\phi_0)$ is the di-pion yeald. This ratio is largely affected by the detector acceptance effects. In Fig.**3** on the right are shown distributions of the ratio R, from MonteCarlo simulated data where the Collins effect is not simulated, that

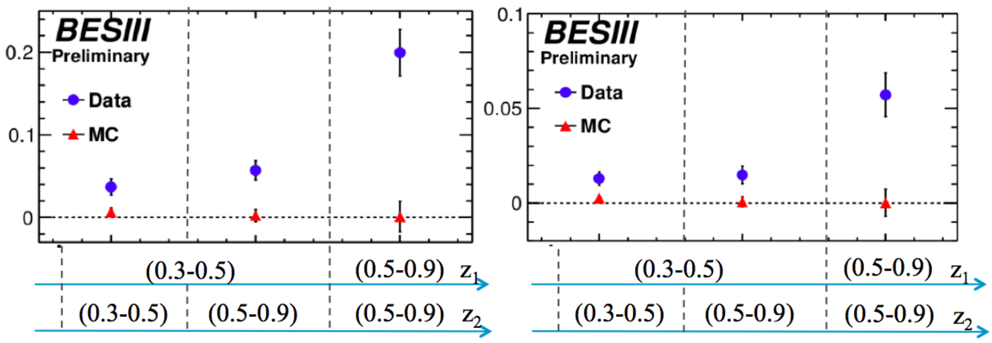

Fig. 4. – Asymmetries results as a function of symmetrized fractional energies bins

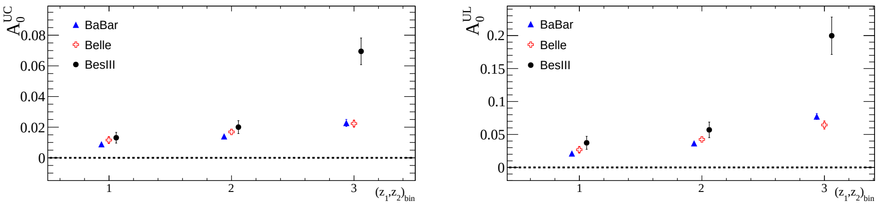

Fig. 5. – Comparison of the Asymmmetries A^{UC} and A^{UL} for BaBar, Belle and BESIII as a funcion of the fractional energies z

shows the importance to minimize the detector induced contribution to the azimuthal modulation. To reduce it, suitable ratios of normalized distributions were built dividing the pion pairs in two sub-samples: Like(L)-pions with the same charge, Unlike(U)-pions with opposite charge. The sum of the two samples was denoted as (C). Double ratios were built and fitted with a linear cosine function as:

$$R = \frac{N^U(2\phi_0)/ < N^U >}{N^{L,C}(2\phi_0)/ < N^{L,C} >} = B + A_{UL(UC)} \times cos(2\phi_0) \tag{2}$$

The $A_{UL(UC)}$ coefficient is sensitive to the Collins effect and accounts for the searched asymmetry while B must be consistent with unity within the errors. The preliminary results are shown in Fig. 4 as a function of symmetrized fractional energy bins (z_1, z_2), where $z = 2E_h/Q$), with boundaries at z_i=0.2, 0.3, 0.5, 0.9 (i=1,2), where the complementary off-diagonal bins (z_1, z_2) and (z_2, z_1) are combined. In Fig. 5 the BESIII results are shown together with those from BaBar [10] and Belle[11] for both the measured asymmetries A_{UL} and A_{UC} as a function of fractional energy. Clean asymmetries are observed that increase with the fractional energy z.

* * *

REFERENCES

[1] M. Ablikim et al. (BESIII Collaboration), in *Nucl. Instrum. Meth. A614*, 2010, 345.
[2] M. Ablikim et al. (BESIII Collaboration), in *Phys. Rev. Lett. 110*, 2013, 252001,
[3] Z. Q. Liu et al. (Belle Collaboration), in *Phys. Rev. Lett. 110*, 2013, 252002.
[4] T. Xiao, S. Dobbs, A. Tomaradze, and K. K. Seth, in *Phys.Lett. B727*, 2013, 366-370.
[5] M. Ablikim et al. (BESIII Collaboration), in *Phys. Rev. Lett. 111*, 2013, 242001.
[6] M. Ablikim et al. (BESIII Collaboration), in *Phys.Rev.Lett. 112*, 2014, 022001.
[7] M. Ablikim et al. (BESIII Collaboration), in *Phys.Rev.Lett. 112*, 2014, 132001.
[8] C. Collins, in *Nucl. Phys B396*, 1993, 161.
[9] D. Boer, R. Jakob and P.J. Mulder, in *Nucl. Phys. B504*, 1997, pag.345.
[10] J. P. Lees et al.(BaBar Collaboration), in *Phys. Rev. D90*, 2014, 052003.
[11] R. Seidl et al. (Belle Collaboration), in *Phys. Rev. D78*, 2008, 032011.