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Latest results and hardware activities from BESIII

M. Destefanis for the BESIII Collaboration
Università di Torino and INFN, Sezione di Torino - Torino, Italy

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Summary. — The BESIII spectrometer is hosted at the BEPCII e^+e^- collider of the IHEP, Beijing. Since July 2008, it has collected the largest data sample available in the world at the energies of the J/ψ, $\psi(2S)$, $\psi(3770)$ and $\psi(4040)$ resonances; data taking at high luminosities will go on for years. In this work I will describe the experiment peculiarities, showing in particular some of the most recent results involving light hadron spectroscopy, charmonium spectra and transitions, and charm physics. I will also describe in details those contributions coming from the Italian component of the Collaboration, focusing on those hardware projects (Zero Degree Detector, ZDD, and cylindrical GEMs, CGEM) the Italian BESIII researchers have devoted most of their efforts to.

PACS 13.66.Bc – Hadron production in e^-e^+ interactions.
PACS 14.40.Lb – Charmed mesons.
PACS 29.40.Gx – Tracking and position-sensitive detectors.
PACS 29.40.Vj – Calorimeters.

1. – The BESIII experiment

The Beijing Spectrometer III (BESIII) [1] is hosted on the BEPCII e^+e^- collider at the Institute of High Energy Physics (IHEP) in Beijing. With its excellent performances it offers the appropriate scenario to investigate light hadrons and charmonium physics. The BEPCII (Beijing Electron-Positron Collider II) is designed to provide an instant luminosity up to $10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ with beam currents up to 0.93 A. The beam energy (up to 2.3 GeV) can be tuned according to the required center of mass energy, for example to produce different charmonium resonances as J/ψ, $\psi(2S)$ or $\psi(3770)$. The BESIII spectrometer, shown in fig. 1, is characterized by a shell-like structure, which provides a wide geometrical acceptance, 93% of 4π. Departing from the interaction point, it hosts a 43-layer small-celled, helium-based main drift chamber (MDC), a time-of-flight system (TOF) for particle identification, and an electromagnetic calorimeter (EMC) composed of 6240 CsI (Tl) crystals arranged in a cylindrical shape (barrel) plus two end-caps. The above mentioned detectors operate inside a 1 T solenoidal magnetic field. The magnet

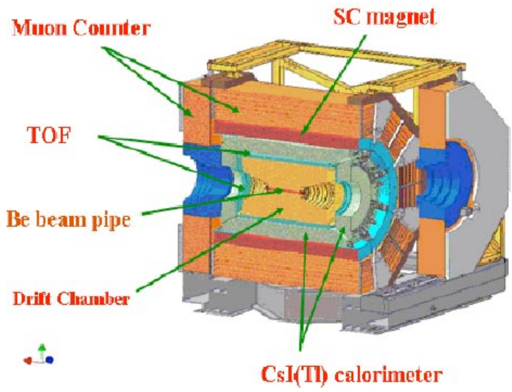

Fig. 1. – 3D view of the BESIII spectrometer.

iron yoke is segmented to host a muon chamber system composed of resistive plate chambers arranged in 9 layers in the barrel and 8 layers in the end-caps. An electromagnetic calorimeter which covers the zero degree region, ZDD (Zero Degree Detector), has been installed for Initial State Radiations (ISR) studies, and $\gamma\gamma$ physics.

The excellent spectrometer performances allowed to collect the world's largest data sample at the J/ψ, $\psi(2S)$, $\psi(3770)$ and $\psi(4040)$ resonance energies. Moreover, data were also collected for XYZ physics, and for the strong and EM relative phase measurement below the J/ψ resonance. In order to characterize the spectrometer performances, among all the published results some of the most significant were chosen.

2. – Spectrometer performances

The investigation of the $c\bar{c}$ radiative decays allowed to explore a new feature of the $J/\psi \to \gamma p\bar{p}$ final state to study its production at threshold [2]. Moving closer to the $p\bar{p}$ production threshold, an increase of the $p\bar{p}$ pairs was observed. The experimental data were described by means of the Partial Wave Analysis (PWA), and the new structure was fitted with a Breit-Wigner distribution. The fit components introduced were: $X(p\bar{p})$, $f_2(1920)$, $f_0(2100)$, and 0^{++} wave, which follows the phase space (PHSP) distribution. The final state interactions (FSI) do not explain in details this behavior. Figure 2 shows the different contributions to the obtained $\gamma p\bar{p}$ final state distributions. This analysis allowed to define the characteristics of the new found structure: $M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{syst}) \pm 19(\text{model})$ MeV, $\Gamma < 76\,\text{MeV}$ at 90% C.L., $\text{Br}(J/\psi \to \gamma X)\text{Br}(X \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(\text{stat})^{+1.5}_{-5.0}(\text{syst}) \pm 2.3(\text{model})) \cdot 10^{-5}$, and $J^{PC} = 0^{+-}$.

The most precise measurement of the η_c resonance parameters was obtained [3]. In this study, the following η_c decays were investigated: $K_S K\pi$, $KK\pi^0$, $\pi\pi\eta$, $K_S K3\pi$, $2K2\pi\pi^0$, and 6π. The invariant mass distributions are shown in fig. 3. A simultaneous fit of the presented η_c decay modes was performed. The resonance shape suggests that this resonance interferes with non-η_c decays; this feature was taken into account when extracting the resonance parameters. The obtained results are the following: $M(\eta_c) = 2984\pm0.6\pm0.6\,\text{MeV}$, and $\Gamma(\eta_c) = 32.0\pm1.2\pm1.0\,\text{MeV}$, where the errors are the statistical and the systematic ones, respectively.

For the first time the $M1$ transition $\psi(2S) \to \gamma\eta_c(2S)$ was observed [4]. The $\psi(2S)$ decays into $K^0_S K^\pm\pi^\mp$ and $K^+K^-\pi^0$ were investigated. In this analysis, all the possible

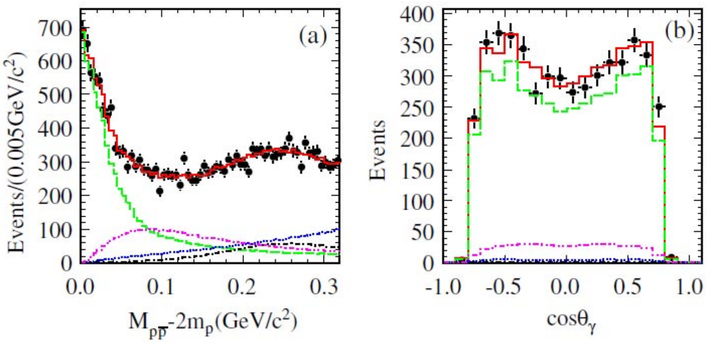

Fig. 2. – $\gamma p\bar{p}$ distributions. The different lines correspond to the different PWA contributions.

backgrounds, including also other charmonium states, were taken into account. The invariant mass distributions, presented in fig. 4, were simultaneously fitted with the function $(E_\gamma^3 \cdot BW(m) \cdot f_d(E_\gamma) \cdot \varepsilon(m)) \otimes G(\delta m, \sigma)$, where E_γ^3 is the part connected to the $M1$ transition and $f_d(E_\gamma)$ is the dumping function. The $\mathrm{Br}(\psi(2S) \to \gamma\eta_c(2S)) \cdot \mathrm{Br}(\eta_c(2S) \to KK\pi)$ was found to be $(1.30 \pm 0.20 \pm 0.30) \cdot 10^{-5}$.

The $515\,\mathrm{pb}^{-1}$ data collected at the $4260\,\mathrm{MeV}$ energy allowed to find a new charmonium like charged structure, the $Z_c(3900)^\pm$ which decays into $\pi^\pm J/\psi$ [5]. The J/ψ was reconstructed via the leptonic decay channels e^+e^- and $\mu^+\mu^-$. The invariant mass distribution obtained considering both the pion charged states, shown in fig. 5, was fitted with a Breit-Wigner function in the peak region. This discovery was confirmed one week later by the Belle Collaboration [6], although with a lower statistic. The $Z_c^\pm$ resonance parameters are the following: $M(Z_c^\pm) = (3899.0 \pm 3.6 \pm 4.9)$ MeV, and $\Gamma(Z_c^\pm) = (46 \pm 10 \pm 20)$ MeV. The production ratio is found to be $R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c(3900)^\mp \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} = (21.5 \pm 3.3 \pm 7.5)\%$. The nature of the $Z_c^\pm$ is still not completely understood, and for this reason the BESIII Collaboration decided to increase the statistics to study its properties and its decays.

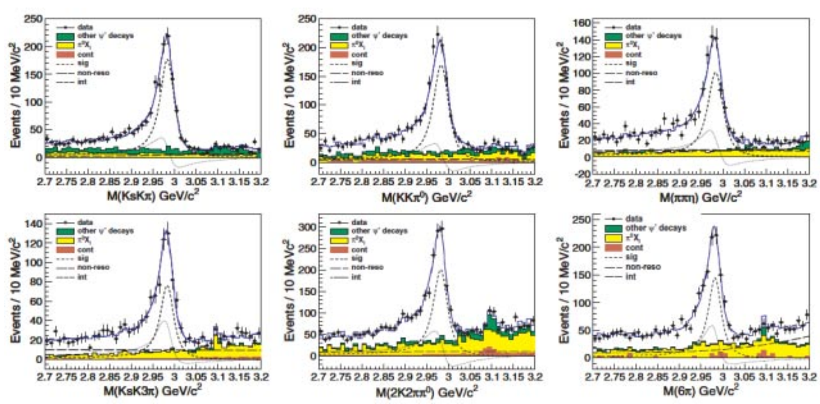

Fig. 3. – Invariant mass distributions of $\eta_c \to K_S K\pi$, $KK\pi^0$, $\pi\pi\eta$, $K_S K3\pi$, $2K2\pi\pi^0$, and 6π, from left to right, and from up to down, respectively.

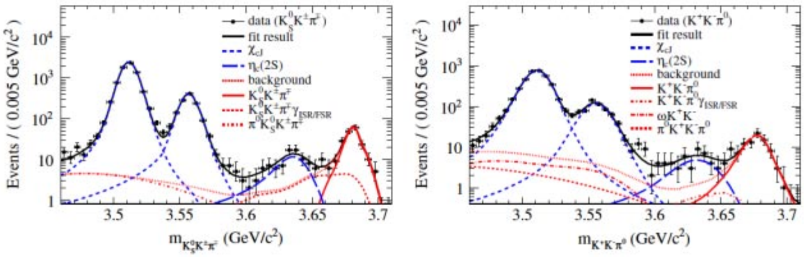

Fig. 4. – Invariant mass distributions of the $\gamma\eta_c(2S) \to K^0_S K^\pm \pi^\mp$ and $K^+K^-\pi^0$ final states, respectively.

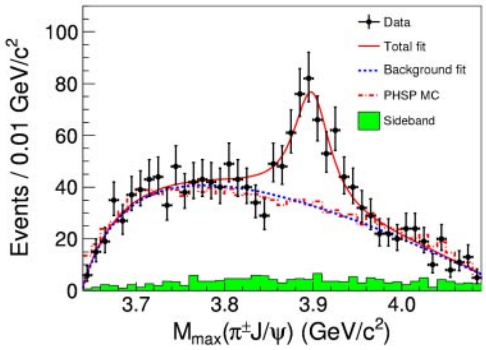

Fig. 5. – Invariant mass distribution of the $\pi J/\psi$ final states. The clear structure around 3900 MeV is the new charged Z_c state.

During the 2012 data taking run, BESIII collected the integrated luminosity required to study the relative phase between the strong and the EM decay amplitudes below the J/ψ resonance peak. With this measurement, proposed by the Italian part of the BESIII Collaboration, we want to investigate the phase difference between the resonant amplitude and the non-resonant one by searching for interference in the Q^2 behavior. According to the perturbative QCD, the EM amplitudes should be real, and the strong one is expected to be real as well. If this is correct, we should observe and interference pattern (0°/180°), but from the experimental data we have indications of 90° relative phases, hence no-interference pattern. The aim of the work was to obtain an inclusive set of exclusive measurements in order to deeply investigate in a model independent way the relative phase. Detailed information about this measurement can be found in [7]. The high level analysis is ongoing for many final states, and the results are expected soon.

3. – Hardware development

Beyond the promising physics results obtained, there is also an important hardware R&D activity mainly conducted by the Italian part of the Collaboration.

The central portion of the drift chambers is reaching the end of its operative activity, and for this reason the BESIII Collaboration is evaluating the possibility to substitute it with a cylindrical GEM (CGEM) detector. The GEMs are well known detectors [8], characterized by a good radiation hardness. The project implies the use of GEMs arranged

Fig. 6. – The ZDD detector installed at BESIII. The arrow indicates the position of the beam line. On both sides, the photomultipliers used to collect the signal from the different zones of the ZDD are shown.

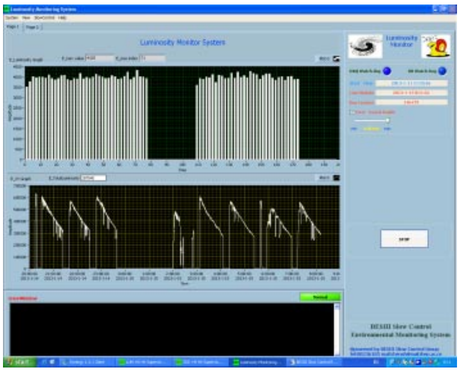

Fig. 7. – ZDD as online luminometer. The beam bunches can be identified in the upper row, while the collected integrated luminosity per data taking run is shown in the lower row.

in a cylindrical geometry, following the example of the only existing CGEM constructed for the KLOE2 experiment [9]. The peculiarities of the BESIII CGEM detector are not foreseen to be too much different from those of the KLOE2 CGEM. In this scenario, the expected radiation length is in the order of 1%.

The initial state radiation (ISR) technique, heavily used by the Babar Collaboration, is an important experimental technique which allows the simultaneous study of physics processes at different center of mass energies. This technique takes advantage of those events in which a photon emission from one of the beam particles allows a boost of the center of mass of the investigated process. The main advantages of the ISR are the following: the study at the same time of more center of mass energies for the same processes without changing the beam energies, and the possibility to investigate these processes even at threshold exploiting the excellent experimental efficiency and taking advantage of the boost which gives to the final state particles higher momenta in the laboratory system. The distribution of the ISR photons is expected to be extremely forward peaked. This implies that a zero degree detector (ZDD), placed around the beam line (see fig. 6), should be able to collect alone around 40% of the ISR statistics, while in the whole spectrometer only 20% of the events are foreseen. With this preamble, the Italian component of the Collaboration has build and installed an electromagnetic calorimeter (ZDD). The ZDD is already working as online luminometer, as shown in fig. 7, and soon it will be completely interfaced with the DAQ system.

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