Status Update from BESIII Experiment

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Abstract

Since 2009, the BESIII spectrometer, hosted at the $e^+ e^-$ collider BEPCII of the IHEP, Beijing (China), collected the world largest sample of J/ψ, $\psi(3686)$, and $\psi(3770)$ data. Such a scenario allows to conduct a wide physics program on charmonium spectroscopy, mesonic and baryonic decays, light hadron spectroscopy, and search for new physics. Exploiting the direct access to 1^{--} states, BESIII has a unique opportunity to access the exotic states XYZ; for instance, the low hadronic background allows the investigation of the $Y(4260)$ and the $Y(4360)$, directly produced, and grants the access to the $X(3872)$ and $Z_c(3900)$ states. In this communication, a collection of the BESIII latest results as well as the main experimental innovations will be discussed.

1 Introduction

The BEijing Spectrometer III (BESIII) [1] is hosted at the Beijing Electron-Positron Collider II (BEPCII) at the IHEP of Beijing, China. The BEPCII works with beam currents up to 0.93 A, and it can provide an instantaneous luminosity up to 10^{33} cm^{-2} s^{-1}. In order to address the required center of mass energies, for example the charmonium resonances, the beam momentum can be tuned raging from 1 to 2.3 GeV/c. The shell-like structure of the spectrometer, shown in Fig. 1, allows a wide geometrical acceptance of about 93% of 4π, granting excellent performances. From the interaction point, it hosts, inside a 1T solenoidal magnetic field, 43 small-celled, helium-based main drift chamber (MDC) chambers for charged tracks reconstruction, a time-of-flight system (TOF) for particle identification, and an EM calorimeter (EMC) composed of 6240 CsI (Tl) crystals arranged in a cylindrical shape (barrel) plus two end-caps. The magnet iron yoke is segmented to host a muon chamber system (MUC) composed of resistive plate chambers arranged in 9 layers in the barrel and 8 layers in the end-caps. Precision studies as well as new physics searches are granted by the excellent quality of the experimental data collected at the accessible charmonium resonances as well as at the highest achievable energies.

2 The CGEM inner tracker

BESIII and BEPCII are undergoing an upgrade program to improve the physics capabilities. Among other upgrades, there is a plan to replace the inner layers of the present MDC with a new inner tracker. For this reason, an European and Chinese collaboration are building a new inner tracker exploiting the GEM technology. A three layers cylindrical GEM (CGEM) detector [2,3] has been build and is going to be installed in the spectrometer. The new CGEM detector will replace the first 8 MDC layers, as shown in Fig. 2. In order to reconstruct the tracks trajectories the needed signal multiplication is provided exploiting three GEM foils, as shown in Fig. 3, which compose each CGEM layer. The low material budget, the high rate capability, and the high momentum resolution will grant the excellent performance of the detector. The anode is segmented in axial and stereo strip. While the CGEM will provide similar momentum resolution, the spatial resolution on the z coordinate will increase thanks to the larger stereo angle. Both charge centroid and μTPC techniques [4] will be exploited to reconstruct the hits' position. A new ASIC chip [5] has been designed and constructed and it will be employed in the analog readout, which allows to collect charge and time signals. The readout design gives the possibility to reduce the strip pitch and to handle about 10000 channels as well.

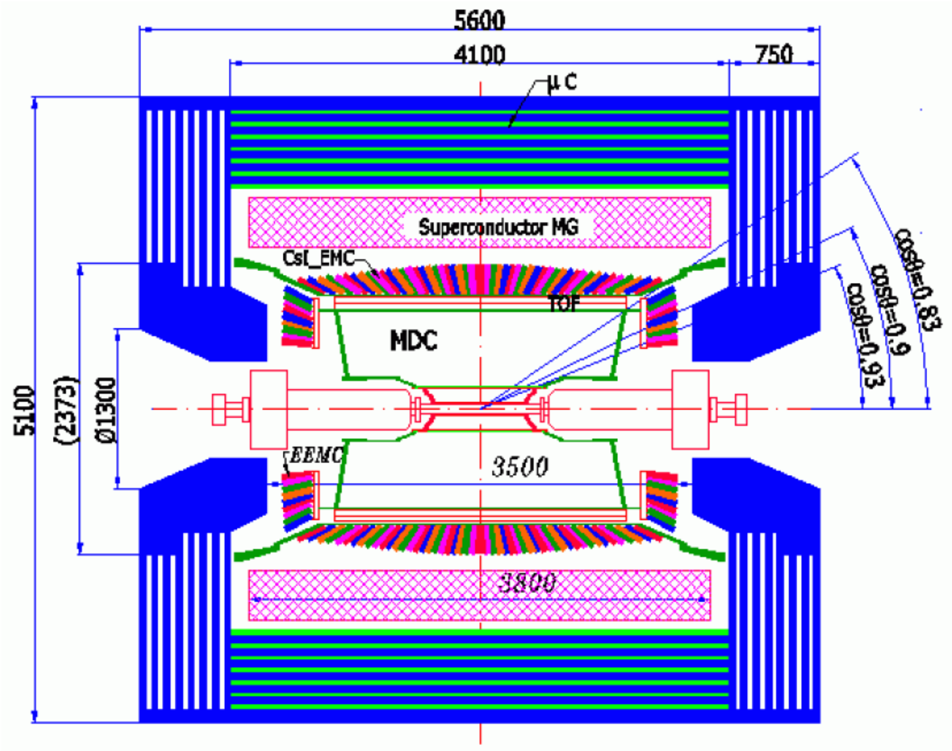

Figure 1: *View of the BESIII spectrometer [1].*

3 Physics

A huge amount of data in the charmonium region, including the data at the J/ψ, $\psi(2S)$, $\psi(3770)$, and $\psi(4040)$ resonance energies, which are by now the worlds largest samples available, have been already collected by the BESIII Collaboration taking advantage of the excellent spectrometer performance. The physics program is quite wide, and in order to access hadron, meson, and XYZ physics fine and coarse scans were performed in the whole accessible energy region. In order to characterize the spectrometer performance, some of the most recent and significant results will be discussed.

3.1 XYZ states

The scenario of the charmonium states is quite different from what expected. The $c\bar{c}$ potential model describes quite well the states observed below the $D\bar{D}$ threshold. Instead, above the $D\bar{D}$ threshold many of the observed states are not consistent with the expectations for charmonia. This is the case of the X,

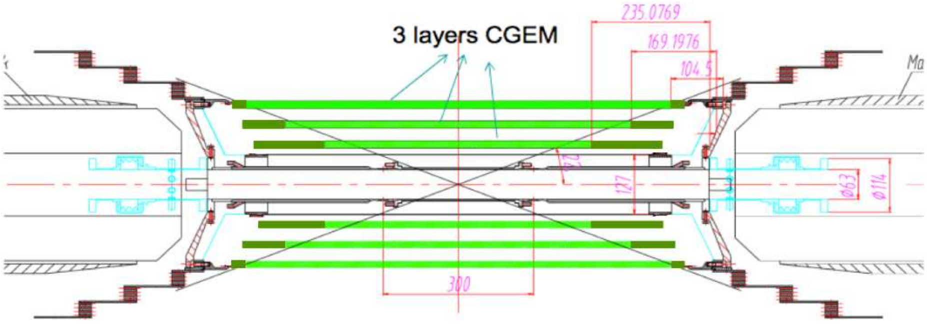

Figure 2: Schema of the three CGEM layers positions.

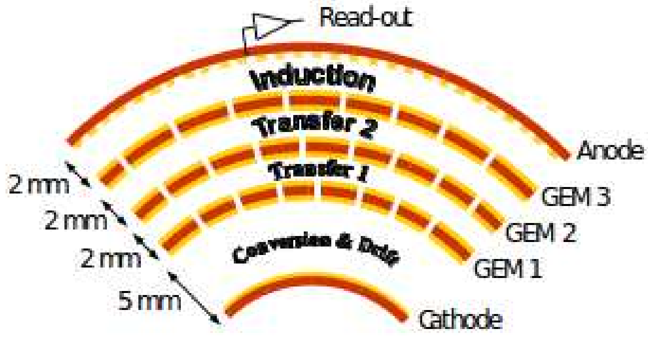

Figure 3: Construction detail of each CGEM layer.

Y, and Z states. For this reason, the BESIII experiment is trying to build the connections between the found states.

The nature of the observed charmonium like states $Y(4260)$, $Y(4360)$, and $Y(4660)$ is yet not known, since they cannot be interpreted as conventional charmonia. Moreover, they strongly couple to hidden-charm final states and they have relatively narrow widths. For this reason, the different properties of the Y states have to be deeply investigated by means of lineshape measurements as well as studing their hadronic transition. All those searches will allow to perform a complete partial wave analysis (PWA), giving access to the proper tools to understand their nature and properties.

The $Y(4660)$ resonance, discovered by the Babar [6] and Belle [7] Collaborations by investigating the $e^+e^- \to \psi(3686)\pi^+\pi^-$ final state, offers a quite interesting scenario. A tetraquark structure is able to explain this resonance, which should be seen in hadronic decays as well. Unfortunately, this scenario cannot be confirmed by the $\Lambda_c\bar{\Lambda}_c$ final state from the available BESIII data [8]. An unexpeced scenario is supplied by the fact that the mesonic coupling is more than one order of magnitude less than the baryonic one, when comparing the $\psi(3686)\pi^+\pi^-$ cross section (about 0.04 nb) to the $\Lambda_c\bar{\Lambda}_c$ one [9]. Another peculiarity of the $Y(4660)$ resonance is that it fulfills the old Rossi-Veneziano paradigm of a charm tetraquark decay: a charm quark pair pop up mostly from the vacuum, and it falls apart as a charmed baryon pair [10, 11]. From the BESIII data [8], Fig. 4 shows the $\Lambda_c\bar{\Lambda}_c$ cross section. It is clear the presence of a jump at threshold followed by a plateau, which is in partial contraddiction with the Belle

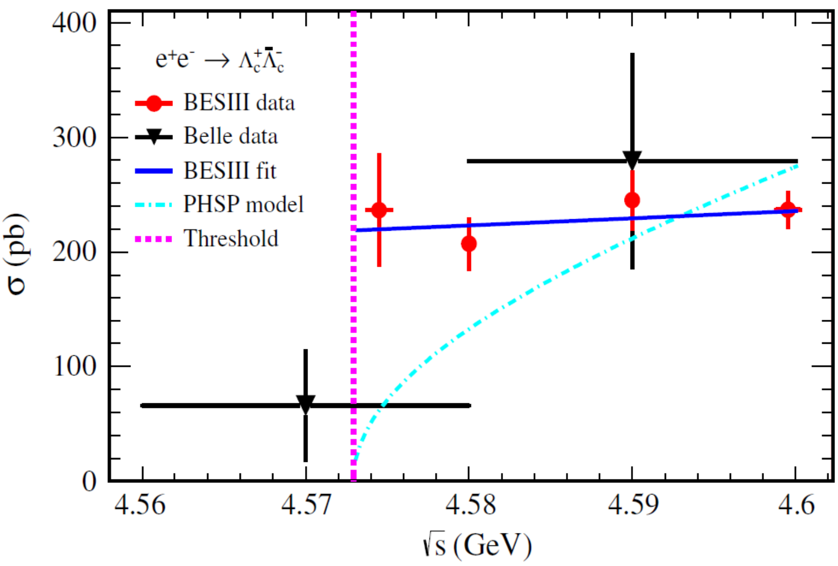

Figure 4: Cross section of $e^+e^- \to \Lambda_c\bar{\Lambda}_c$ from BESIII data [8], compared with the Belle ones [12]. The dash-dotted line shows the phase space (PHSP) model prediction, obtained with the parametrization of [13], but with $C = 1$ and a flat $|G_M|$.

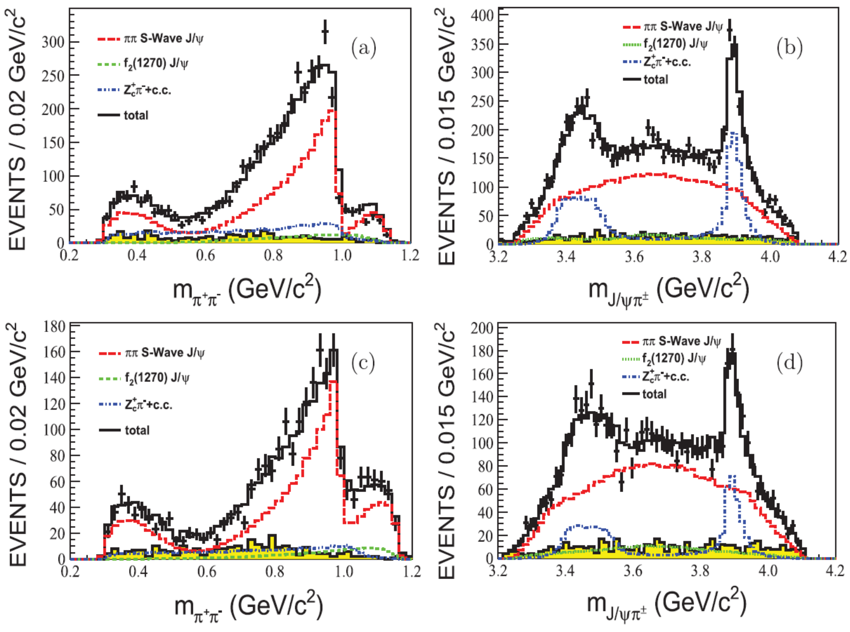

Figure 5: $\pi^+\pi^-$ (left side) and $J/\psi\pi^\pm$ (right side) invariant masses for the $\sqrt{s} = 4.23$ GeV (top) and 4.26 GeV (bottom) data. The $J/\psi\pi^\pm$ histograms are filled with two entries ($m_{J/\psi\pi^+}$ and $m_{J/\psi\pi^-}$). The shaded histograms represent the background.

data [12], that show clearly the $Y(4660)$ structure. The two data sets show a different trend in energy, although they agree on the cross section magnitude. Indeed, at threshold the cross section is closed to the pointlike value (about 145 pb), since threshold is a region sensitive to the Coulomb interaction. This behavior at threshold is similar to the $p\bar{p}$ one, as confirmed by the new CMD3 data [14]. In order to search for the $Y(4660)$ resonance and confirm the indications so far extracted, a more complete investigation of the $\Lambda_c\bar{\Lambda}_c$ cross section is now mandatory, and it will be possible when an improvement of the BEPCII maximum energy from 2.3 GeV to 2.45 GeV will be available.

For the $Z_C^\pm$ state, observed by BESIII [15] and Belle [16] Collaborations and confirmed by CLEO-c data [17], there are still questions about its nature. The extraction of the spin and parity of the $Z_C(3900)$ state [18] is thus mandatory. A data sample of 1.92 pb^{-1} collected at $\sqrt{s} = 4.23$ and 4.26 GeV was exploited to investigate the reaction $e^+e^- \to J/\psi\pi^+\pi^-$. To improve the signal to background ratio, the J/ψ was reconstructed via its leptonic decays; the sidebands technique was employed for J/ψ background determination. The process is assumed to proceed via both the Z_c resonance and the non-Z_c decays, thus the helicity-covariant method [19] was used to construct the amplitudes for the partial wave analysis (PWA) to describe the data. In order to properly describe the $\pi^+\pi^-$ mass spectrum, four resonances were introduced: σ, $f_0(980)$, $f_2(1270)$, and $f_0(1370)$. The $f_0(980)$ resonance was described with a Flatté formula [20], while the other resonances were described by means of relativistic Breit-Wigner (BW) functions. The introduced resonances were tested in the J/ψ recoil spectrum in order to understand if such states can produce rescattering peaks. The oppositely charged Z_c states were treated as isospin partners, when fitting simultaneously both data sets. The statistical significance of each state and of the non-resonant interaction was estimated to be larger than 5σ. In Fig. 5 the results on $\pi^+\pi^-$ (non-resonant decays) and on $J/\psi\pi^\pm$ (resonant decay) are shown separated by the center of mass energy. The shown distributions indicate a spin parity value of 1^+ for the Z_C resonance, with a statistical significance larger than 7σ with respect to the other possible combinations. This hypothesis is also compatible with the picture provided by the DD^* data [21], where $Z_C(3900)$ and $Z_C(3885)$ are considered as coming from the same resonance.

3.2 Baryons production

The direct access to the 1^{--} charmonium resonance and the high statistic collected offer an important opportunity to study the decay into baryonic final states. Usually, annihilations of nucleons (N) and

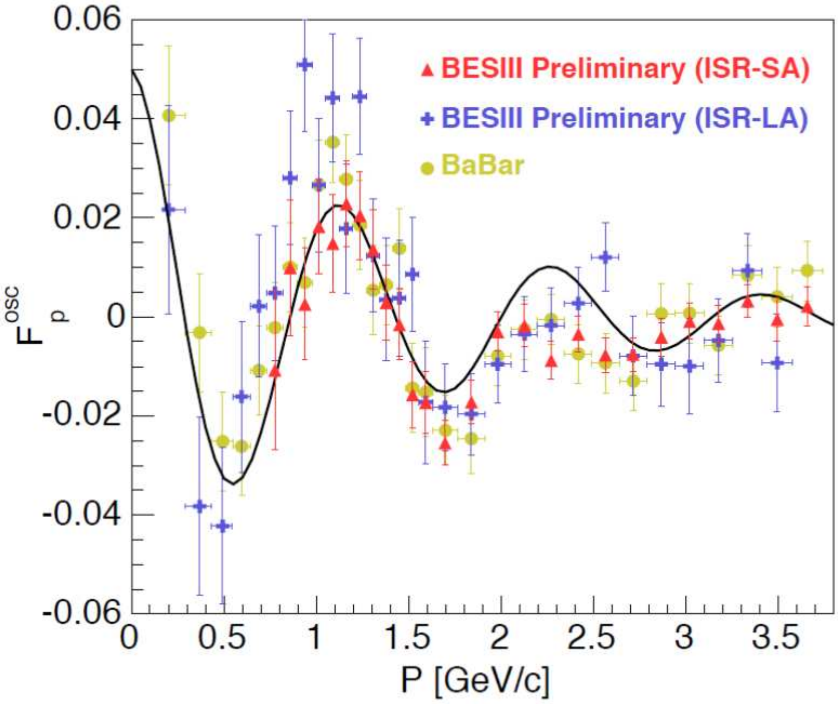

Figure 6: Effective form factor as function of the 3-momentum (P) of the relative motion of the two protons for BESIII preliminary data and Babar [23].

photons are emploied to investigate the baryon production. The access to charmonium decays offer complementary information to the existing data, since the coupling to the conventional production channels could be small, but there could be a large coupling to $gggN$.

A data sample of a total integrated luminosity of about 7.408 fb^{-1} collected at $\sqrt{s}$ = 3.773, 4.009, 4.230, 4.260, 4.360, 4.420, and 4.600 GeV was exploited to investigate the reaction $e^+e^- \to p\bar{p}\gamma$, by means of the ISR technique. Both ISR tagged and untagged modes [22] were investigated. From the BESIII preliminary analysis, oscillations of the proton magnetic form factor as a function of the proton-antiproton invariant mass have been observed. The obtained distributions are shown in Fig. 6, for both tagged and untagged ISR modes. This BESIII analysis is a confirmation of what was already found by the Babar Collaboration [23]. Some tentative explanation of the origin of those oscillations is already ongoing [24]. According to [24], the oscillations could be extracted from the effective form factor as $F_{osc} = |G_{eff}| - F_0$, where F_0 describes the regular behavior of the form factor over the long range of the $p\bar{p}$ invariant mass.

Hyperon production can be accessed as well taking advantage of the high quality of BESIII data. The associate production of $\Lambda\bar{\Lambda}$ pairs from e^+e^- annihilations was investigated by means of a sample of $1.3{\cdot}10^9$ events collected by the BESIII experiment at the J/ψ resonance energy. The spin polarization of the $\Lambda\bar{\Lambda}$ pair production [25] from $e^+e^- \to \gamma^* \to J/\psi \to \Lambda\bar{\Lambda}$ reactions was studied. The identified process is described by two form factors, which are both complex numbers. Spin-1/2 baryon pairs are produced either with the same or opposite helicity, thus making Λ pair production an important tool to study the spin orientation of baryons. The Λ was reconstructed via its charged decay channel ($p\pi^-$), while the $\bar{\Lambda}$ via both charged and neutral decay channels ($p\pi^-$ and $\bar{n}\pi^0$). The kinematic variables, the polarization, and the spin correlation were taken into account during the fitting procedure. Figure 7 shows a certain asymmetry in the Λs' angular distribution. This asymmetry is connected to a phase between G_E and G_M, which was measured for the first time to be about 42.4°, and it could be due to a strong interaction in the final state. The $\Lambda \to p\pi^-$ decay parameter α_- was extracted as well, taking advantage of the high statistics collected, and it was found to be 0.75, a value closer to α_+, but quite far from the PDG one (0.642) [26].

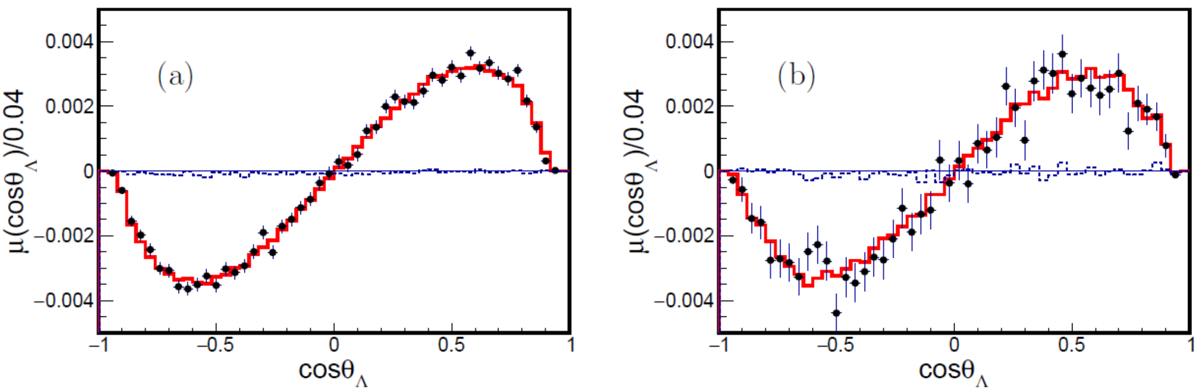

Figure 7: Moments $\mu(\cos\vartheta_\Lambda)$ as a function of $\cos\vartheta_\Lambda$ for the $p\pi^-\bar{p}\pi^+$ (a) and $p\pi^-\bar{n}\pi^0$ (b) final states, where the solid line is the global fit result. The no-polarization scenario is shown by the dashed histogram.

3.3 Muon magnetic moment

The determination of the anomalous part of the magnetic moment of the muon, (g-2)$_\mu$ is one of the most precise tests of the Standard Model of particle physics. The muon anomalous magnetic moment can be defined as $a_\mu = \frac{g_\mu - 2}{2}$, where g_μ is the gyromagnetic ratio, according to the Dirac theory. QED, weak and hadronic contributions have to be taken into account with high precision, since the muon anomaly arises from quantum fluctuation. A discrepancy of $a_\mu^{theo} - a_\mu^{exp} = 27.6 \cdot 10^{-10}$ between the experimental data and the theoretical predictions, which are limited by the hadronic contributions, has been observed [27]; this discrepancy is even higher than the weak contribution. The hadronic effects could be divided into two classes depending on the process they undergo: the hadronic vacuum polarization (HVP) and the hadronic light-by-light (HLBL) processes. For HVP we have already important experimental indications, while HLBL is still under investigation at different experiments. The HVP is mainly driven by low mass final states, starting from pion pairs production. Thus is of utmost importance a measurement of exclusive hadronic cross section channels, such as the 2π, 3π and 4π final states, for an improved calculation of the HVP contribution. Moreover, although the KLOE [28] and Babar [29] experiments managed to reach the sub-percent region, there is a discrepancy of 3%-5% between their measurements. A high precision measurement of the pionic contributions can be provided by the BESIII experiment by means of a wider accessible mass range and a lower suppression of ISR events. From the theoretical

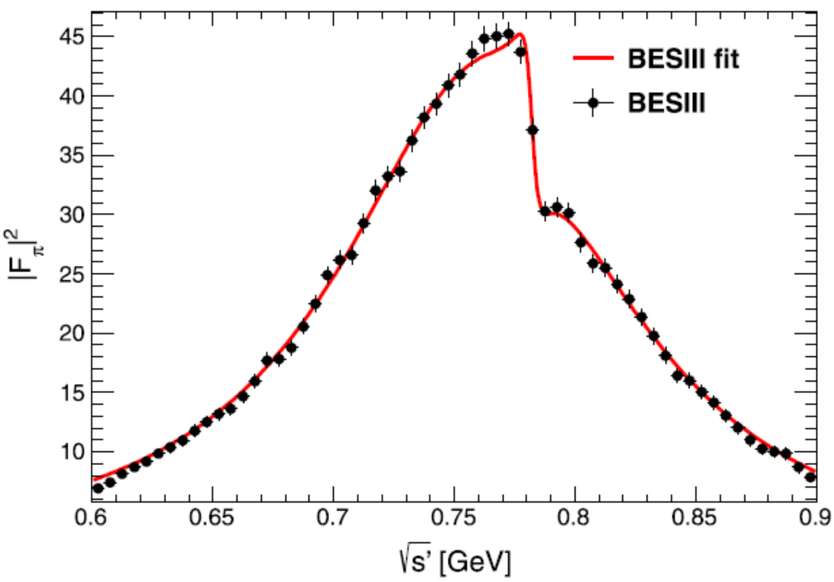

Figure 8: The measured squared pion form factor $|F_\pi|^2$.

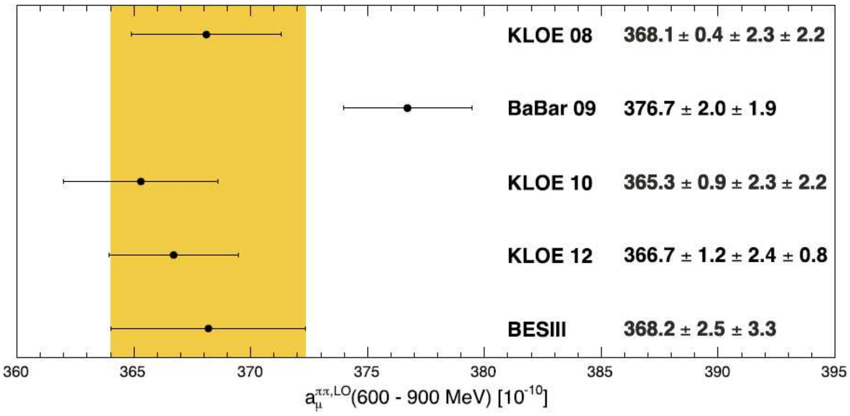

Figure 9: Comparison between BESIII, KLOE and Babar data.

expectations, the higher contribution comes from the two pion final state. For the BESIII measurement of the $\pi^+\pi^-$ final state [30], the selection of $\pi^+\pi^-$ pairs was accomplished by means of Artificial Neuronal Network (ANN), which were extensively trained on 5 different parameters: the Zernicke moments of the EMC clusters, induced by pion or muon tracks, the ratio of the energy E of a track deposited in the EMC and its momentum p measured in the MDC, the ionization energy loss dE/dx in the MDC, and the depth of a track in the MUC. The ANN method hallowed to remove the leptonic contributions. The obtained distribution, shown in Fig. 8 and where it is also possible to note the ρ-ω interference, were fitted with a Gounaris-Sakurai function [31]. Those data agree with the KLOE and BABAR ones, and their results are compared in Fig. 9. Unfortunately, the BESIII measurements were not able to solve the discrepancy on the muon anomalous magnetic moment. New light on this topic could be shed by the new experimental measurements planned at J-PARC, in Japan, and at Fermilab, in USA.

3.4 Dark photon

The data set collected with an integrated luminosity of 2.93 fb^{-1} at the $\psi(3770)$ energy was exploited to search for an extra U(1) gauge boson. The dark photon would appear as an enhancement in the invariant mass distribution of the leptonic pairs, so, in order to investigate the $e^+e^- \to e^+e^-\gamma_{ISR}$ and $e^+e^- \to \mu^+\mu^-\gamma_{ISR}$ reactions, the ISR technique was exploited. By means of kinetic mixing [32], with a mixing strenght $\varepsilon = \frac{\alpha'}{\alpha} \approx 10^{-2}$, where α' is the coupling of the dark photon to the electromagnetic charge, and α is the fine structure constant, the dark photon (γ') would couple very weakly with the Standard Model particles. The leptonic invariant masses ($m_{l^+l^-}$) in the region between 1.5 and 3.4 GeV/c^2 were subject to BESIII investigations. Unfortunately, one has to handle with some irreducible background, composed of the ISR QED processes $e^+e^- \to e^+e^-\gamma_{ISR}$ and $e^+e^- \to \mu^+\mu^-\gamma_{ISR}$. The γ' is expected to be found as a narrow structure [33] in the $m_{l^+l^-}$ mass spectrum on top of the QCD background. The $\mu^+\mu^-$ and e^+e^- invariant mass distributions are shown in Figs. 10 and 11, respectively. The invariant mass region between 2.95 and 3.2 GeV/c^2 has been excluded, since it could be affected by possible contribution from the J/ψ resonance. No obvious enhancement in the invariant mass spectra was observed and hence no dark photon signature. To complete the investigations, the exclusion limit on the mixing parameter ε^2 as cross section ratio between $\gamma'\gamma_{ISR}$ and $\gamma^*\gamma_{ISR}$ intermediate states was calculated, following the parametrization from Ref. [33]. As shown in Fig. 12, at 90% confidence level the exclusion limit overlaps the indications coming from the Babar experiment [34].

4 Conclusions

Taking advantage of the excellent performance of the spectrometer, the BESIII Collaboration is performing a wide series of precision measurements in order to deeply understand the Standard Model and to search for new physics. Many new unpredicted results were found and many are still under study. In order to extend our knowledge on particle production processes as well as on their real nature, the possibility of an increase of the beam energy is quite intriguing.

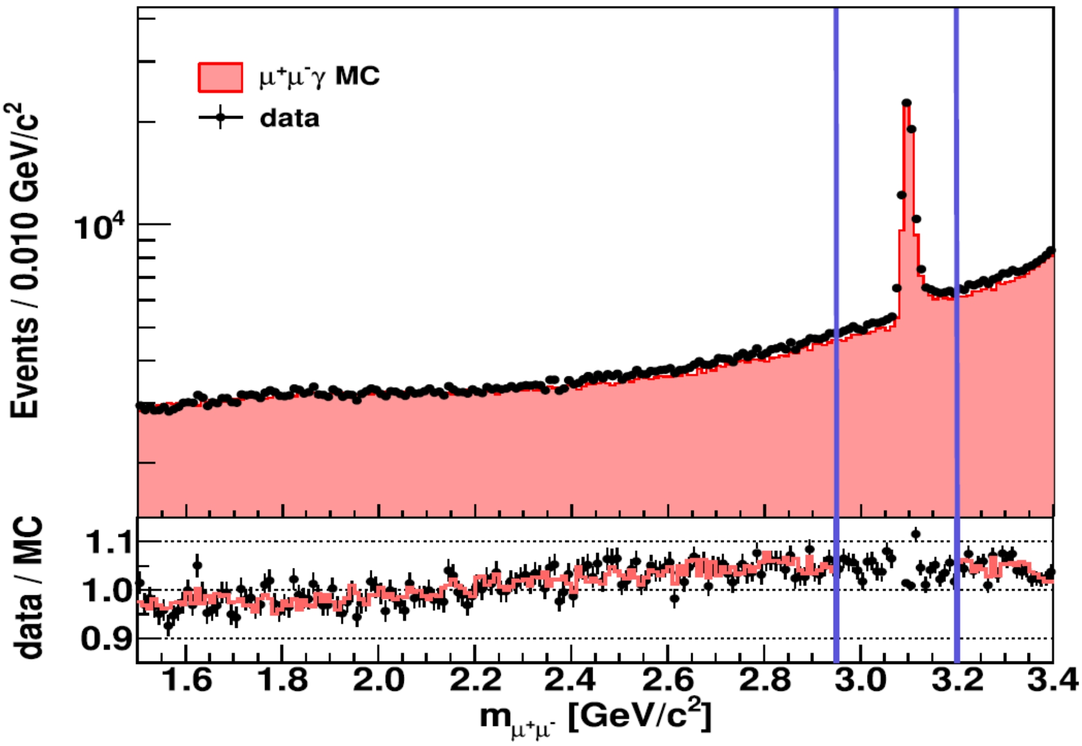

Figure 10: Invariant mass distribution of $m_{\mu^+\mu^-}$. The area around the J/ψ resonance is excluded from the analysis.

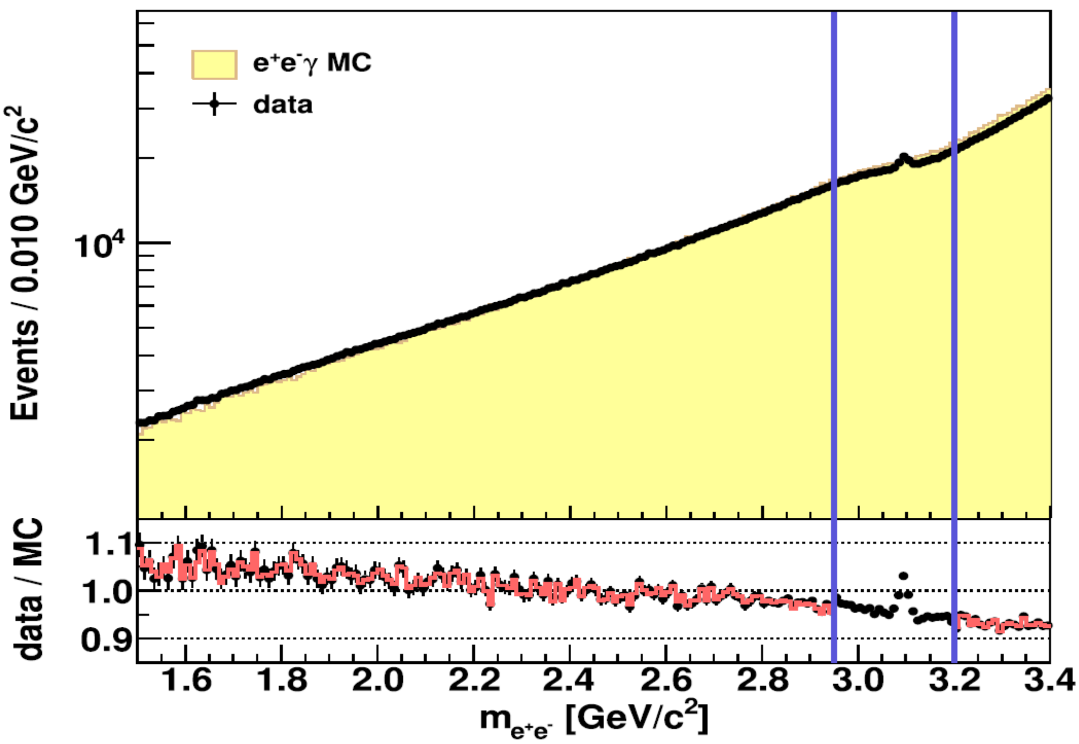

Figure 11: Invariant mass distribution of $m_{e^+e^-}$. The area around the J/ψ resonance is excluded from the analysis.

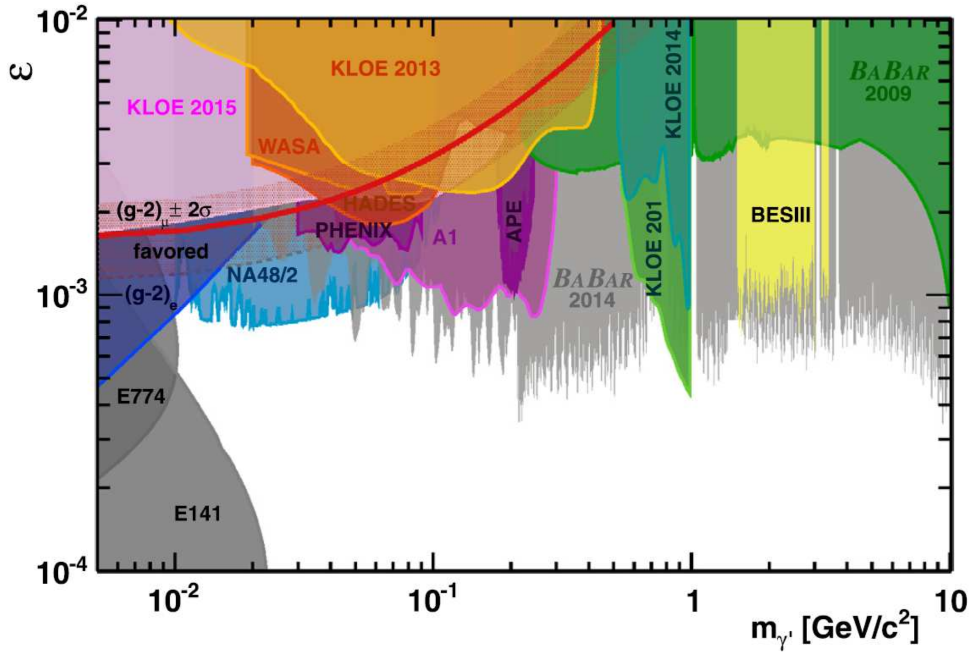

Figure 12: Exclusion limit at the 90% confidence level on the mixing parameter ε as a function of the dark photon mass.

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