

Results from Electron-Positron Collisions at BESIII

Ryan E. Mitchell^{*†}

Indiana University

E-mail: remitch@indiana.edu

A selection of results from electron-positron collisions at BESIII are reviewed. The results presented here illustrate the wide range of physics topics that can be studied using the Beijing Electron Positron Collider (BEPC). At low collision energies, the cross section for $e^+e^- \rightarrow \pi^+\pi^-$ provides much-needed input into theoretical calculations of the anomalous magnetic moment of the muon, and the reaction $e^+e^- \rightarrow p\bar{p}$ provides access to the electromagnetic form factors of the proton. In the charmonium region, a large sample of ψ' decays can be used to measure new decay modes of charmonium states. And at higher energies, BESIII is uniquely situated to explore questions concerning the still-unexplained XYZ states.

*38th International Conference on High Energy Physics
3-10 August 2016
Chicago, USA*

^{*}Speaker.

[†]On behalf of the BESIII Collaboration.

BESIII has collected a variety of data sets for e^+e^- collisions with center-of-mass energies between 2.0 and 4.6 GeV [1]. A few of the highlights, from low to high energy, include: a scan of the region between 2.0 and 3.0 GeV; 1.3 billion J/ψ decays; 450 million ψ' decays; 2.9 fb^{-1} of data at the $\psi(3770)$ mass; about 3 fb^{-1} at 4.18 GeV (primarily for studies of the D_s meson); 0.8 fb^{-1} in a scan of the region between 3.85 and 4.59 GeV (spread over 104 points); and over 4 fb^{-1} collected between 3.81 and 4.60 GeV (in sets ranging from 50 pb^{-1} to 1.1 fb^{-1}) for studies of the XYZ states. In addition to these fixed energies, one can also study e^+e^- collisions at any lower center-of-mass energy using the Initial State Radiation (ISR) technique, where photons are radiated from the primary e^+ or e^- before the collision. The following represents a small selection of the recent results that have been derived from these data sets.

1. Anomalous Magnetic Moment of the Muon

The difference between the Standard Model (SM) and the experimental (E821) values for the anomalous magnetic moment of the muon, $a_\mu \equiv (g_\mu - 2)/2$, is currently larger than 3σ :

$$\begin{aligned} a_\mu^{\text{SM}} &= (11659180.2 \pm 4.9) \times 10^{10} [2], \\ a_\mu^{\text{E821}} &= (11659209.1 \pm 6.3) \times 10^{10} [3], \\ \Delta a_\mu &= a_\mu^{\text{E821}} - a_\mu^{\text{SM}} = (28.9 \pm 8.0) \times 10^{10} \quad (3.6\sigma). \end{aligned}$$

The error in the SM calculation is dominated by the Hadronic Vacuum Polarization (HVP) contribution, which is estimated using experimental input from e^+e^- collisions to hadrons. The cross section for e^+e^- collisions to hadrons, in turn, is dominated by the reaction $e^+e^- \rightarrow \pi^+\pi^-$ in the region of the ρ meson, corresponding to collision energies between 600 and 900 MeV. But here there are experimental differences between BaBar and KLOE, as shown in Figure 1b, on the order of several sigma. If only the BaBar measurement is used in a_μ^{SM} , the difference between SM and experiment drops below 3σ . It is thus crucial to provide more experimental input.

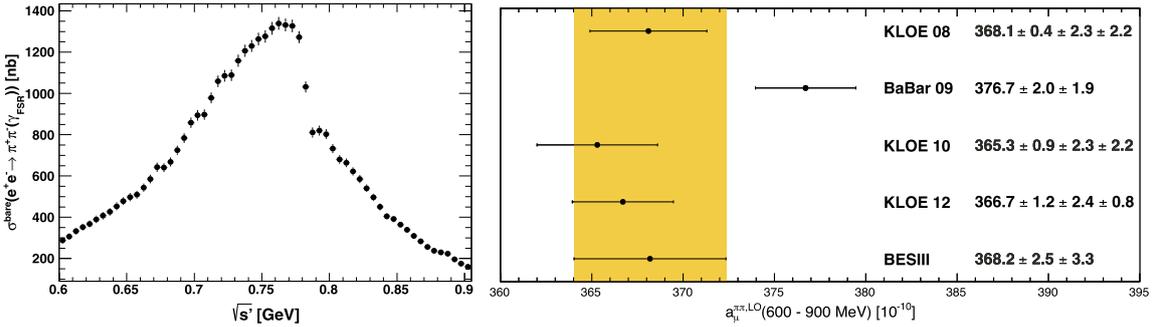


Figure 1: (left) The cross section for $e^+e^- \rightarrow \pi^+\pi^-$ [4]. (right) A comparison of measurements of $a_\mu^{\pi\pi\text{LO}}(600\text{-}900 \text{ MeV})$, where the yellow band illustrates the new BESIII measurement.

This discrepancy between BaBar and KLOE was addressed at BESIII using 2.9 fb^{-1} of e^+e^- data at a nominal center-of-mass energy of 3.773 GeV [4]. The ISR technique was used to measure the cross section for $e^+e^- \rightarrow \pi^+\pi^-$ in the region between 600 and 900 MeV (Fig. 1a). This was then integrated using a dispersion relation to obtain a new value for $a_\mu^{\pi\pi\text{LO}}(600\text{-}900 \text{ MeV})$ (Fig. 1b).

The BESIII measurement, by favoring KLOE, confirms the existence of a larger than 3σ deviation of Δa_μ from zero.

2. Electromagnetic Form Factors of the Proton

The electromagnetic form factors of the proton can be measured in the spacelike region (where the momentum transfer, q^2 , is less than zero) using elastic scattering of the electron off of the proton, $e^-p \rightarrow e^-p$. The same form factors can also be studied in the timelike region ($q^2 > 0$) using the corresponding reaction $e^+e^- \rightarrow p\bar{p}$. BESIII has preliminary results for $e^+e^- \rightarrow p\bar{p}$ covering a wide range of collision energies, obtained using the ISR technique, starting with seven data samples at higher energies with a total integrated luminosity of 7.4 fb^{-1} . The form factors $|G_E(q^2)|$ and $|G_M(q^2)|$ are measured by binning the data in q^2 (which in this case is equivalent to the center-of-mass energy of the collision) and fitting the distribution of the scattering angle of the proton (θ_p) using:

$$\frac{d\sigma_{p\bar{p}}(q^2)}{d\cos\theta_p} = \frac{2\pi\alpha^2\beta C}{4q^2} \left[|G_M(q^2)|^2(1 + \cos^2\theta_p) + \frac{4m_p^2}{q^2}|G_E(q^2)|^2\sin^2\theta_p \right],$$

where α is the fine structure constant, β is the proton velocity, and C is a Coulomb correction factor. The results for the ratio $|G_E|/|G_M|$ are shown (in red) in Figure 2a. Assuming $|G_E| = |G_M| \equiv |G_{eff}|$, the results for $|G_{eff}|$ are shown (in red) in Figure 2b.

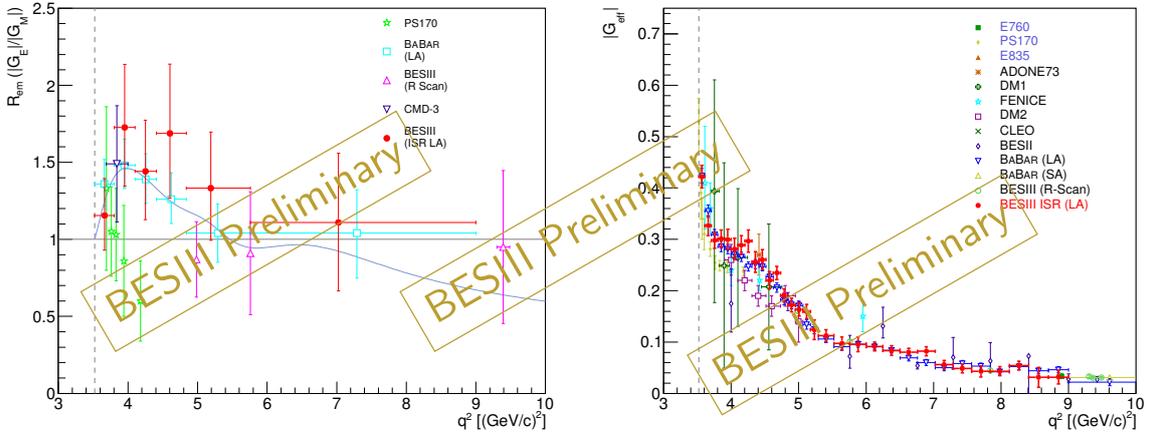


Figure 2: (left) The ratio $|G_E|/|G_M|$ in the timelike region as recently measured by BESIII (red). (right) The value for $|G_{eff}| \equiv |G_E| = |G_M|$ as recently measured by BESIII (red). Previous measurements are shown using other colors. See, for example, Ref. [5]. The line is from the Phokhara event generator.

3. Studies of Charmonium

One of the most interesting problems in charmonium physics is the unexpected difference between decays of the J/ψ and ψ' to light hadrons. This was first noticed in the $\rho\pi$ system, where the ψ' decay to $\rho\pi$ is suppressed relative to expectations based on the corresponding J/ψ decay [6].

But related phenomena have since been seen in many more channels. One striking example is in radiative decays to the η and η' . While the ratio of branching fractions, $B(\gamma\eta)/B(\gamma\eta')$, is $21.9 \pm 0.9\%$ for the J/ψ , it is only $1.1 \pm 0.4\%$ for the ψ' [3].

Using a sample of 450 million ψ' decays, BESIII has been able to make a measurement of the same ratio, $B(\gamma\eta)/B(\gamma\eta')$, for h_c decays [7]. The processes $\psi' \rightarrow \pi^0 h_c$ with $h_c \rightarrow \gamma\eta^{(\prime)}$ were reconstructed using two decay modes of the η' ($\pi^+\pi^-\eta$ (Fig. 3a) and $\gamma\pi^+\pi^-$ (Fig. 3b)) and two decay modes of the η ($\gamma\gamma$ (Fig. 3c) and $\pi^+\pi^-\pi^0$ (Fig. 3d)). Simultaneous fits were performed for the two η and η' channels and the ratio was measured to be $B(\gamma\eta)/B(\gamma\eta') = 30.7 \pm 11.3 \pm 8.7\%$, showing that the h_c decays behave more like the decays of the J/ψ than the ψ' .

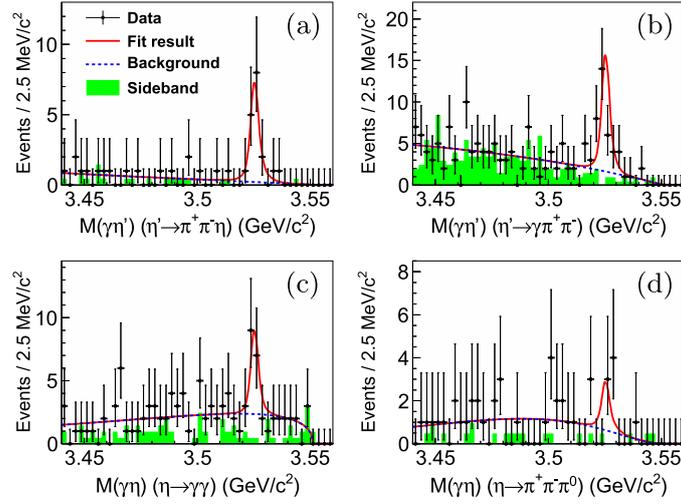


Figure 3: Measurement of $h_c \rightarrow \gamma\eta^{(\prime)}$ for the decays (a) $\eta' \rightarrow \pi^+\pi^-\eta$, (b) $\eta' \rightarrow \gamma\pi^+\pi^-$, (c) $\eta \rightarrow \gamma\gamma$, and (d) $\eta \rightarrow \pi^+\pi^-\pi^0$ [7].

4. Results on the “Y” States

Above the threshold to produce open charm, e^+e^- cross sections to final states including charmonium show many puzzling features [8]. The first to be discovered, and the best known of these features, is the $Y(4260)$, which was originally seen as a peak in the $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ cross section at a mass of around 4.26 GeV. New results from BESIII, however, show that the $Y(4260)$ is not a simple peak [9]. The BESIII measurement of the $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ cross section, measured using both a small number of high-statistics data points and a large number of low-statistics data points, is shown in the top plots of Figure 4. The peak that was formerly known as the $Y(4260)$, can, in fact, be better described as a combination of two peaks, one with a mass of $4222.0 \pm 3.1 \pm 1.4$ MeV/ c^2 and width of $44.1 \pm 4.3 \pm 2.0$ 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.

Similarly, the $e^+e^- \rightarrow \pi^+\pi^-h_c$ cross section is much more complex than previously suspected. The latest measurement from BESIII is also shown in Figure 4 [10]. It can also be described as two peaks, 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 $4391.6 \pm 6.3 \pm 1.0 \text{ MeV}/c^2$ and width of $139.5 \pm 16.1 \pm 0.6 \text{ MeV}$. The parameters of the lighter peak agree with the parameters of the lighter peak in $\pi^+\pi^-J/\psi$. Whether or not they originate from the same resonance is a question that requires more investigation.

Finally, BESIII has a new preliminary result on the shape of the $e^+e^- \rightarrow \pi^+\pi^-\psi'$ cross section, also shown in Figure 4. The new measurements are in agreement with those from Belle and BaBar, which were used to determine the parameters of the $Y(4360)$ [8].

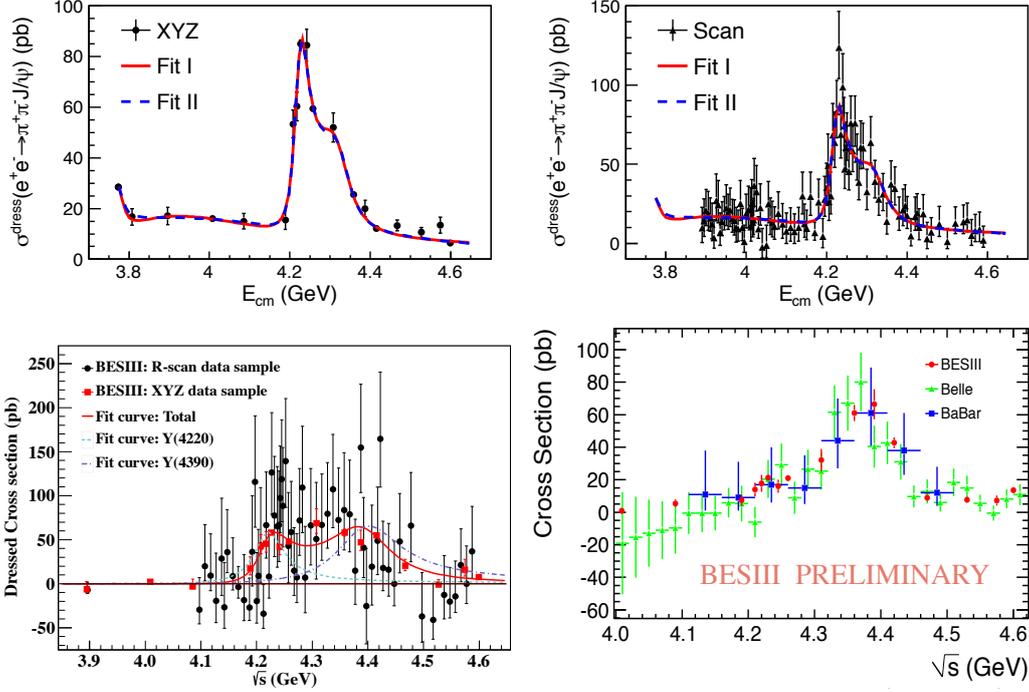


Figure 4: Measurements of e^+e^- cross sections to exclusive final states including charmonium at BESIII. (top left) The $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ cross section measured using high-statistics data points [9]; (top right) the same using a larger number of low-statistics data points; (bottom left) the $e^+e^- \rightarrow \pi^+\pi^-h_c$ cross section [10]; (bottom right) preliminary results for the $e^+e^- \rightarrow \pi^+\pi^-\psi'$ cross section.

5. Results on the “X” States

Besides the $Y(4260)$, another well-known mystery in the charmonium spectrum is the nature of the $X(3872)$ [8]. BESIII has recently shown that there may be a connection between them. Using high-statistics data points at 4.01, 4.23, 4.26, and 4.36 GeV, BESIII observed the process $e^+e^- \rightarrow \gamma X(3872)$, where the $X(3872)$ decays to $\pi^+\pi^-J/\psi$ (Fig. 5a) [11]. The cross section as a function of center-of-mass energy (Fig 5b) shows a shape that is consistent with a peak between 4.2 and 4.3 GeV, which may be consistent with the structure seen in other channels. More data is needed to resolve this issue, but finding a connection between the $X(3872)$ and the “Y” states seen in e^+e^- cross sections is a promising lead.

Similarly, BESIII searched for the $X(4140)$ (also known as the $Y(4140)$) in the analogous process $e^+e^- \rightarrow \gamma X(4140)$ with $X(4140) \rightarrow \phi J/\psi$ [12]. Upper limits were set on the product

$\sigma(e^+e^- \rightarrow \gamma X(4140)) \times B(X(4140) \rightarrow \phi J/\psi)$ that are of the same order of magnitude as the measurements of $\sigma(e^+e^- \rightarrow \gamma X(3872)) \times B(X(3872) \rightarrow \pi^+\pi^- J/\psi)$.

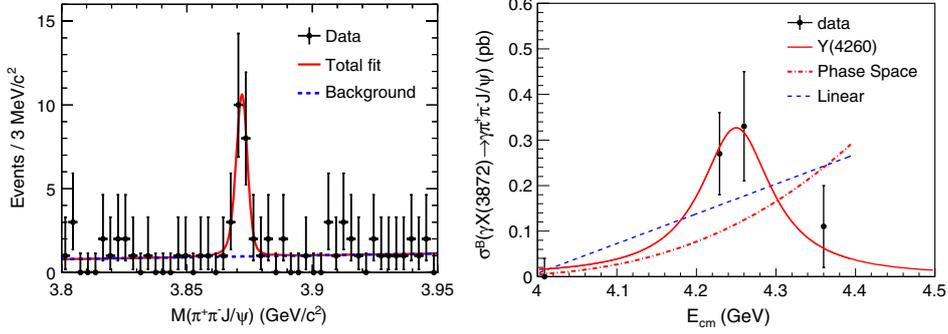


Figure 5: (left) Observation of the $X(3872)$ in the process $e^+e^- \rightarrow \gamma X(3872)$ with $X(3872) \rightarrow \pi^+\pi^- J/\psi$ [11]. (right) The $e^+e^- \rightarrow \gamma X(3872)$ cross section as a function of center-of-mass energy [11].

References

- [1] R. A. Briere, F. A. Harris and R. E. Mitchell, *Physics Accomplishments and Future Prospects of the BES Experiments at the BEPC Collider*, *Annu. Rev. Nucl. Part. Sci.* 2016.66:143-170 [arXiv:1603.09431].
- [2] M. Davier, A. Hoecker, B. Malaescu and Z. Zhang, *Reevaluation of the Hadronic Contributions to the Muon $g-2$ and to $\alpha(MZ)$* , *Eur. Phys. J. C* **71**, 1515 (2011) Erratum: [*Eur. Phys. J. C* **72**, 1874 (2012)] [arXiv:1010.4180].
- [3] C. Patrignani *et al.* [Particle Data Group Collaboration], *Review of Particle Physics*, *Chin. Phys. C* **40**, no. 10, 100001 (2016).
- [4] M. Ablikim *et al.* [BESIII Collaboration], *Measurement of the $e^+e^- \rightarrow \pi^+\pi^-$ cross section between 600 and 900 MeV using initial state radiation*, *Phys. Lett. B* **753**, 629 (2016) [arXiv:1507.08188].
- [5] M. Ablikim *et al.* [BESIII Collaboration], *Measurement of the proton form factor by studying $e^+e^- \rightarrow p\bar{p}$* , *Phys. Rev. D* **91**, no. 11, 112004 (2015) [arXiv:1504.02680].
- [6] N. Brambilla *et al.*, *Heavy quarkonium: progress, puzzles, and opportunities*, *Eur. Phys. J. C* **71**, 1534 (2011) [arXiv:1010.5827].
- [7] M. Ablikim *et al.* [BESIII Collaboration], *Observation of h_c radiative decay $h_c \rightarrow \gamma\eta'$ and evidence for $h_c \rightarrow \gamma\eta$* , *Phys. Rev. Lett.* **116**, no. 25, 251802 (2016) [arXiv:1603.04936].
- [8] R. F. Lebed, R. E. Mitchell and E. S. Swanson, *Heavy-Quark QCD Exotica*, arXiv:1610.04528.
- [9] M. Ablikim *et al.* [BESIII Collaboration], *Precise measurement of the $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ cross section at center-of-mass energies from 3.77 to 4.60 GeV*, arXiv:1611.01317.
- [10] M. Ablikim *et al.* [BESIII Collaboration], *Observation of two resonant structures in $e^+e^- \rightarrow \pi^+\pi^- h_c$* , arXiv:1610.07044.
- [11] M. Ablikim *et al.* [BESIII Collaboration], *Observation of $e^+e^- \rightarrow \gamma X(3872)$ at BESIII*, *Phys. Rev. Lett.* **112**, no. 9, 092001 (2014) [arXiv:1310.4101].
- [12] M. Ablikim *et al.* [BESIII Collaboration], *Search for the $Y(4140)$ via $e^+e^- \rightarrow \gamma\phi J/\psi$ at $\sqrt{s}=4.23, 4.26$ and 4.36 GeV*, *Phys. Rev. D* **91**, no. 3, 032002 (2015) [arXiv:1412.1867].