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Recent results of Baryon electromagnetic form factors at BESIII

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At BESIII, the electromagnetic form factors (EMFFs) and the pair production cross sections of various baryons have been studied. The proton EMFF ratio $|G_E/G_M|$ is determined precisely and line-shape of $|G_E|$ is obtained for the first time. The recent results of neutron EMFFs at BESIII show great improvement in comparison with previous experiments.

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Electromagnetic form factors (FFs) provide information on the internal structure and dynamics of hadrons, describing the modifications of the point-like photon-hadron vertex due to the hadron structure and allow a better understanding of the strong interaction.
In the Born approximation, the total and the differential cross section for the annihilation reaction $e^+e^- \to B\overline{B}$ in the centre of mass system are expressed as functions of the two baryon electromagnetic FFs, $|G_E|$ and $|G_M|$ [1]. In the past, due to the low statistics, only the so-called effective FF, G_{eff}, could be determined from the total cross section. With the Initial State Radiation (ISR) technique, the total cross section can be factorized, disentangling the reaction of interest from the radiator function $W(x, s)$, which gives the probability of emission of a hard photon. Moreover, the ratio of the electric and magnetic form factors FFs, R_{em}, is experimentally accessible with both methods by the measurement of the differential cross section at a given q^2. A precise measurement of R_{em} allow the FFs' moduli to be disentangled. In BESIII, with electron-positron annihilation, both energy scan and the ISR techniques can be applied to measure proton time-like form factors. Details of each sub-detector and their performance, together with the trigger system, are discussed in Ref. [2]. Our scan-method analysis [3] profits of all the collected high-statistics data set between $\sqrt{s} = 2.2$ and 3.08 GeV (669 pb^{-1}), while untagged and tagged ISR analyses were performed, based on the same data collected between $\sqrt{s} = 3.773$ and 4.6 GeV (7.5 fb $^{-1}$), but with complementary samples. Indeed the untagged ISR analysis [4] (SA-ISR) exploits events in which the ISR photons cannot be detected by the ElectroMagnetic Calorimeter, because of the small angle of the photon, with a statistics increased by a factor 3 compared to the tagged analysis (LA-ISR) [5]. In the latter analysis, the Born cross section and the effective form factor of the proton are measured from the production threshold to 3.0 GeV. Although the signal/background separation is more complicated, it is the only way to reach the threshold, which is a valuable harvest because the peculiar features of this region are not yet understood. In Fig. 1, the experimental measurements of the Born cross section σ_B (right) and effective FF G_{eff} (centre) can be found as a function of the momentum transfer squared for all BESIII analyses and the other measurement available in literature. The wider momentum transfer range and the high relative precision are evident in comparison with the previous measurements.The two-three step behavior in the cross section is confirmed, most likely due to final state interactions. In particular the behavior at threshold, shown in the insight of Fig. 1, measured

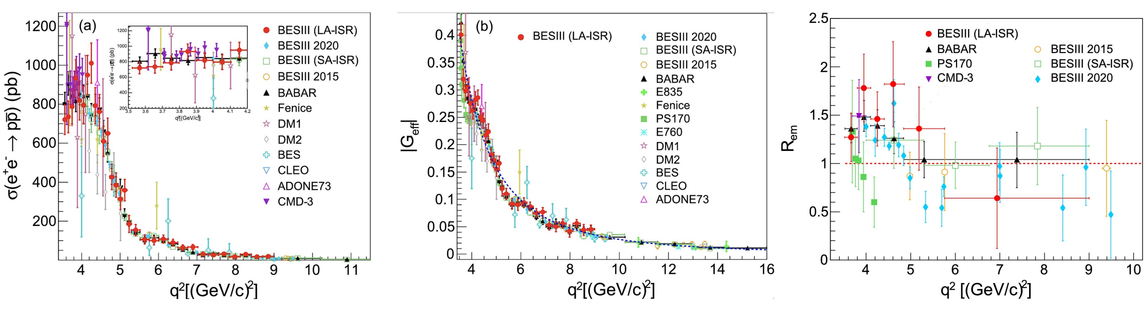

Figure 1: The Born cross section on the left (a) and the $|G_{eff}|$ (b) on the centre, with a fit through the data (blue dashed line) for BESIII in red and previous experiments (references in [3]). On the right, $|R_{em}|$ as a function of the q^2 for LA-ISR BESIII analysis (red points) together with the results from previous experiment.

by BaBar with lower uncertainties, is confirmed even if our LA-ISR measurements seem to be systematically lower. The effective form factor distribution is well described by a modified dipole function shown as a blue dashed line in the central plot of Fig. 1, phenomenologically motivated in Ref. [6]. We will come back to the oscillating behaviour in the following. From the analysis of the proton-helicity angular distribution $|R_{em}|$ of the proton is determined, with an improved precision, confirming an enhancement of $|R_{em}|$ in the region below 2.2 GeV/c^2 previously observed by BaBar, but not by PS170. In Fig. 1 the dotted line represents pQCD asymptotic prediction and nucleon final state interactions can account for deviations for q^2 <5 GeV^2. Moreover, BESIII was able to measure, for the first time, $|G_E|$ and $|G_M|$ independently thanks to its high statistics and moreover to obtain the most precise results for $|G_M|$ and $|R_{EM}|$ with a relative precision of 1.8% - 3.6% and 3.5% - 96%, respectively. Our results bring new information with a comparable precision to the scattering region and helps going towards a unified view of the scattering and annihilation regions. Concerning neutron FFs, our large-integrated-luminosity data sample represents a unique opportunity for a precise measurement in $e^-e^+ \longrightarrow n\bar{n}$. Because of the difficulties in the (anti-)neutron detection, only a few measurements were available by three experiments: FENICE, DM2 and SND [9]. Indeed these challenging measurements have been awaited since long time and it allows both the comparison with proton FF measurements and with Space-Like (SL) FFs. In our analysis [10] three statistically independent event categories are used to maximize the reconstruction efficiency of the $n\bar{n}$ final state, depending on the interaction of the (anti-)neutrons with the detector, selected using the elctromagnetic calorimeter and/or time of flight system only and combined to reduce the statistical uncertainty. The cross section of the process is measured at 18 c.m. energies, obtaining the best precision of 8.1% at $\sqrt{s}$ =2.396 GeV. Then the effective form factors are extracted under the assumption $|G_E| = |G_M|$ with an improvement of the statistical precision by more than a factor of 60 over previous measurements from the FENICE and DM2 experiments.The results are shown in Fig. 2, in which the importance of our measurements is evident for both its wide range and very low uncertainties, starting to be competitive with SL ones. They agree with SND and FENICE at 2.0 GeV, but above 2.0 GeV they are systematically lower. The reduced form factor, after the subtraction of a dipole-like function [6], can be described by $G_{osc}(p) = A\ \exp(-Bp)\cos(C \cdot p + D)$,

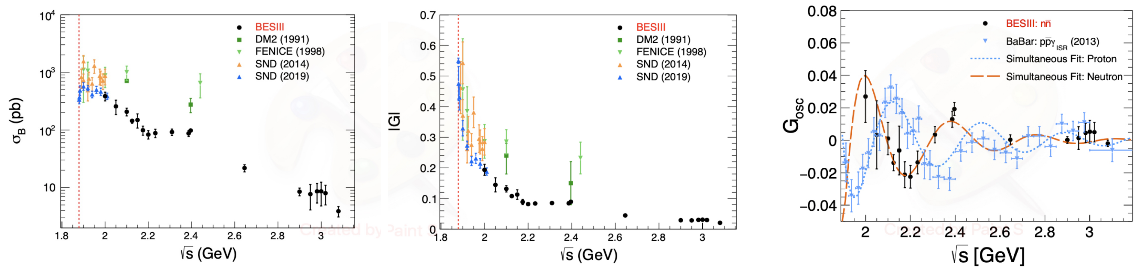

Figure 2: Results for the Born cross section (left) and the corresponding form factor $|G_{eff}|$ (centre) of the $e^-e^+ \longrightarrow n\bar{n}$ for BESIII (black solid circles) and FENICE [9]. The red dashed line indicates the production threshold. On the right the reduced form factor G_{osc} of the nucleon is shown as a function of the relative momentum of the nucleon pair with the simultaneous fit for FF measured by BESIII (black circles) for nutron and BaBar (blue triangles) [11] for proton

where p is the relative momentum of the nucleon pair, A the normalization, B the inverse oscillation damping, C the momentum frequency, and D the phase. A fit to the proton and neutron data can simultaneously describe the oscillation with a phase shift of $(125 \pm 12)^{\circ}$, as shown in Fig. 2. This is most likely sign of a more complex dynamic effect, which still needs clarification, like interference effects in final state re-scattering [7] or presence of resonances in the data [8]. Moreover the preliminary BESIII results for $|G_M|$ can be compared to the results from FENICE, extracted from the Born cross section using the hypothesis $|G_E| = 0$. They are significantly larger compared to BESIII.

In conclusion, the BESIII experiment is ideal to measure the nucleon FFs in the time-like region. With the large data sets collected, the precision of the effective form factors of the proton and the neutron is increased with respect to previous experiments. The magnetic and electric form factors of the proton are measured independently for the first time and $|R_{em}|$ is measured with improved precision. An oscillating behavior of the effective form factor is observed both for neutron and proton FFs.

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