1 The BESIII experiment

The BESIII experiment is taking data since 2009 at the Beijing Electron Positron Collider BEPC-II, at the Beijing Institute of High Energy Physics, IHEP. The BESIII detector is designed to study the $\tau$-charm physics and so far BESIII collected the world largest samples of $J/\psi$, $\psi(3686)$, $\psi(3770)$ and $\psi(4040)$, $Y(4260)$, $Y(4360)$, the latter two having already led to a number of surprises (par 2). The actual maximum instantaneous value of the luminosity reached is $0.7 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$.

2 Five XYZ discoveries from BESIII in 2013

The quark model of charmonium, with a charm quark bound to an anticharm quark with a particular configuration of quantum numbers, has been very successful in describing the spectrum of the observed states below the $D\bar{D}$ threshold. At higher masses many new states seem to point beyond the simple $c\bar{c}$ picture, such states are often referred to as XYZ states and can open the window to new physics beyond the quark model. BESIII is in the unique position to provide direct production of $Y(4026)$ and $Y(4360)$ by simply tuning the BEPCII collider to these c.m. energies.

Between December 2012 and June 2013 BESIII collected $2.9 \text{ fb}^{-1}$ of data in this energy region, mainly at $E_{cm} = 4.23, 4.26, 4.36 \text{ GeV}$ useful also for the production of "charged charmoniumlike states", the $Z_c(3900)$ and the $Z_c(4020)$ as well as radiative production of $X(3872)$.

2.1 The Charged $Z_c(3900)$

The $Y(4260)$ was originally discovered by BaBar1) and later confirmed by Belle 2) in the initial state radiation (ISR) process $e^+e^- (\gamma_{ISR}) \rightarrow Y(4260) \rightarrow \pi^+\pi^-J/\psi$. BESIII directly produced it via $e^+e^- \rightarrow Y(4260)$ at $E_{cm}=4.26 \text{ GeV}$ with $515 pb^{-1}$ 22) confirming the cross section for this process. More surprisingly, BESIII also found a charged charmoniumlike structure in the $\pi^\pm J/\psi$ subsystem. Fitting this structure, referred to as the $Z_c(3900)$, with a resonant line shape (upper left of fig.1) resulted in a mass and width of $(3899.0 \pm 3.6 \pm 4.9) \text{ MeV}/c^2$ and $(46 \pm 10 \pm 20) \text{ MeV}$, respectively. The observation of this state is remarkable because since the $Z_c(3900)$ contains $c\bar{c}$ but it is also charged, it must be composed of four quarks. It may be a tetra quark state (like $cu\bar{c}d$) or a molecular state (such as $D^+\bar{D}^{*-}$). Only a few days later the $Z_c(3900)$ was confirmed by Belle 3).

2.2 Structure in charged in $D\bar{D}^*+c.c.$

To investigate the interpretation of the $Z_c(3900)$ as a virtual $D\bar{D}^*$ molecular structure, BESIII analysed the process $e^+e^- \rightarrow \pi^-D^+\bar{D}^{*-}+c.c.$ and $e^+e^- \rightarrow \pi^-\bar{D}^0D^{*+}+c.c.$ at $E_{cm} = 4.26 \text{ GeV}$ 13). Clear structure, referred to as the $Z_c(3885)$, in the mass spectrum of both $D^+\bar{D}^{*-}$ and $\bar{D}^0D^{*+}$ are found (middle left of fig.1). The measured mass and width are $(3883.9 \pm 1.5 \pm 4.2) \text{ MeV}/c^2$ and $(24.8 \pm 3.3 \pm 11.0) \text{ MeV}$ respectively, being both slightly lower than those of the $Z_c(3900)$, and it is likely that the two structures are related to the same resonance.
Figure 1: The five discoveries by BESIII in 2013 (see text for details): 1) Upper left: $Z_c(3900)$; 2) middle left: $Z_c(3885)$; 3) Upper right: $Z_c(4020)$; 4) middle right: $Z_c(4025)$; 5) bottom right: $X(3872)$ mass peak and bottom left: cross section for $e^+e^- \to \gamma X(3872)$ as a function of energy.
2.3 The Charged $Z_c(4020)$ in $\pi h_c$

BESIII studied also $e^+e^- \rightarrow \pi^+\pi^- h_c$ at 13 c.m. energies from 3.90 GeV to 4.42 GeV. It is found that the Born cross section is of the same order of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ but with different lineshape. More surprisingly, in the $\pi^\pm h_c$ mass spectrum, a distinct structure, the $Z_c(4020)$, is observed $^{14}$ at 4.02 GeV/$c^2$ (upper right of fig 1). The mass and width of this structure are measured to be $(4022.9 \pm 0.8 \pm 2.7)$ MeV/$c^2$ and $(7.9 \pm 2.7 \pm 2.6)$ MeV. Like the $Z_c(3900)$, the $Z_c(4020)$ is charged and so must contain more quarks than just $c\bar{c}$.

2.4 Structure in charged $D^*\bar{D}^*$

Since the masses of $Z_c(3900)$ and $Z_c(4020)$ are slightly larger than the $D\bar{D}^*$ and $D^*\bar{D}^*$ mass threshold, a search for $Z_c$ candidates via direct decay into $D^*\bar{D}^*$ has been performed at 4.26 GeV by BESIII. A structure decaying to $(D^*\bar{D}^*)^\pm$ in the process $e^+e^- \rightarrow \pi^\pm(D^*\bar{D}^*)^\pm$ has been found $^{15}$ (middle right plot of fig 1). The mass and width of the structure, $(4026.3 \pm 2.6 \pm 3.7)$ MeV/$c^2$ and $(28.4 \pm 5.6 \pm 7.7)$ MeV respectively, are somewhat larger than those of the $Z_c(4020)$ but close enough to suggest a connection between the two.

2.5 Observation of the radiative production of X(3872)

One final surprise from the 2013 BESIII data is the observation for the first time of the X(3872) in the process $e^+e^- \rightarrow \gamma X(3872)$ with $X(3872) \rightarrow \pi^+\pi^- J/\psi$ (lower right plot of fig 1) $^{12}$. This is a new way to access the X(3872) which is still one of the least understood of the XYZ states. The cross section of $e^+e^- \rightarrow \gamma X(3872)$ as a function of c.m. energies shown in the left bottom plot of fig 1, suggests the X(3872) is more consistent with a Y(4260) shape rather than phase space or a liner line shape. The five discoveries of BESIII seen in $e^+e^-$ collisions with c.m. energies near the mass of the Y(4260) suggest there is an intimate connection between Y(4260) and the $Z_c(3900)$, the $Z_c(4020)$ and the X(3872) and further studies are going on in BESIII.

3 Cylindrical GEMs study for the of the BESIII Inner Tracker

The BESIII group applied at the end of 2012 for funding to the Italian Ministry of Foreign Affairs (MAE) in the cadre of a Program of Great Relevance between Italy and the People Republic of China. The proposition was for constructing a prototype layer of a Cylindrical GEM Inner Tracker, much similar to the one made in previous years at LNF by the KLOE-2 group.

This one layer is designed to be incorporated in a final, 3-layer complete detector to be installed in the year 2017 in BESIII, with the object to replace the inner part of the present BESIII drift chamber, that shows signs of degradating performance due to the high machine background.

The innovative part of the proposal consists in the strip readout, that in KLOE-2 is digital: we propose an analogic readout, to measure the particle impact points via weighted averages of charges developed on adjacent strips. This improvement on hit resolution is necessary because the magnetic field in BESIII, higher than in KLOE-2, has a greater dispersing effect on the charges migrating in the detector cells, resulting in wider clusters.

The proposition was approved by MAE in January 2013, and the group started intensive cooperation with the Chinese counterpart to discuss and clarify all details regarding construction, in view of final installation of this prototype in BESIII (once proved functional). In 2013 the MAE project was advanced by procurement of all materials and parts needed to build the first CGEM-IT prototype: molds, GEM and electrode foils, and all parts for the HV system. Preparation of the clean room at LNF where the prototype will be built has also been concluded.
The LNF-specific work was dedicated to refurbishment of the clean room used by the KLOE-2 physicist to produce their detectors, modifications to fixtures and apparata for lamination of planar electrodes into cylindrical ones, made necessary by the different dimensions of our detectors with respect to KLOE-2, and to the setup of a cosmic ray laboratory to investigate the behaviour of a small planar chamber that we built, but otherwise identical to the final cylindrical prototype.

![Cosmic Ray Setup Test](image.jpg)

**Figure 2:** Picture of the cosmic ray setup test in LNF, see description in the text.

### 3.1 Cosmic Ray Test Setup

A cosmic ray setup has been implemented to test different gas mixtures and readout electrode geometries on a new $10 \times 10 \text{cm}^2$ planar chamber with analog readout. The setup is composed of two $10 \times 10 \text{cm}^2$ scintillators and three $10 \times 10 \text{cm}^2$ GEM tracking chambers of the KLOE-2 type, using 650µm wide XY strips.

The scintillators are used to generate the acquisition trigger, while the tracking chambers, instrumented with the GASTONE64 chip developed in Bari for digital readout, measure the impact point of cosmic rays with a single-hit resolution of about 200µm.

The hardware setup, shown in fig.2, is built around a support structure for detectors, a 2-component (Argon/Isobutane) gas system, a system for HV distribution and associated slow controls, and a VME readout chain. It was implemented in late 2013, and the early 2014 cosmic ray activity will be mainly devoted to the development and crosscheck of the acquisition and tracking software.
4 Physics analysis

The relative phase between the \( J/\psi \) decay amplitudes, strong and electromagnetic one, is a hot topic and raised wide interests in the high energy physics community for many years. Knowledge of this fundamental parameter will help us to understand the decay mechanics and sub-structure of hadrons. Many studies have been done via \( J/\psi \) two body decays to \( 0^+0^- \), \( 1^-0^- \), \( 1^-1^- \), and \( N\bar{N} \) \(^4\), \(^5\), \(^7\), also reported in the 2012 LNF Activity Report, and all of these results favour a nearly orthogonal relative phase angle between strong and electromagnetic amplitudes in the \( J/\psi \) decays. In contrast, this large phase angle has not been observed in \( \psi(3686) \) decays so far. Within the experiment uncertainties, the relative phase angle is consistent with zero in \( 1^-0^- \) and \( 1^-0^+ \) decays. Some suggestions are proposed to explain this marked difference between the phase angles in \( J/\psi \) and \( \psi(3686) \) decays. However, none of these explanations has been widely accepted as a final answer to this question partially due to the lack of information also from experimental side. However no simple explanation has been put forward until now on why in the case of \( J/\psi \) decay there is this large phase angle.

In this regard, following the analysis reported last year on \( J/\psi \rightarrow p\bar{p} \) and \( n\bar{n} \) at BESIII, we have studied the relative phase between the amplitudes of strong and electromagnetic interactions at the \( J/\psi \) through an energy scan, it is a model independent method, and also we looked to \( \psi(3686) \rightarrow p\bar{p} \) and \( n\bar{n} \), as reported in the following two paragraphs.

On the basis of the results we got (no interference with the continuum for hadronic \( J/\psi \) decays), in order to explain them, we have developed a new quarkonium model. In short, following a suggestion by Freund and Nambu, it is assumed that quarkonium is a superposition of a very narrow state, coupled to leptons but not to hadrons, and a wide state, not coupled to leptons but coupled to hadrons (a glueball). In this way the 90 degrees phase is naturally achieved and the glueball can be wide enough do not contradict any experimental result, at least at the present level of accuracy. Remarkably enough the same model, applied to the OZI violating decay of the \( \phi \), predicts a 180 degrees phase, the coupling constant between narrow and wide state is the same as the \( J/\psi \) one, and the glueball is expected at about 1.34 GeV, 0.5 GeV wide, very consistent with an unexpected resonance found by BaBar, decaying into three pions.

Finally a measurement of \( e^+e^- \rightarrow \Lambda\bar{\Lambda} \) cross section close to threshold has been performed, as reported in the third paragraph.

The analysis described in the following have been completed and preliminary results have been submitted to the Collaboration review therefore they cannot yet be listed here.

4.1 Study of the phase between \( J/\psi \) strong and electromagnetic decay amplitudes by means of a resonance scan

The \( J/\psi \) can decay into hadrons mainly via a strong or electromagnetic (EM) process, In pQCD, the \( J/\psi \) strong amplitude \( A_{3g} \) and the EM amplitude \( A_{EM} \) are predicted to be both real as expected for the non-resonant amplitude. According to QCD, the phase angle between \( A_{3g} \) and \( A_{EM} \) should be no more than 10°. On the other side, experimental evidences point toward an unexpected 90° phase difference \(^4\), \(^5\), \(^7\) which means \( A_{3g} \) is orthogonal to \( A_{EM} \). All the category, modelling the amplitudes by means of \( SU_3 \) and \( SU_3 \) breaking.

In this work, a model-independent way to measure the phase difference between the strong and EM amplitudes is used by searching for an interference in \( Q^2 \) behavior. With a serie of data samples scanning the \( J/\psi \) peak in 2012 by BESIII, the phase angle between \( A_{3g} \) and \( A_{EM} \) is measured in \( \pi^+\pi^-\pi^+\pi^- \) and \( \pi^+\pi^-\pi^0 \) channels. The full interference between the c.m. decays and the continuum (\( A_{cont.} \)) has been observed in \( e^+e^- \rightarrow \mu^+\mu^- \) at SLC, BES and KEDR, which
means $A_{EM}$ and $A_{cont.}$ share one common phase. This is also verified in $\mu^+\mu^-$ and $\pi^+\pi^-\pi^+\pi^-$ in our work.

After having applied common track event selections and calculated the number of events $N_{obs}$, the cross section for each multi-channel process is calculated with $\sigma_{obs} = N_{obs}/L\epsilon_{obs}$, where $L$ is the luminosity of each data sample and $\epsilon_{obs}$ is the efficiency of our event selections. The phase angles are obtained by fitting $J/\psi$ lineshapes and taking into account initial state radiation (ISR) and beam energy spread. The fitting results on $J/\psi$ lineshape from the channels analysed are shown in Fig. 3. We have started to analyse the $\mu^+\mu^-$ and $2\pi^+2\pi^-$ channels where full interference is expected between $J/\psi$ e.m. decay and continuum, the preliminary results are shown in figs. 3(a) and (b).

An interference pattern in the $\mu^+\mu^-$ channel was identified and measured soon after the discovery of $J/\psi$ at SLAC, the relative phase between the resonant and non-resonant amplitudes being in good agreement with the one expected. The $J/\psi$ lineshape of $\mu^+\mu^-$ from BESIII improves the significance of previous results and is consistent with full interference between $A_{EM}$ and $A_{cont.}$.

In $e^+e^- \rightarrow 2\pi^+2\pi^-$ no strong decay is allowed because of G-parity conservation and full interference between the e.m. decay and the continuum is expected. The sign of the interference is not established a priori and should be an interesting byproduct.

From the analysis of the $\pi^+\pi^-\pi^+\pi^-$ channel in BESIII, the phase angle between $A_{EM}$ and $A_{cont.}$ is verified to be consistent with $0^\circ$ as expected. The interference in $2\pi^+2\pi^-$ has never been measured before.

Based on $\varphi_{EM,cont.} \sim 0^\circ$, the phase angles between $A_{3g}$ and $A_{QED}$ are measured from $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ and from $e^+e^- \rightarrow \pi^+\pi^-\pi^0$, the corresponding line shapes and fit results are shown in figs. 3(c) and (d). Preliminary results on the phase angle between $A_{3g}$ and $A_{EM}$ turn out to be about $105^\circ$ both for $\pi^+\pi^-\pi^-\pi^0$ and $\pi^+\pi^-\pi^0$, confirming other results from direct hadronic decays.

### 4.2 Study of $\psi(3686) \rightarrow p\bar{p}$ and $n\bar{n}$

As already stated, the measurement of $\psi(3686) \rightarrow p\bar{p}$ and $n\bar{n}$ can give information on the relative phase between the strong and electromagnetic amplitude. Moreover another interesting topic would be the angular distribution of the final $N\bar{N}$ states. As it is well known, the interaction rate for the decay of a neutral vector resonance $V$ into a particle-antiparticle pair $hh$ has a general structure $dN/d\cos\theta \propto 1 + \alpha \cos^2\theta$ derived from the helicity formalism, where $\theta$ is the polar angle which specifies the direction of motion of the produced $h$ or $\bar{h}$ in the $V$ rest-frame. In an original paper by Brodsky and Lepage (6), they predicted $\alpha = 1$ on the basis of the QCD helicity conservation rule. However, after a very small $\alpha$ value of $J/\psi \rightarrow p\bar{p}$ was reported MARK II (unpublished) data, later theoretical calculations suggested the $\alpha$ should be smaller than 1, i.e. 0.46, if the hadron mass effect had been considered. Since then, measurements and theoretical calculation on $J/\psi$ decays favoured the small $\alpha$ value conclusion. For the measurements on the $\alpha$ in $\psi(3686)$ decays to proton and anti-proton pairs, several results have been reported, they all prefer to a value of $\alpha$ smaller than 1 with large uncertainty. But the information from $\psi(3686)$ decays to neutron and anti-neutron is still missing.

In our work, we measured the branching fractions and $\alpha$ value via the processes of $\psi(3686) \rightarrow p\bar{p}$ and $\psi(3686) \rightarrow n\bar{n}$. This analysis is based on a $\psi(3686)$ data sample of $1.06 \times 10^8$ events collected by BESIII.

The preliminary results show a $Br(\psi(3686) \rightarrow p\bar{p}) \sim Br(\psi(3686) \rightarrow n\bar{n})$, $\alpha$ consistent with 1 and a phase angle around $50^\circ$. 
Figure 3: Fit results of $J/\psi$ lineshape from $\mu^+\mu^-$ (a), $\pi^+\pi^-\pi^+\pi^-$ (b), where full interference is observed, $\pi^+\pi^-\pi^+\pi^-\pi^0$ (c), and $\pi^+\pi^-\pi^0$ (d) with no interference.
4.3 Study of $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ close to threshold

The cross section for process $e^+e^- \rightarrow B\bar{B}$, where $B$ is a spin-1/2 neutral baryon is expressed as follow:

$$\sigma_{B\bar{B}}(m) = \frac{4\pi\alpha^2\beta^3}{3m^2}[G_M(m)^2 + \frac{1}{2\tau}|G_E(m)|^2]$$ (1)

where $\beta = \sqrt{1 - 4m_B^2/m^2}$. It indicates that at threshold, cross section of neutral baryon pair production is expected to be almost 0. It could be a little larger than 0 due to the energy spread. However, the BABAR cross section $\sigma = 204 \pm 60 \pm 20$ pb, which is an average value from threshold up to $W = 2270$ MeV, implies that there should be a spike close to threshold in the cross section. At BESIII, with 2.631 pb$^{-1}$ data collected at 2.2324 GeV, the cross section for $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ at threshold, where $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$, has been measured to be $(442 \pm 67)$ pb.

Figure 4: Comparison of the cross section for the BESIII preliminary results with BABAR results and theoretical expectation.

In this work with the 2.631 pb$^{-1}$ data collected at 2.2324 GeV, process $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ is studied. Instead of selecting the charged channel of $\Lambda \rightarrow p^+\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$, we only tag the $\Lambda$ side with $\bar{\Lambda} \rightarrow \bar{n}\pi^0$. The smaller branching fraction of $\bar{\Lambda} \rightarrow \bar{n}\pi^0$ comparing to charged decay channel of $\Lambda$ or $\bar{\Lambda}$ can be recovered by the semi-inclusive method. In the neutral channel of $\bar{\Lambda}$, $\bar{n}$ has information in EMC and the monoenergetic $\pi^0$ has a momentum of 105 MeV. Furthermore, $\bar{n}$ and $\pi^0$ has an angle larger than 140$^\circ$. These information can be used to preliminarily select signals from data. A Boosted Decision Trees (BDT) based Multiply Variable Analysis is applied to classify signal events and hadronic background. The yields in data is obtained by fitting the $\pi^0$ momentum distribution. The cross section preliminary result is shown in fig. 4 together with BABAR results. At threshold, a cusp is observed which is much larger than the expectation in Eq. 1.

5 List of talks by LNF Authors in 2013

1. Y. Wang, "Looking for the phase interference between strong and EM in $J/\psi$ decays", Radio MontecarLow WG meeting: ECT* Trento, 10-12 April 2013


3. Y. Wang, " Baryon form factors at BESIII", International Workshop on e+e- collisions from Phi to Psi, 9-12 September 2013, Rome
References


6 Publications in 2013

13. M. Ablikim et al. [BESIII Collaboration], “Observation of a charged (D\bar{D}^*)^\pm mass peak in e^+e^- → π(D\bar{D}^*) at E_{cm} = 4.26GeV,” arXiv:1310.1163 [hep-ex].
15. M. Ablikim et al. [BESIII Collaboration], “Observation of a charged charmoniumlike structure in e^+e^- to (D^*\bar{D}^*)^\pmπ^\mp at \sqrt{s} = 4.26GeV,” arXiv:1308.2760 [hep-ex].
34. M. Ablikim et al. [BESIII Collaboration], Phys. Rev. D 87 (2013) 012002