An amplitude analysis of the $\pi^0\pi^0$ system produced in radiative $\psi(2s)$ decays: Current results

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Abstract

Glueballs are predicted in a wide range of nonperturbative approaches to QCD, but such states have not been reliably identified experimentally. Their existence (or non-existence) is a crucial test for our understanding of QCD. In the analysis of radiative J/ψ decays, with a strong contribution from the JINR BESIII group, strong evidence of the scalar gluon production is obtained. At the same time, no evidence of the tensor gloun production is seen in the available J/ψ decay data, despite the higher expected production rate. This motivates a comprehensive study of radiative $\psi(2S)$ decays where hadrons with larger mass can be produced.
We present the current state of the amplitude analysis of $\psi(2S)$ radiative decays into $\pi^0\pi^0$ system. Approximately 96.000 events of these decays were selected from the BESIII data of $\psi(2S)$ decays gathered during 2021. The background ratio for selected events is estimated to be less than 2%.

1. Introduction

The search for the particles outside of the quark model remains one of the most important tasks within modern QCD [1]. Coincidentally, one of the main goals of the BESIII experiment is to search for specific type of these "abnormal" particles - glueballs [2]. In the analysis [3], which is based on the BESIII data of radiative J/ψ decays, enhancement was observed which authors interpreted as a scalar glueball with $M_G = (1865 \pm 25^{+10}_{-30})$ and $\Gamma_G = (370 \pm 50^{+30}_{-20})$.

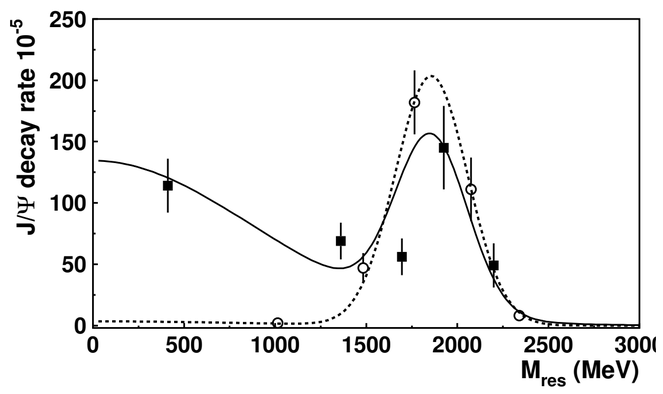

Figure 1: Yield of radiatively produced scalar isoscalar octet mesons (open circles) and singlet (full squares) mesons.

Notably, a tensor glueball must have a higher mass and have a three times higher yield in comparison with the scalar glueball. However, in the study [4], which was performed by the same authors, an enhancement observed in the tensor wave had lower mass and substantially lower yield than predicted for the tensor glueball. Therefore, the study of radiative $\psi(2S)$ was proposed with the main motivation that it would test the conjecture that the enhancement observed in [4] could be the low-energy tail of a tensor glueball centered at a higher mass.
During 2021 more than 2 billion events of $\psi(2S)$ decays were gathered at the BESIII experiment. Combined with data for the same decays from 2009 and 2012, it makes it the largest dataset of $\psi(2S)$ decays in the world. In case of production of a tensor glueball we expect to be able to observe it in the spectrum of $\pi^0\pi^0$ invariant masses produced in radiative $\psi(2S)$ decays.

2. BESIII experiment at BEPCII collider

The BEPCII is an electron-positron collider located in IHEP, Beijing, China. It was designed to collide e^+e^- beams in the energy range of $\sqrt{s} = 2.0-4.9$ GeV. The designed (and achieved) luminosity of the collider is $1.0 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Crossing angle between rings is ± 11 mrad (or 22 mrad in total).
The BESIII is a cylindrically symmetrical general purpose detector located at the interaction point of the BEPCII. Design of this detector allows to take advantage of high luminosity delivered by BEPCII and to collect large data samples. The BESIII detector overs 93% of the full solid angle, and consists of a helium-based main drift chamber (MDC), a plastic scintillator time-of-flight system (TOF), and a CsI(Tl) electromagnetic calorimeter (EMC), all enclosed in a superconducting solenoidal magnet providing a magnetic field of 1.0 T. The charged particle momentum resolution at 1 GeV is 0.5%.
For this analysis EMC plays an important role due to the fact that it provides high resolution for energy measurement. The EMC measures 1 GeV photons with an energy resolution of 2.5% in the barrel region and 5% in the end cap region.
More detailed description of the experimental setup is provided in [5].

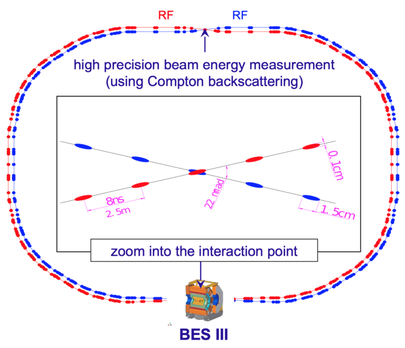

Figure 2: The BEPCII schematic layout

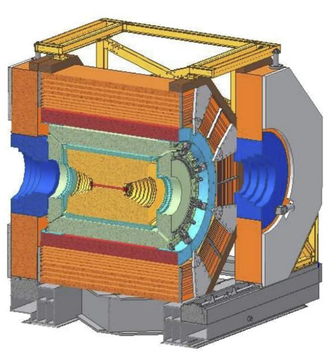

Figure 3: The BESIII layout

3. Current results

For this analysis we have developed an algorithm for selecting radiative decays of $\psi(2S) \to \gamma X \to \gamma\pi^0\pi^0$. After applying selection procedures to the data sample from 2021 we have been able to obtain ≈96.000 events with $M_{inv}(\pi^0\pi^0) < 3.0$ GeV/c^2. Combined with data from 2009 and 2012, the total number of selected events will be above 100.000 which is our requirement for the successful amplitude analysis.
Importantly, the estimation for the number of background events is quite low, the total background for events with $M_{inv}(\pi^0\pi^0) < 3.0$ GeV/c^2 does not exceed 2%. This number was acquired by using the sideband subtraction for the non-peaking background and inclusive Monte-Carlo data for the external background.
One can notice that inclusive Monte-Carlo poorly describes experimental data, especially in $2.0-3.0$ GeV/c^2 range. For this reason we are currently working on a data-driven approach to estimate the background from events with the $\gamma\pi^0\pi^0\pi^0$ final state.

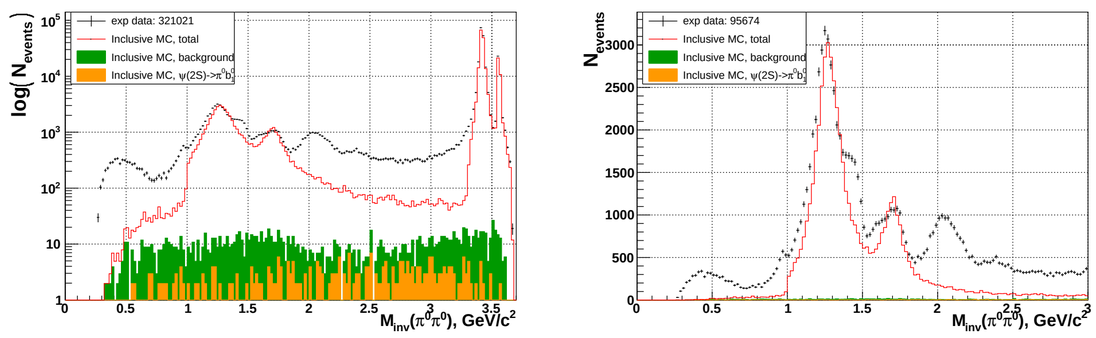

Figure 4: Distribution of the invariant mass of $\pi^0\pi^0$ system

4. PWA (preliminary results)

At this moment, partial wave analysis is in the early state of research. Our plans are to perform both model-dependent and model-independent analyses with the focus on the latter. For more information about these methods see [6] and [7]. Our focus on the model-independent method is motivated by the fact that the simple sum of Breit-Wigner functions provides a poor approximation for the amplitude of the $\pi^0\pi^0$ system. We plan to use results of this fit in the coupled-channel analysis. Here we show the preliminary result for one of our model-dependent fits.

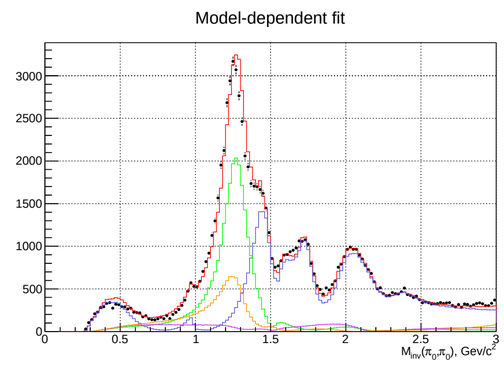

Figure 5: Model-dependent solution which was obtained using K-matrix plus sum of Breight-Wigner functions

5. Future plans

Our plans for the future research are:

- Measure the background from events with $\gamma\pi^0\pi^0\pi^0$ final state using experimental data
- Investigate sources of systematic uncertainties and estimate these uncertainties
- Perform a model-independent amplitude analysis based on selected data
- Search for the tensor glueball using results of the amplitude analysis

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