An amplitude analysis of the $\pi^0\pi^0$ system produced in radiative $\psi(3686)$ decays

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Abstract

A model-independent amplitude analysis of the $\pi^0\pi^0$ system produced in the radiative decays $\psi(3686) \to \gamma\pi^0\pi^0$ is presented. The analysis is based on the unique dataset of $(2712.4 \pm 14.3) \times 10^6$ $\psi(3686)$ decays collected by the BESIII detector. Scalar and tensor partial wave contributions are obtained as piecewise functions of $M_{\text{inv}}(\pi^0\pi^0)$ with minimal model assumptions being made. The observed contribution of the scalar partial wave exhibits similar behaviour to the one reported in the study of radiative J/ψ decays, while the tensor contributions provide no evidence for resonance-like structures except for the clearly visible $f_2(1270)$. The results are supplied in the form of log-likelihood scans in $M_{\text{inv}}(\pi^0\pi^0)$ bins, which preserve all the statistical information as well as account for relevant systematic uncertainties. Provided model-independent description allows to combine presented results with other related data in the process of development of phenomenological models.

1. Introduction

- The search for the particles outside of the conventional quark model – one of the most important tasks within modern Quantum Chromodynamics (QCD) [1].
- Glueballs – colorless bound states of gluons – still remain elusive for the most part.
- Multiple theoretical predictions for masses and widths of glueballs are available, all point to three lightest glueballs ($J^{PC} = 0^{++}, 2^{++}, 0^{-+}$) having mass below 3 GeV/c^2 [2].
- Experimental evidence obtained only for scalar and pseudoscalar glueballs, but not for the tensor one.
- Charmonium annihilation allows for creation of the glue-rich environment, which greatly enhances production rates of glueballs [1].
- The BESIII collaboration has acquired the largest dataset of $\psi(3686)$ decays, which provides access to higher invariant mass range than J/ψ decays.

2. BESIII experiment at BEPCII collider

- The BEPCII is a e^+e^- collider located in IHEP, Beijing, China.
- Energy range of beams in c.m.s. is $\sqrt{s} = 1.84{-}4.95$ GeV, the peak achieved luminosity is 1.1×10^{33} cm^{-2}s^{-1} achieved at $\sqrt{s} = 3.773$ GeV.
- The BESIII is a cylindrically symmetrical general purpose detector located at the interaction point of the BEPCII. Main systems of the detector: multilayer drift chamber, time-of-flight system, electromagnetic calorimeter, superconducting solenoidal magnet (1.0 T), muon system.
- The charged particle momentum resolution at 1 GeV is 0.5%, 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 Ref. [3].

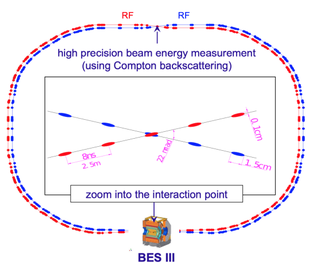

Figure 1: The BEPCII schematic layout.

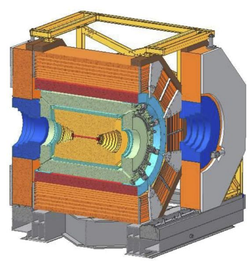

Figure 2: The BESIII layout.

3. Selection results

- Signal events – radiative decays $\psi(3686) \to \gamma X \to \gamma\pi^0\pi^0$.
- Number of initially available $\psi(3686)$ decays – 2712 million, number of selected events – 103018.
- Levels of background contamination: 0.92% – non-5γ events, less than 0.5% – events with $\gamma\pi^0\pi^0\pi^0$ final state, 0.2% – non-resonant background, (0.14 ± 0.01)% – misreconstructed background.

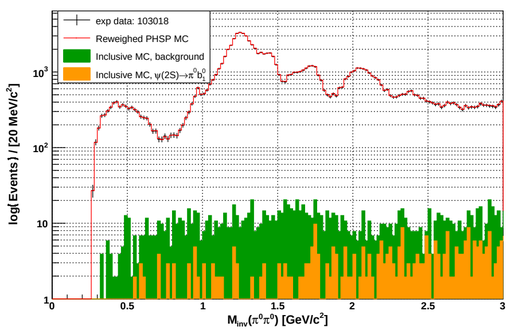

Figure 3: Spectrum of the $M_{\text{inv}}(\pi^0\pi^0)$ after all selection procedures have been applied.

4. Amplitude analysis formalism

- We utilise model-independent approach in the PWA, which was used in multiple BESIII studies (for example, see [4]).
- The method introduces minimal model bias and allows to combine obtained results with other relevant data to develop phenomenological models. Example of such analysis can be found in Ref. [5].
- Factorisation of the decay amplitude in MI approach:

$$U^{M,\lambda_\gamma}(\vec{x}, s) = \sum_{j,J_\gamma} V_{j,J_\gamma} A^{M,\lambda_\gamma}_{j,J_\gamma}(\vec{x}). \tag{1}$$

- The data sample is binned as a function of $\pi^0\pi^0$ invariant mass, with V_{j,J_γ} assumed to be constant in each bin.
- Only 0^{++} and 2^{++} partial waves are taken into account.
- The unbinned extended maximum likelihood method is used for the fitting procedure.
- Two ambiguous solutions arise above rescattering threshold of $M_{\text{inv}}(\pi^0\pi^0) = 0.99$ GeV/c^2.

5. Uncertainties

- Due to the observed non-parabolicity of log-likelihood function, statistical uncertainties are obtained directly from scans of the log-likelihood function, scanned parameters are intensities of each partial wave.
- Systematic uncertainties are divided into two types:
  - Type 1: the same for each bin, can be estimated as a single number. Total is 5.1%.
  - Type 2: must be propagated through the partial-wave analysis procedure.
- For each type 2 uncertainty, a separate fit is performed, with difference in intensities between this fit and nominal solution taken as a variance parameter σ_i.
- Aforementioned scans are convolved with a gaussian function with $\sigma^2 = \sum \sigma_i^2$, resulting in the elimination of ambiguities.

6. Final results

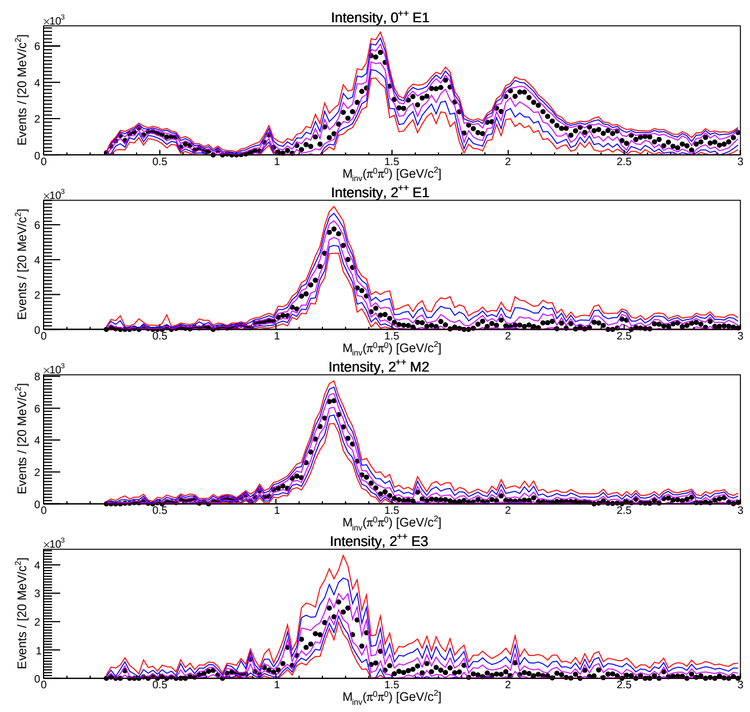

Figure 4: Partial-wave intensities obtained from the PWA.

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[2] Franz Gross et al. "50 Years of quantum chromodynamics". In: *Eur. Phys. J. C* 83.12 (Dec. 2023), p. 1125. ISSN: 1434-6052. DOI: 10.1140/epjc/s10052-023-11949-2. URL: https://doi.org/10.1140/epjc/s10052-023-11949-2.

[3] M. Ablikim et al. "Design and construction of the BESIII detector". In: *Nucl. Instrum. Methods Phys. Res., Sect. A* 614.3 (2010), pp. 345–399. ISSN: 0168-9002. DOI: https://doi.org/10.1016/j.nima.2009.12.050.

[4] M. Ablikim et al. "Amplitude analysis of the $\pi^0\pi^0$ system produced in radiative J/ψ decays". In: *Phys. Rev. D* 92 (5 Sept. 2015), p. 052003. DOI: 10.1103/PhysRevD.92.052003.

[5] A.V. Sarantsev et al. "Scalar isoscalar mesons and the scalar glueball from radiative J/ψ decays". In: *Phys. Lett. B* 816 (2021), p. 136227. ISSN: 0370-2693. DOI: https://doi.org/10.1016/j.physletb.2021.136227.

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