Feasibility studies for $f_0(1500)$ glueball resonance state using PANDARoot

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Introduction

The $\overline{\text{P}}$ANDA (AntiProton Annihilations at Darmstadt) experiment is planned to be operated at the High Energy Storage Ring (HESR) of the Facility for Anti-Proton and Ion Research (FAIR) at Darmstadt to study the interaction of cooled anti-protons with a fixed target. The main objective of this experiment is to study strong interaction in the charm sector to improve our understanding of Quantum Chromodynamics (QCD), with a flux of anti-proton beam having a momentum up to 15 GeV/c [1, 2, 3].

The existence of the bound state of interacting coloured gluons called glueballs is one of the predictions of QCD. With increasing experimental evidences on the predictions of QCD, the search for the detection of the glueballs, an exotic state with no quark content in it has become more interesting and demanding. Experimentally, glueballs are difficult to identify as they easily get mixed up with the nearby meson states. Even then there are many exotic states which are considered as strong glueball candidates. In principle, it is theoretically possible to calculate all the properties of glueballs directly from the equations and fundamental physical constant of QCD without using experimental input. All the phenomenological approaches and lattice QCD calculations have predicted the existence of pure glueballs in the range of 1-3 GeV. The lightest (scalar) glueball is estimated to have a mass in the range from 1 to 2 GeV/c^2 and the pseudoscalar as well as the tensor glueballs are expected to have masses more than 2 GeV/c^2[4].

$\overline{\text{P}}$ANDA is designed to detect these glueball resonances and to measure their masses and other properties. These resonances have short life times. However, the particles into which they decay can be identified and their energies and momenta can be measured. This information then allows us to reconstruct the glueball properties.

Glueball Resonance in PANDA-Root

With the help of appropriate event generation that contains our interested glueball resonance as an intermediate state, a decay channel is chosen to have final states as e^+, μ^+, π^+, k^+ and their charge conjugates. In order to remove unwanted background signals, we assume here that the chosen decay channel has hundred percent probability to occur. These product particles are then identified by considering all the strong interaction conservation rules. These events are generated using Monte Carlo simulation GEANT3 under PANDARoot framework. The process followed to study a particular channel is shown in Figure 1.

We define the glueball state with its proper properties like particle code, mass, width, spin, charge etc. in the PANDARoot off-line package [5]. The energies and momenta of end product particles are used to reconstruct the state at vertex which is the intermediate glueball state as we chosen in decay channel for

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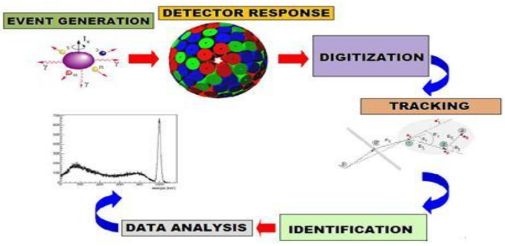

Figure 1: Process flow in PANDARoot simulation

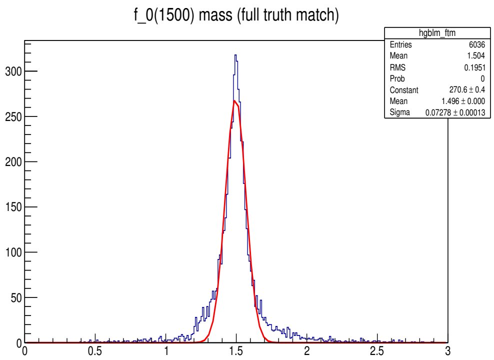

Figure 2: Glueball resonance state $f_0(1500)$ as identified by PANDARoot simulation for 10000 events.

a given number of antiproton-proton collision events. We fit the Gaussian probability distribution on the full truth match energy curves of the identified glueball resonance state. The histogram for the simulated events along with Gaussian probability distribution is given in Figure 2.

From the Gaussian fit, we calculate the full width at half maximum (FWHM) of the glueball resonance state (see in Table 1) as

$$FWHM(\sigma) = \sqrt{8\ln(2)} \cdot \sigma \qquad (1)$$

which is used to determine stability or the decay time of our selected glueball candidate.

The resonance cross-section gives the probability of the glueball resonance of chosen decay channel and is obtained with the help of

Table 1: Comparison of the width of $f_0(1500)$ obtained from the PANDARoot simulation with Particle Data Group (PDG) data.

Glueball Resonance State	$I^G J^{PC}$	Decay into	Simulation FWHM (MeV)	PDG Width (MeV)
$f_0(1500)$	0^+0^{++}	$\pi^+\pi^-$	171 ± 13	114 ± 30 (OBLX)

Table 2: Cross-section of $f_0(1500)$ using Breit-Wigner formula.

Glueball Resonance State	J	final state particles	$\mathcal{B}(I \to R \to F)$ $\times 10^{-4}$ (PDG)	cross-section σ_{BW} (nb)
$f_0(1500)$	0	$\pi^+\pi^-$	1.09 ± 0.24	105.8104

Breit-Wigner formula [6, 7] (see in table 2) as

$$\sigma_{BW} = 4\pi \frac{2J+1}{E_{cm}^2 - (2m_p)^2} \mathcal{B}(I \to R \to F) \quad (2)$$

Where J is an isolated spin of the resonant particle, m_p is the mass of the proton (or antiproton), E_{cm} is fixed centre-of-mass energy of proton-antiproton system, and $\mathcal{B}$ represent the branching fraction and I, R and F represent the initial, resonance and final state of the decay channel respectively.

Conclusion

In the present study, we have identified $f_0(1500)$ as a possible glueball state and its energy and widths are tabulated. Further, the production cross sections of these states are also computed as a sample study.

References

[1] B. Singh et al.($\overline{\text{P}}$ANDA Collaboration). Phys. Rev. D **95** 032003 (2017).
[2] B. Singh et al.($\overline{\text{P}}$ANDA Collaboration). Eur. Phys. J. A **52** 325 (2016).
[3] B. Singh et al.($\overline{\text{P}}$ANDA Collaboration). Eur. Phys. J. A **51** 107 (2015).
[4] V. Crede, C.A. Meyer, Progress in Particle and Nuclear Physics **63** 74 (2009).
[5] Tutorial on PANDARoot Simulation and Analysis (2013).
[6] Elisabetta Prencipe. AIP Conf. Proc. **1735** 060011 (2016).
[7] Francesco Giacosa. J. of Phys. conf. Series **599** 012004 (2015).