Search for $\psi(3770)$ in its decay to D^+D^-

Summer Student Project

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1 Introduction

Despite the fact that the $\psi(3770)$ resonance has been measured relatively well [1] at e^+e^- colliders, it has never been observed in hadron colliders. $\psi(3770)$ decays mostly into correlated $D\bar{D}$ pairs with $D_0\bar{D}_0(52\%)$ and $D^+D^-(41\%)$ contributions [2]. The information from these quantum correlated D's coming from the $\psi(3770)$ can be used to reduce the uncertainty on the γ CP violation parameter of the Unitary Triangle [3], one of the primary goals of the LHCb experiment. So far the efforts in identifying a $\psi(3770)$ signal have unsuccessfully been concentrated in the decay channels most useful for the γ measurement. On the other hand in this analysis we have searched for the $\psi(3770)$ in its decay to D^+D^- pair and their further decays to $K^-\pi^+\pi^+$ and $K^+\pi^-\pi^-$. The high final state multiplicity implies a lower overall detection efficiency compared to other decay channels such as $D_0\bar{D}_0$ in K-π pairs. Furthermore this search suffers from a higher contribution of combinatorial background.

2 A few words about the LHCb experiment

The LHCb detector is a single-arm forward spectrometer [4] detecting particles with a pseudorapidity in the range $1.6 < \eta < 4.9$ [5]. In this report we used data in the pseudorapidity range $2.0 < \eta < 4.5$. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector (VELO) [6], a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of abut 4 Tm, and three stations of silicon-strip detectors and straw drift tubes [7] placed downstream of the magnet. The VELO provides precise measurements of track coordinates close to the pp interaction region, which are used to identify the displaced secondary vertices which are a distinctive feature of b- and c-hadron decays.

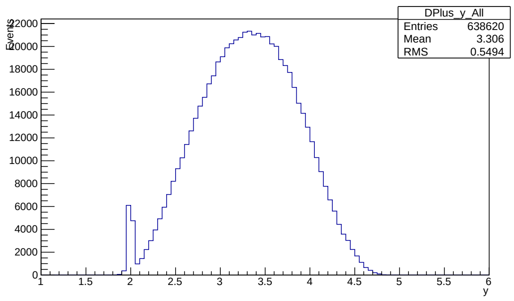
$\psi(3770)$ decays almost immediately to D^+D^- pair. The D-mesons fly a little before they decay to a kaon and two pions. Kaons and pions have relatively long lifetime they are key particles for the reconstruction of physics data.

3 Analysing the data to find $\psi(3770)$ 101

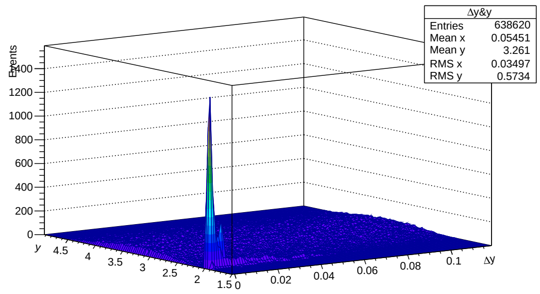
We used two LHCb standard pre-selections of LHCb 2012 data in this project: PsiCCLine and PsiDiCharmLine. The two pre-selections apply standard quality and kinematic cuts to the D^+ and D^-. The most important difference between them is the second requires one of the two D-mesons to have a p_t of at least 3 GeV/c. As it turned out later the data from this pre-selection is much more interesting for searching $\psi(3770)$ than the first one.

The selection of di-mesons begins by requiring six reconstructed tracks that incorporate VELO information. As mentioned the analysis is performed in the fiducial region where each meson has a rapidity between 2.0 and 4.5. For the PsiCCLine pre-selection the rapidity and pseudorapidity distributions show an unexpected peak around η or $y = 2$, Fig.1(a). This peak can be explained as originating from cloned particles, where the D^+ and D^- are formed from the same tracks with different particle assignment. This is confirmed in Fig.1(b), where the correlation between the D^+ rapidity and the rapidity difference between the two D shows a peak at $y = 2$ and Δy $= 0$. It is not yet understood why these cloned particles appear exactly in this region and only in the PsiCCLine.

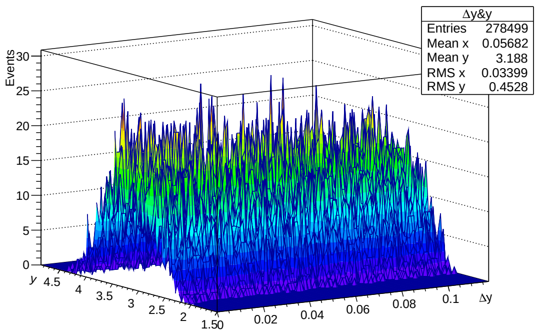
To remove this source of background we required the 2 D-mesons to be in the range $0.003 < \Delta$y< 0.12 where the left limit removes the peak, as shown in Fig.1(d).



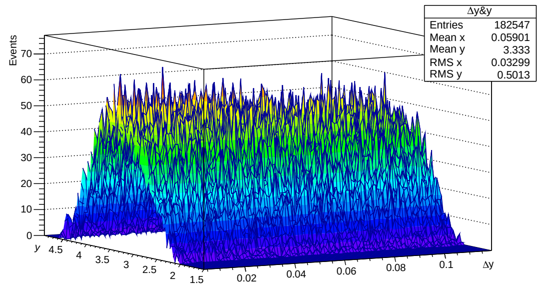
(a) D y for PsiCCLine events



(b) y vs Δy for PsiCCLine events



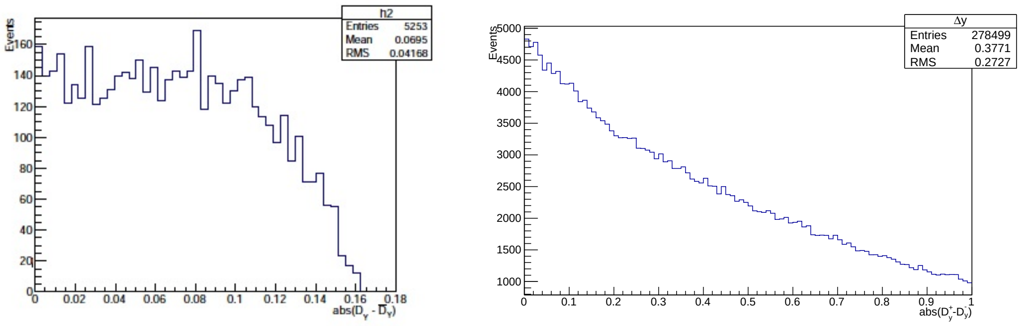
(c) y vs Δy for PsiDiCharmLine events



(d) y vs Δy for PsiCCLine events after selection

Figure 1: Rapidity for PsiCCLine events (a). Dependence y vs Δy for the two preselections in the Δy range: PsiCCLine (b) and PsiDiCharmLine (c) without requirements, PsiCCline after requiring Δy between 0.003 and 0.12 (d). The background contribution at y=2 is removed by these requirements.

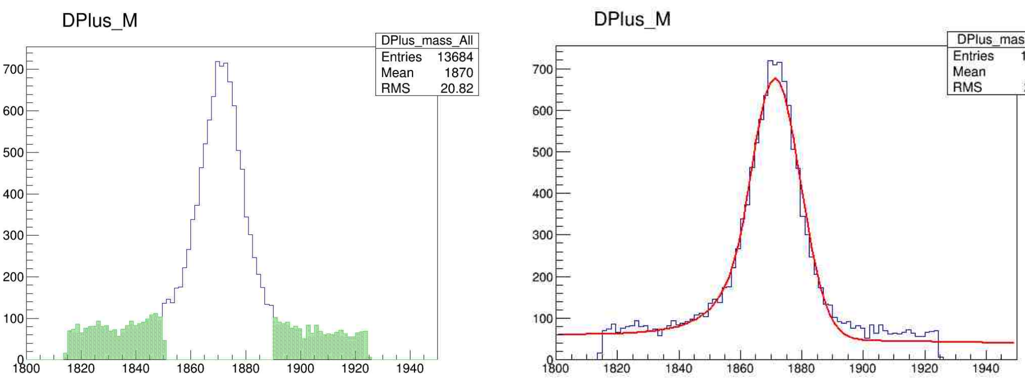
The value for the right limit for Δy is obtained from $\psi(3770)$ simulation, which shows there are no signal events for Δy> 0.16. (Fig.2 is a result of simulation courtesy of Daniel Souza [3]).



(a) simulation (b) data

Figure 2: $D^+ D^-$ Δy distribution for simulated (a) and real (b) data

Another kind of background affected this analysis: combinatorial background. This was removed using the sideband (SB) subtraction method, Fig.3(a). The background distribution is obtained from the sidebands. The D mesons invariant mass distribution is fitted to estimate the signal and background. The signal is described by a Crystal Ball function, the background by a first order polynomial, Fig.3(b). The rescaled SB distribution is subtracted from the total distribution to obtain the distribution for the signal.



(a) D invariant mass with sidebands (b) D invariant mass with fit superimposed

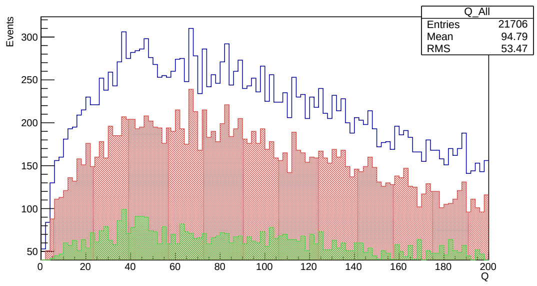
Figure 3: Sideband and fit used to subtract the combinatorial background

A further reduction of the combinatorial background is achieved requiring that the $\psi(3770)$ Q-value, ($Q = M_\psi$ - M_{D+} - M_{D-}) is < 200 MeV: it is clear that if the D^+D^- pair was originated from $\psi(3770)$ decays the difference between those masses can't be very large. To increase the probabilty the K and 2π were indeed produced in a D meson decay the χ^2 of each D vertex is required to be < 6.5. Finally the D p_t is chosen > 1300 MeV/c.

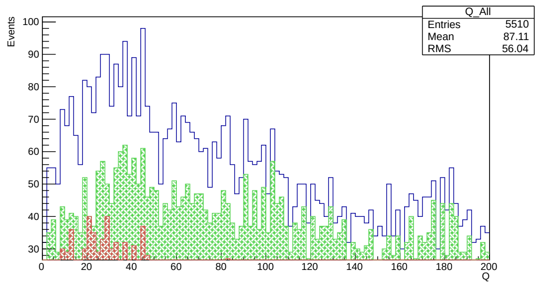
We also tried to remove this background selecting events with D-mesons with large flying distance, however this affected the signal efficiency as well and this criteria was not used for the final results.

4 Result

As it was mentioned before the PsiCCLine pre-selection does not provide useful results as shown in Fig.4(a): while it is richer in signal it is also affected by a much larger background. Further studies to determine selection criteria are needed to use it. After our selection criteria, and having subtracted the combinatorial background from the PsiDiCharmLine pre-selection the Q-value distribution, Fig.4(b), shows an increase near $Q = 40$ MeV, where it is expected.



(a) Q for PsiCCLine



(b) Q for PsiDiCharmLine

Figure 4: The Q-value distribution: blue all events, brown background events, green signal after background subtraction

5 Conclusion

While we have not been able to clearly identify the decay of $\psi(3770)$ in D^+D^- pairs, the increase at the correct value of the Q-distribution shows promise. Further studies to improve the selection criteria to isolate the $\psi(3770)$ peak are left to the next generation of summer students.

References

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[7] R. Arink et al., Performance of the LHCb Outer Tracker, arXiv:1311.3893.