Charm Tags

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1 Charm Physics at Threshold

BEPCII will run at charm threshold, it provide a unprecedented physics opportunities to study the weak decay of charm mesons. Only the $D^0\overline{D^0}$ and D^+D^- are pair produced with no other particle involved at the resonance of $\psi(3770)$. This provide extremely clean and pure charm signal. The large cross section of $\psi(3770)$, large decay fractions and high tagging efficiencies allow us to reconstruction the both D's. Lots of systematic uncertainties will be canceled out while applying the double tag method. The quantum coherence of the two initial state D mesons for $\psi(3770)$ allows both simple and sophisticated methods to measure $D^0 - \overline{D^0}$ mixing parameters, strong phase, CP eigenstate branching fractions and CP violation.

2 The Tagging Technology

The general technique used in charm physics study is referred to as tagging. Since the $D\overline{D}$ are pair produced in charm threshold, fully reconstructing a D decay from a subset of tracks in an event therefore guarantees that the remaining tracks originated from the recoiling $\overline{D}$. The reconstructed D is referred to as the tagged D or simply the tag, while everything not associated with the tag is referred to as recoil. Once a tag has been obtained, the recoil track can be analyzed for the decay modes of interest. Usually, Cabibbo favored hadronic decay modes, such as: $D^0 \to K^-\pi^+(\sim 4\%)$, $D^0 \to K^-\pi^+\pi^+\pi^-(\sim 8\%)$, $D^0 \to K^-\pi^+\pi^0(\sim 14\%)$, $D^+ \to K^-\pi^+\pi^+(\sim 9\%)$, $D^+ \to \overline{K^0}\pi^+(\sim 3\%)$, $D^+ \to \overline{K^0}\pi^+\pi^0(\sim 14\%)$,$D^+ \to \overline{K^0}\pi^+\pi^+\pi^-(\sim 6\%)$, $D^+ \to K^-\pi^+\pi^+\pi^0(\sim 6\%)$ and $D_s^+ \to K^-K^+\pi^+(\sim 5\%)$, $D_s^+ \to \overline{K^0}K^+(\sim 4\%)$, and some D_s^+ decays into final state with η/η''s etc, with large branching ratios, are selected to be as the flavor tags.

2.1 Tag Reconstruction

Tag reconstruction begins with the charged track selection. All charged tracks must have a good helix fit, and are required to be measured in the reliable region of drift chamber. Their parameters must be corrected for energy loss and multiple scattering according to the assigned mass hypotheses. Tracks not associated with K_S^0 reconstruction are required to be originate from the interaction point. To reduce the combinatoric background Kaons and pions are well identified by the PID algorithm.

Neutral kaon candidates are mainly reconstructed through the decay of $K_S^0 \to \pi^+\pi^-$. The decay vertex formed by the $\pi^+\pi^-$ pair is required to be far away from the interaction point, and the momentum vector of $\pi^+\pi^-$ pair must be aligned with the position vector of the decay vertex to the interaction point. The $\pi^+\pi^-$ invariant mass is required to be consistent with the K_S^0 nominal mass. The track parameters and the error matrices are recalculated at the secondary vertex. The K_L^0 tag in some double tag analysis is reconstructed by the requirements of the recoil mass of all detected particle is within the range of K_L^0 nominal mass and the interaction in EMC or muon counter is observed in a confined region.

The neutral pions are reconstructed from $\pi^0 \to \gamma\gamma$ decays using the photons observed in the good barrel and endcap regions of EMC. At the energies of interest, a π^0 decays into two isolated photons. In the identification of neutral tracks in the EMC, one has to address a number of processes which can produce both real and spurious showers. The major source of these "fake photons" arised from hadronic interaction between π's or K's and the material before or in the crystals, the secondary particles from these interaction can "split-off" and create a shower which the pattern recognition does not associate to the main shower. Other source of fake photon are particle decays, back splash, beam associated background and electronic noise. A shower is selected as an isolated photon by requirements of a deposit energy cut, e.g. $E_\gamma > 40$MeV and a spatial cut far away from the nearest charged tracks. In addition we also reconstruct η/η' candidates in the modes of $\eta \to \gamma\gamma$, $\eta \to \pi^+\pi^-\pi^0$, $\eta' \to \gamma\rho^0$ and $\eta' \to \eta\pi^+\pi^-$. For these modes, 3σ consistency with the $\pi^0/\eta/\eta'$ mass is required, followed by a kinematic mass constraint.

Finally for the full D reconstruction, all tracks with consistent mass hypotheses and, if appropriate, reconstructed K_S^0's, π^0's and η/η''s are permuted to form the candidate combinations. To be accepted as D tags, candidate combinations of final particles with the reconstructed total energy E_D, total momentum p_D must fulfill the ΔE requirements, the energy difference $\Delta E = E_D - E_{\rm beam}$ of a D candidate is consistent with zero.

2.2 Beam constrained mass

The conventional method of observing resonant signals in particle physics analyses is by selecting a set of tracks and studying the invariant mass ($M_{\rm inv}$):

$$M_{\rm inv} = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p_i}\right)^2} \tag{2.1}$$

where $(E, \vec{p})_i$ are the energy and three-momentum of track i. For reconstructing D decays at the $\psi(3770)$ at BESIII, the resolution of the invariant mass is typically 6 to 8 MeV if the modes contain only charged tracks and somewhat worse, 12 MeV, if the modes contain a π^0. The resolution is largely due to errors on the momentum and not to errors on the track angles. Improvements can be obtained by exploiting the pair production of kinematic of D mesons near threshold. Since the D's are pair produced and the laboratory frame is also the rest frame of the $D\overline{D}$ system, each D is produced with an energy equal to that of the beam in the laboratory frame. Another mass quatity known as the beam constrained mass($M_{\rm bc}$) can therefore be constructed by replacing the energy of the D (E_D) with the energy of the beam ($E_{\rm beam}$):

$$M_{\rm bc} = \sqrt{E_{\rm beam}^2 - \left(\sum_i \vec{p_i}\right)^2} = \sqrt{E_{\rm beam}^2 - p_D^2} \tag{2.2}$$

This mass quantity is simply a function of the total momentum of the decay products, $p_D = \sum_i \vec{p_i}$. The resolution of $M_{\rm bc}$ can be calculated by

$$\delta M_{\rm bc} = \frac{E_{\rm beam}}{M_{\rm bc}} \delta E_{\rm beam} \oplus \frac{p_D}{M_{\rm bc}} \delta p_D \tag{2.3}$$

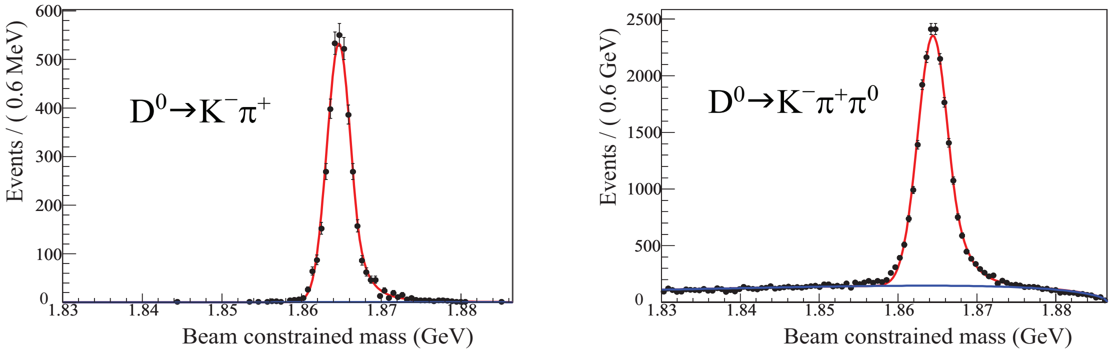

Figure 2.1: Beam constrained mass distribution for the tags of $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^0$. The red curves show the sum of signal and background functions. The blue curves indicate the background fits.

Because of the smaller energy spread of the beam ($\delta E_{\rm beam} \sim 0.9$ MeV) and the low value of $p_D(\sim 270$MeV/c for the D^0, ~ 242 MeV/c for the D^+) and its error, $\delta p_D \sim 5$ MeV, resolution of $M_{\rm bc}$ are of the order 1.2−2 MeV.

Another advantage of having a second independent mass variable lies in the reduction of background from misidentification. The total energy (or the invariant mass) is sensitive to the mass hypotheses made on the decay products, while the beam constrained mass quantity requires that they have the correct momentum (the measured momentum is dependent on the mass hypotheses only to the extent that the small dE/dx correction are mass dependent). Imposing a cut to ΔE, leave the $M_{\rm bc}$ to be examined to search for a "signal"; Fitting to the plot of ΔE and $M_{\rm bc}$ simultaneously can improve the ratio of signal to background.

2.3 Multiple Counting

One event could be counted more than once as a tag candidate. The multiple counting can occur in two ways:

1) Two or more different tag channels can be reconstructed for a give event; this can occur, for example, when both D's in an event can be reconstructed.

2) Two or more possible combinations of tracks can yield a consistent tag for a given channel; tag modes with higher multiplicity like $D^+ \to \overline{K^0}\pi^+\pi^+\pi^-$ and those containing π^0's tend to be more susceptible to this problem.

To count the actual number of tagged events in an unbiased manner, the following criteria is used to select only one tag combination per event:

1) If more than one tag channel can be reconstructed, select the channel with the largest signal-to-noise ratio.

2) For all tags containing charged track only, if more than one combination of tracks form the tag, choose the combination whose lowest momentum track has the largest momentum of all the combinations.

3) For all tags containing neutrals, if more than one combination of photon pair can reconstruct the tag, choose the combination with the lowest χ^2 from the π^0 fit, or choose the combination whose lowest energy track has the highest energy of all the combinations.

The item 2) and 3) is based on the fact that the tracking efficiency is higher for high momentum/energy track, and the measurement is more reliable.

2.4 Mass plots fitting

After the selection procedure described in Sec. 2.1, Sec. 2.2 and Sec. 2.3, the result mass plot of beam constrained mass are drawn in Figure 2.1. The number of tags is determined by a extended unbinned maximum likelihood fit to a signal function on the top of background. The background shape is represented by the well known Argus function[1] which is an empirical formula to model the phase space of multi-body decays near threshold and is frequently used in B physics. The Argus function take the following form:

$$\mathcal{B}(M_{\rm bc}) = M_{\rm bc}\left[1-\left(\frac{M_{\rm bc}}{E_{\rm beam}}\right)^2\right]^p \cdot \exp\left(c\left[1-\left(\frac{M_{\rm bc}}{E_{\rm beam}}\right)^2\right]\right) \tag{2.4}$$

where p is for the power term(usually take its value as 0.5); c is a scale factor for exponential term. The shape parameters are determined by fitting $M_{\rm bc}$ distribution selected by the ΔE sidebands.

There is a tail towards the high-end of $M_{\rm bc}$ in the signal distribution, which is caused by the initial state radiation(ISR). The effect of ISR, the resonant parameters and the lineshape of $\psi(3770) \to D\overline{D}$, the beam energy spread and the detector resolution can contribute to the signal shape, usually it takes the form of CBL[2] as:

$$\mathcal{S}(M_{\rm bc}) = \begin{cases} A\cdot\exp\left[-\frac{1}{2}\left(\frac{M_{\rm bc}-M_D}{\sigma_{M_{\rm bc}}}\right)^2\right] & \text{for } M_{\rm bc} < M_D - \alpha\cdot\sigma_{M_{\rm bc}} \\ A\cdot\frac{\left(\frac{n}{\alpha}\right)^n \exp\left(-\frac{1}{2}\alpha^2\right)}{\left(\frac{M_{\rm bc}-M_D}{\sigma_{M_{\rm bc}}}+\frac{n}{\alpha}-\alpha\right)^n} & \text{for } M_{\rm bc} > M_D - \alpha\cdot\sigma_{M_{\rm bc}} \end{cases} \tag{2.5}$$

which is similar to that used for extracting the photon signal from electromagnetic calorimeters. In Eq. (2.5), the normalized constant $A^{-1} = \sigma_{M_{\rm bc}}\cdot\left[\frac{n}{\alpha}\cdot\frac{1}{n-1}\exp\left(-\frac{1}{2}\alpha^2\right)+\sqrt{\frac{\pi}{2}}\left(1+\text{erf}\left(\frac{\alpha}{\sqrt{2}}\right)\right)\right]$, where M_D is the "true" (or most likely) mass, $\sigma_{M_{\rm bc}}$ is the mass resolution, and n and α are parameters governing the shape of the high mass tail.

3 Double Tags

move to Absolute Branching ratio measurements in Chapter of Hadronic Decay

4 CP Tags

Is it described in chapter of Mixing and CP violation?

5 Charm Tagging above the threshold

move to the Chapter of Charm cross section measurement

6 Tag efficiencies and Charm event rate

References

[1] H. Albrecht et al. Phys. Lett. B **241**, 1990 (278)

[2] T. Skwarnicki, "A study of the Radiative Cascade Transitions between the Upsilon-Prime and Upsilon Resonances", DESY F31-86-02(thesis, unpublished) (1986)