$D\bar{D}$ Shape

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BESIII

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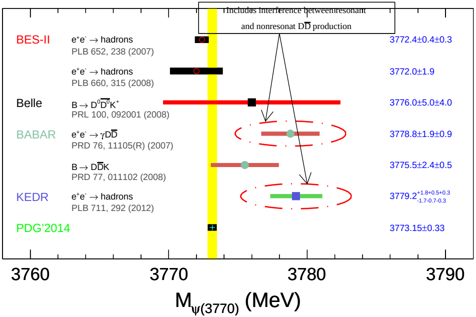
Outline

1. Introduction
2. Analysis
3. Summary

Introduction

- Since the discovery of ψ(3770), it is a long-standing puzzle in understanding of ψ(3770) production and decays



- Discrepant results of ψ(3770) parameters are observed
  Model? Interference?

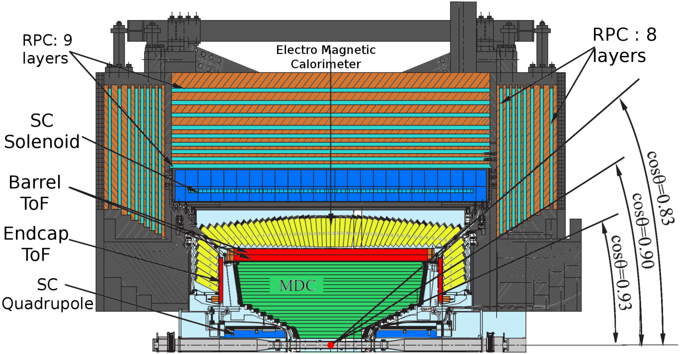
- Analyze $D\bar{D}$ shape around ψ(3770) at BESIII with higher statistic

BESIII Experiment

BEPCII Collider

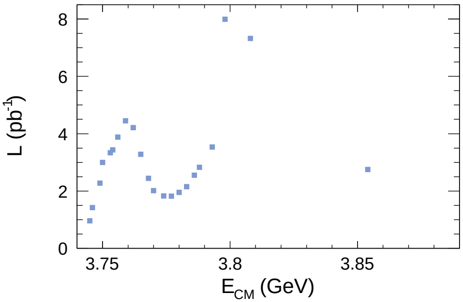
- symmetric e^+e^- collider, double-rings, 2.0 GeV $< E_{\mathrm{CM}} <$ 4.6 GeV

BESIII Detector



Data Sets

- $\psi(3770)$ Scan Data
  - $\sim 70\ \text{pb}^{-1}$, $3.74 < E_{\text{CM}} < 3.89$ GeV
  - Luminosity ($\mathcal{L}$) is determined using large-angle Bhabha scattering events



- Monte Carlo Simulation
  1. $\psi(3770) \to D^0\bar{D}^0, D^+D^-$
  2. $e^+e^- \to q\bar{q}, \tau^+\tau^-, \gamma_{\text{ISR}}J/\psi, \gamma_{\text{ISR}}\psi(2S)$

Reconstruction of D Mesons

- The cross sections for $e^+e^- \to D\bar{D}$ are measured using single tag method
- Tag modes (charge conjunction is implied):

$$\begin{array}{lll} D^0 \to K^-\pi^+ & D^+ \to K^-\pi^+\pi^+ & D^+ \to K^0_S\pi^+\pi^0 \\ D^0 \to K^-\pi^+\pi^0 & D^+ \to K^-\pi^+\pi^+\pi^0 & D^+ \to K^0_S\pi^+ \\ D^0 \to K^-\pi^+\pi^+\pi^- & D^+ \to K^+K^-\pi^+ & D^+ \to K^0_S\pi^+\pi^+\pi^- \end{array}$$

- Define variables:

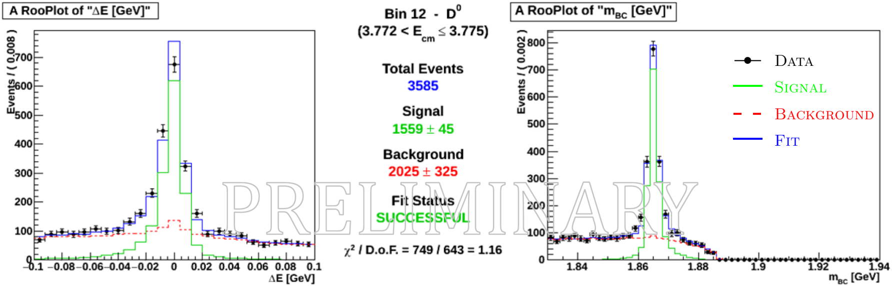
$$\Delta E = E_{\mathrm{tag}} - E_{\mathrm{beam}}$$

$$m_{\mathrm{BC}} = \sqrt{E^2_{\mathrm{beam}} - |\vec{p}_{\mathrm{tag}}|^2}$$

Select D candidate with ΔE closest to 0 for each mode

Extraction of Signal Yields

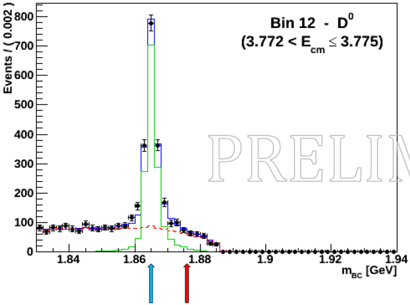
- Signal yield (N_{tag}) is extracted from a maximum-likelihood fit to the 2D distribution in ΔE vs. m_{BC}
  - Signal and background PDFs are formed from MC simulation
  - Float normalization of signal and background



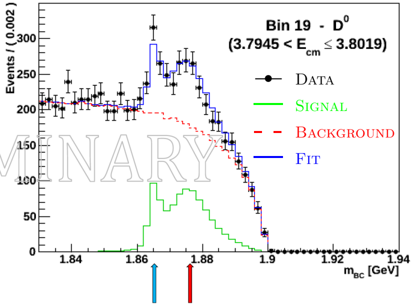
Changes in m_{BC} Shapes due to ISR Effect

- Two peaks seen in higher beam energy m_{BC} distribution

At $\psi(3770)$ peak



Just above Born-Level vanishing



Left Peak — Events from Born Level contribution

Right Peak — Events from ISR contribution

Cross Section

Reconstruction Efficiency

- Tag efficiency (ϵ_i) for each mode is determined from MC simulation via $\epsilon_i = N_i^{\mathrm{found}}/N_i^{\mathrm{generated}}$ and then weighted by the branching fraction of mode i ($\mathcal{B}_i$) to obtain the average efficiency

$$\epsilon = \sum_i \epsilon_i \mathcal{B}_i$$

- $\epsilon^0_{\mathrm{tag}} = (11.3 \pm 0.2)\%$, $\epsilon^+_{\mathrm{tag}} = (9.8 \pm 0.1)\%$
(the branching fractions of sub-resonance decays are included)

Calculation of Cross Section

$$\sigma^{\mathrm{RC}}_{D\bar{D}}(E_i) = \frac{N_{\mathrm{tag}}(E_i)}{2\epsilon_{\mathrm{tag}}\mathcal{L}(E_i)}$$

Fits to Cross Sections

Fit the measured $D^0\bar{D}^0$ and D^+D^- cross sections simultaneously using the theoretical cross sections

$$\sigma^{\mathrm{RC}}_{D\bar{D}}(W) = \int z_{D\bar{D}}(W\sqrt{1-x})\,\sigma_{D\bar{D}}(W\sqrt{1-x})\,\mathcal{F}(x, W^2)\,dx$$

$z_{D\bar{D}}$ Factor describing Coulomb interaction

$\mathcal{F}(x, s)$ Probability to lose a fraction of s in initial state radiation

$$\sigma_{D\bar{D}}(W) = \frac{\pi^2\alpha}{3W^2}\beta_D^3|F_D(W)|^2,\ F_D(W) = F_D^{\mathrm{R}}(W)e^{i\phi_{\mathrm{R}}} + F_D^{\mathrm{NR}}(W)$$

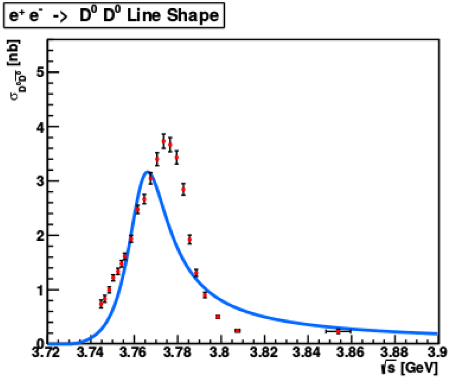
- Use Breit-Wigner formula for resonant component

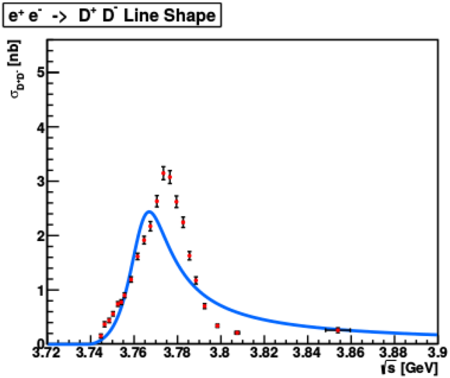
$$F_D^{\mathrm{R}}(W) = \frac{6W\sqrt{(\Gamma_{ee}/\alpha^2)(\Gamma_{D\bar{D}}(W)/\beta_D^3)}}{M^2 - W^2 - iM\Gamma(W)},\ \Gamma_{D\bar{D}}(W) = \Gamma(W)\times(1-\mathcal{B}_{nD\bar{D}})$$

- Analyze two models for non-resonant component
  Exponential Model - $F_D^{\mathrm{NR}}(W) = F_{\mathrm{NR}}\exp(-q_D^2/\alpha_{\mathrm{NR}}^2)$
  Vector Dominance Model (VDM) - $F_D^{\mathrm{NR}}(W) = F_D^{\psi(2S)}(W) + F_0$

Fits to Cross Sections

Single Breit-Wigner Shape

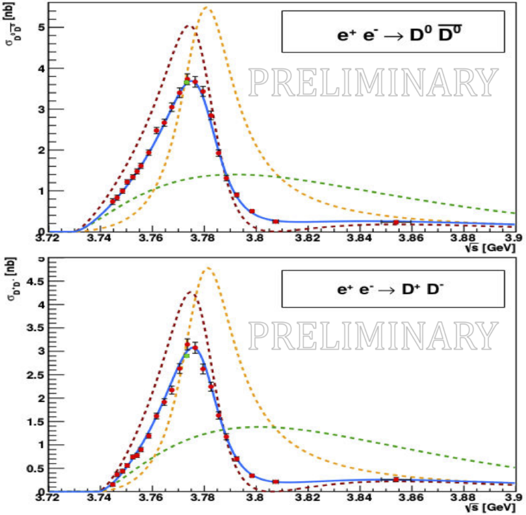




- Single Breit-Wigner formula is unable to describe data

Fits to Cross Sections

Exponential Model



Exponential Fit Results

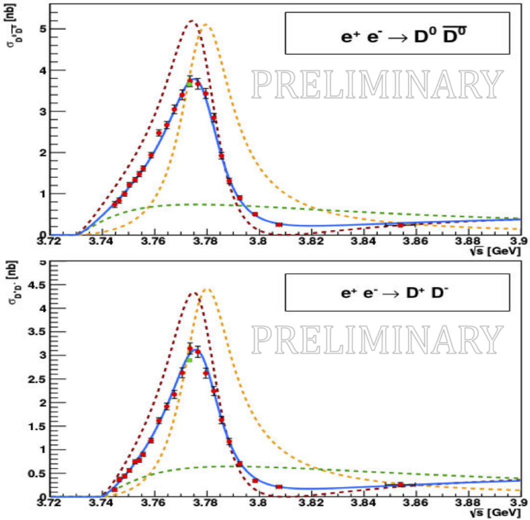
- Data
- Fit $\sigma^{RC}_{D\bar{D}}$
- σ_{Born}
- Resonant - $\psi(3770) \to D\bar{D}$
- Non-resonant - Exponential
- BESIII On-peak Data [2.92 fb^{-1}]

$$M^{\psi(3770)} = (3.7830 \pm 0.0003)$$
$$\Gamma^{\psi(3770)} = (2.7540 \pm 0.0935) \times 10^{-2}$$
$$\Gamma^{\psi(3770)}_{ee} = (2.7012 \pm 0.2392) \times 10^{-7}$$
$$\phi^{\psi(3770)} = (3.8984 \pm 0.0819)$$
$$F_{NR} = (-2.5593 \pm 0.0862) \times 10$$
$$a_{NR} = (4.0560 \pm 0.1175) \times 10^{-1}$$

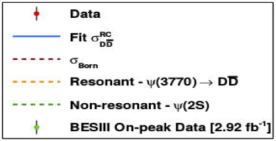
$$\chi^2 / \text{D.O.F.} = 48 / 38 = 1.26$$

Fits to Cross Sections

Vector Dominance Model



VDM Fit Results



$M^{\psi(3770)} = (3.7815 \pm 0.0003)$

$\Gamma^{\psi(3770)} = (2.5244 \pm 0.0683) \times 10^{-2}$

$\Gamma^{\psi(3770)}_{ee} = (2.2993 \pm 0.1800) \times 10^{-7}$

$\phi^{\psi(3770)} = (3.6388 \pm 0.0785)$

$\Gamma^{\psi(2S)} = (2.0895 \pm 0.1784) \times 10^{-2}$

$F_0 = (-1.8035 \pm 0.4623)$

χ^2 / D.o.F. = 50 / 38 = 1.33

Preliminary Results and Comparisons

- Use $\Gamma_{ee}^{\psi(3770)\to D\bar{D}} = \Gamma_{ee}^{\psi(3770)} \times \mathcal{B}(\psi(3770) \to D\bar{D})$
  - Remains constant from fit independent of branching fraction
- Preliminary results of $\psi(3770)$ parameters (errors are only statistical)

Source	$M^{\psi(3770)}$[MeV / c^2]	$\Gamma^{\psi(3770)}$[MeV]	$\Gamma_{ee}^{\psi(3770)\to D\bar{D}}$[eV]
Exponential	3783.0 ± 0.3	27.5 ± 0.9	270 ± 24
VDM	3781.5 ± 0.3	25.2 ± 0.7	230 ± 18
KEDR	$3779.3\,^{+1.8}_{-1.7}$	$25.3\,^{+4.4}_{-3.9}$	$160\,^{+78}_{-58}$, $420\,^{+72}_{-80}$
PDG	3773.2 ± 0.3	27.2 ± 1.0	$[262 \pm 18] \times B_{D\bar{D}}$ †

PRELIMINARY

† $B(\psi(3770) \to D\bar{D})$

- Preliminary results of $\psi(3770)$ parameters are consistent with those measured at KEDR

Systematics

- Expect statistics-limited result due to scan data size
  - Systematics evaluation still in progress
- Current main sources (ranked by contribution to total)
  1. Meson radii used for $\psi(2S)$ and $\psi(3770)$
  2. Charged tracking
  3. Neutral tracking
  4. Luminosity
- Negligible effect seen when altering $\mathcal{B}(\psi(3770) \to D\bar{D})$
  - All parameters remain constant except $\Gamma_{ee}^{\psi(3770)}$
    - Scales inversely to input branching fraction

Summary

- Cross sections for $e^+e^- \to D\bar{D}$ in the vicinity of the $\psi(3770)$ are studied at BESIII
- Able to well fit the $D\bar{D}$ line shape near $\psi(3770)$ with interference based models
  - Both exponential model and vector dominance model provide quality description of data
- Upcoming aspects
  1. Finalize estimation of systematic uncertainty
  2. Compare to alternate models