Measurement of $D\overline{D}$ Decays from the $\psi(3770)$ Resonance

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Overview

1. Introduction
2. Theoretical Background
3. Accelerator and Detector
4. Analysis Software
5. Measurement of the $D\overline{D}$ Cross Section
6. Measurement of the Non-$D\overline{D}$ Branching Fraction
7. Conclusion

Introduction

Introduction

Describe basic meaning of $\psi(3770) \to D\overline{D}$ cross section

Previous Measurements

Show list of previous experimental results

Explain need for interference

Really Quick Overview

Describe need to measure decay products
Describe background subtraction
Describe getting counts to determine cross section

Theoretical Background

Fundamental Forces

1) Electromagnetic (QED)

- Responsible for attracting / repelling electrically charged objects
- Mediated by the massless photon (γ)
- Very precisely calculable using perturbation theory

2) Weak

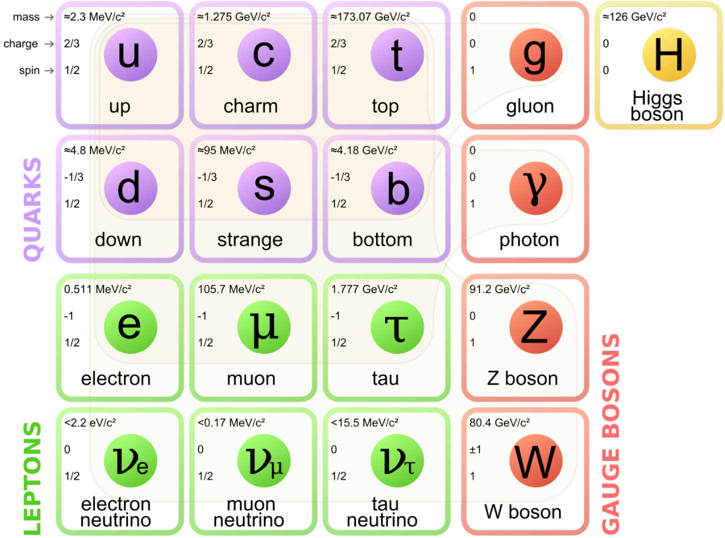
- Responsible for radioactive decays and flavor changes
- Mediated by the very heavy $W^{\pm}$ and Z
- Led to discovery of C and CP violation

3) Strong (QCD)

- Responsible for binding together hadrons
- Mediated by the massless gluon (g)
- Complicated calculations not described by perturbation theory

~~4) Gravity~~ *Negligible at this mass scale*

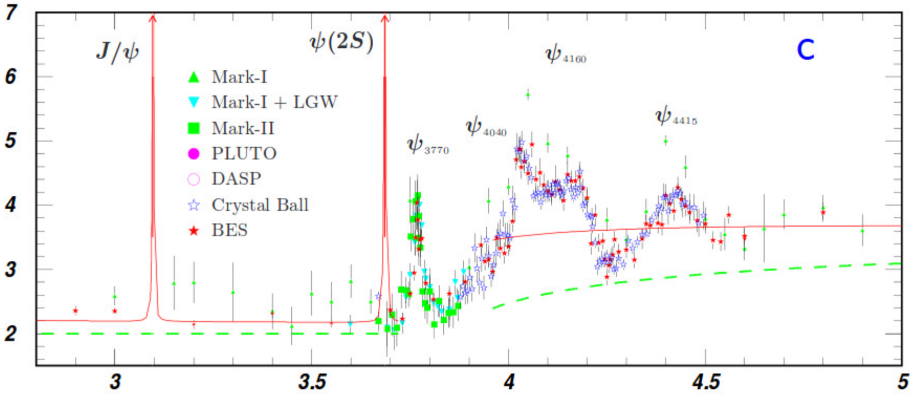
Standard Standard Model Slide



Charmonium

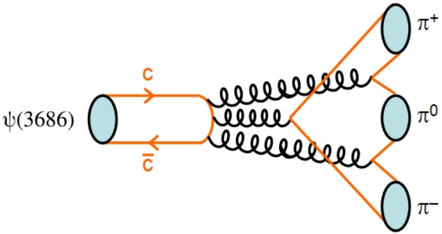
Resonances formed by a $c\bar{c}$ pair: J/ψ, $\psi(2S)$, $\psi(3770)$, ...

- $\psi(2S)$ and $\psi(3770)$ originally interpreted as excited states of J/ψ
- Evidence of mixed-states suggests more complicated picture



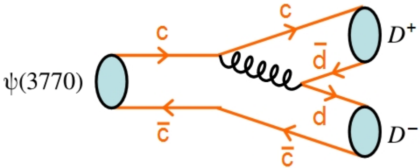
OZI Rule

$\psi(2S)$



- Requires three gluons for decay
- Very narrow decay width
  - $\Gamma_{\psi(2S)} = 0.286\,\text{MeV}$

$\psi(3770)$



- Decays via open charm ($D\overline{D}$)
- Much wider decay width
  - $\Gamma_{\psi(3770)} = 27.5\,\text{MeV}$

Addition of $D\overline{D}$ decays introduces drastically different behavior!

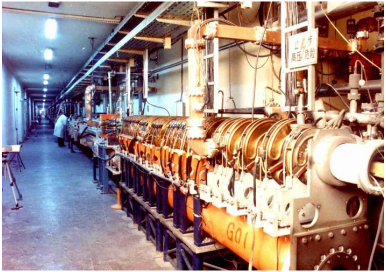
Accelerator and Detector

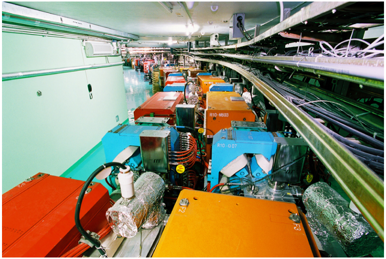
Institute of High Energy Physics (IHEP)

BESIII is hosted at the IHEP Campus located in Beijing, China

Accelerator - Beijing Electron-Positron Collider II (BEPCII)

1. Create positrons by firing electrons into stationary material
    - Generates high energy γs which interact with material to form e^+e^-
2. Separate newly created positrons magnetically
3. Accelerate positrons in linear accelerator and feed into storage ring
4. Accelerate electrons and feed into the oppositely circulating ring
    - Electrons readily available, so extraction from photons unnecessary
5. Focus each beam using magnets along storage rings until collision





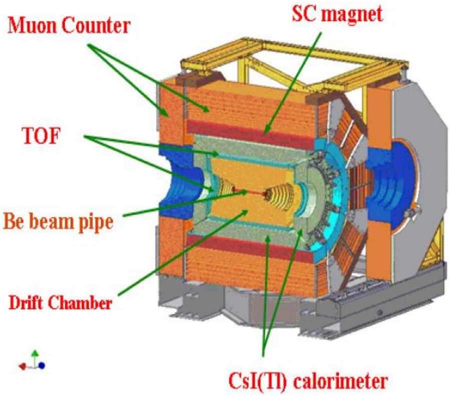
Detector - Beijing Spectrometer III (BESIII)

Collision of beams tuned to occur at central point of detector

- Beams angled during collision to improve integrated luminosity

Four main subdetector systems:

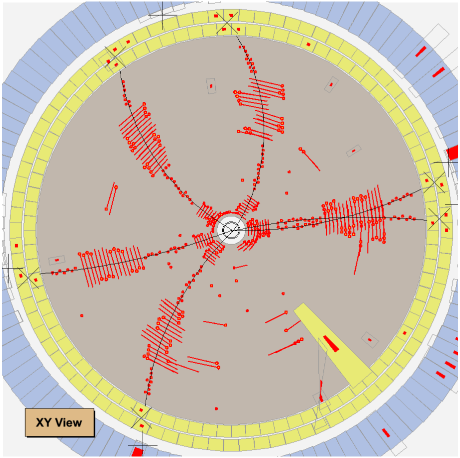
- Main Drift Chamber
- Time-of-Flight
- Electromagnetic Calorimeter
- Muon Identifier



Main Drift Chamber (MDC)

- Reconstruct charged tracks from interactions with sense wires (hits)
  - Wires surrounded by ionizable gas
  - Initial ionization due to particle triggers avalanche of electrons
  - High electric field near wires draws in released electrons to measure energy deposited
- Determine properties of particle from curvature in magnetic field
  - Radius determines momentum
  - Direction determines charge
- Energy deposition rate (dE/dx) helps determine particle candidate

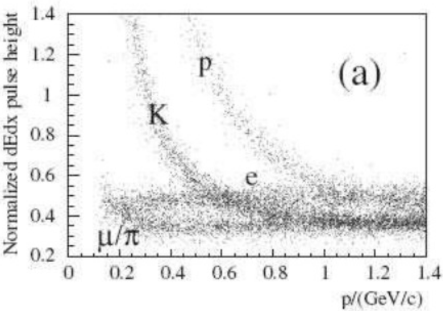
BESIII Event Display



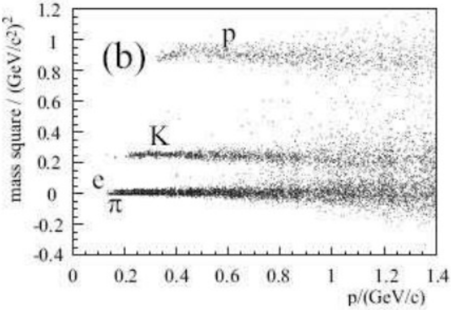
Time-of-Flight (ToF)

- Measure particle velocity using travel time after initial collision
  - Scintillator bands located at 0.81 m and 0.86 m from interaction point
  - Attached to photomultiplier tubes to measure light output
- Helps distinguish between $K^{\pm}$ and $\pi^{\pm}$ candidates at lower momenta
  - Combined with dE/dx measurements in MDC to set particle hypothesis

MDC Measurements

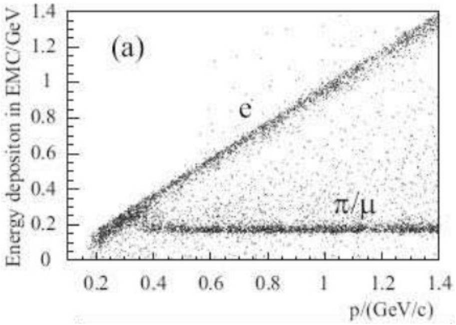


ToF Measurements



Electromagnetic Calorimeter (EMC)

- Measure energy deposited by electron and photon tracks
  - Other particles are generally relativistic and thereby minimum ionizing
    - These deposit relatively constant energy, independent of momenta
  - Use CsI(Tl) crystals attached to photodiodes to measure energy
    - Energy lost primarily in gaps of arrangement or out the back of crystals
- Allows reconstruction of purely neutral decays, such as $\pi^0 \to \gamma\gamma$



Muon Identifier (MUC)

- Identify tracks traversing through multiple layers as muons
  - Most particle types will be stopped before reaching the MUC
    - Electrons susceptible to Bremsstrahlung radiation
    - Kaons and pions susceptible to strong interactions
  - Requires muons with $p > 0.4\,\mathrm{GeV}$ for appropriate curvature

Triggering System

- Events filtered through two-step process
  - L1: Hardware - Extracts information from various subdetectors
    - MDC
      - Examines the number of superlayers each track passes through

        Superlayer: a collection of wires at same radial distance
      - Applies a cut on minimum transverse momentum for each
    - ToF
      - Examines number of hits in barrel and endcap regions
      - Checks for hits which are on opposite sides of the detector
    - EMC
      - Examines clustering of deposited energy around local maximum
  - L3: Software - Assembles information to decide if potentially relevant
- Quickly and efficiently removes non-physics background events
  - e.g., reduces beam-related backgrounds from $\sim$13 MHz to $\sim$1 kHz

Analysis Software

Monte Carlo Generation

- Create simulations of detector construction and particle interactions
  - Model material composition and detector arrangement in GEANT4
  - Simulate particle decay behavior using physics generators
  - Generate decays which could be mistaken as $D\overline{D}$ in reconstruction
    $$e^+e^- \to \tau^+\tau^-, \quad e^+e^- \to \gamma\psi(2S), \quad e^+e^- \to q\bar{q}, \quad \ldots$$
- Process samples using BESIII Offline Software System (BOSS)
  - Use information gathered by subdetectors to reconstruct events
  - Extract relevant physical parameters (ΔE, m_{BC}, $\ldots$) from each
- Identify contributions of generated background samples seen in data
  - Process both data and Monte Carlo (MC) samples identically
  - Subtract background components from data to determine signal events

D-Tagging

- Reconstruct D candidates from decays
  $$D \to \{\pi^{\pm},\ K^{\pm},\ \pi^0,\ K_S^0\}$$
- Modes selected based on reconstruction efficiency
  - High branching fractions
  - Manageable number of tracks (multiplicity)
- Search through track combinations for those matching reconstructed modes
  - Take best set per mode based on
    $$\Delta E = |E_{\text{beam}} - E_{\text{tag}}|$$
    $$m_{\text{BC}} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_{\text{tag}}|^2}$$
  - Allows multiple candidates per event

Reconstructed Modes	
(0)	$D^0 \to K^- \pi^+$
(1)	$D^0 \to K^- \pi^+ \pi^0$
(3)	$D^0 \to K^- \pi^+ \pi^+ \pi^-$
(200)	$D^+ \to K^- \pi^+ \pi^+$
(201)	$D^+ \to K^- \pi^+ \pi^+ \pi^0$
(202)	$D^+ \to K_S^0 \pi^+$
(203)	$D^+ \to K_S^0 \pi^+ \pi^0$
(204)	$D^+ \to K_S^0 \pi^+ \pi^+ \pi^-$
(205)	$D^+ \to K^+ K^- \pi^+$

*Charge conjugation implied

Measurement of the $D\overline{D}$ Cross Section

Procedure

Derive theoretical model used to describe cross section
List data samples used for measurement
Determine E_{cm} and $\mathcal{L}$ for each data point
Identify signal and background components
Measure efficiency of reconstruction
Combine everything to determine cross section
Assess systematic uncertainties

Derivation of $\sigma(\psi(3770) \to D\overline{D})$

- Need to convert integral expression into measurable function
  $$\sigma^{RC}_{D\overline{D}}(W) = \int z_{D\overline{D}}(W\sqrt{1-x})\,\sigma_{D\overline{D}}(W\sqrt{1-x})\,\mathcal{F}(x, W^2)\,dx$$
  - $z_{D\overline{D}}$: Coulomb interaction (D^+D^-) and mass constraints
  - $\sigma_{D\overline{D}}$: Born level (lowest order) cross section
  - $\mathcal{F}$: Initial State Radiation (ISR) correction
  - x: Approximation for fraction of energy radiated away
- Strategy: Split integral over x into small intervals and sum results
  - Treat $z_{D^+D^-}$ and $\sigma_{D\overline{D}}$ as constant in each interval
    - Use value at midpoint of interval for approximation
  - Integrate simple function of $\mathcal{F}(x, W^2) = \beta\, x^{\beta-1} F(W^2)$ over x
  - Obtain complicated, but calculable function for $D\overline{D}$ cross section

Form Factors

- Need to parameterize the form factor in the Born level cross section

$$\sigma_{D\overline{D}}(W) = \frac{\pi\alpha^2}{3W^2}\beta_D^3 |F_D(W)|^2, \qquad \beta_D = \sqrt{1 - \frac{4m_D^2}{W^2}}$$

- Comprised of resonant (R) and non-resonant (NR) components

$$F_D(W) = F_D^{\mathrm{NR}}(W) + \sum_r F_D^{R_r}(W)\, e^{i\phi_r}$$

- Resonant components parametrized by Breit-Wigner shape

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

- Non-resonant component has no definitive parametrization
    - Investigate two potential models for analysis
        - Exponential: generic form to approximate shape
        - Vector Dominance Model (VDM): physically based parameters

Form Factor Models

Exponential Model

$$F_D^{NR} = F_{\mathrm{NR}} \exp(-q_D^2/a_{\mathrm{NR}}^2)$$

- Fit Parameters
  - F_{NR}: Amplitude
  - a_{NR}: Width
- Used for systematic check

Vector Dominance Model

$$F_D^{NR}(W) = F_D^{\psi(2S)}(W) + F_0$$

- Fit Parameters
  - $\Gamma^{\psi(2S)}$: Decay width for $\psi(2S)$*
  - F_0: Higher resonances ($\psi(4040)$)
- Used for final results
- Use $M^{\psi(3770)}$ in place of $M^{\psi(2S)}$
  - Avoid mass below $D\overline{D}$ threshold
  - *Unclear physical meaning

Data Samples

- Use scan data to determine overall cross section shape
  - Taken over an energy range of 3.643 GeV to 3.890 GeV
  - Split into 34 bins based on measurements of E_{cm}
  - Luminosity measured using $e^+e^- \to e^+e^-(\gamma)$ events ($\mathcal{L} = 69.80\,\mathrm{pb}^{-1}$)
  - Chosen to be above $D^0\overline{D^0}$ threshold and below $D^{*0}\overline{D^0}$ threshold
  - Includes two bins below D^+D^- threshold which have zero production
- Use additional high statistics samples for comparison measurements

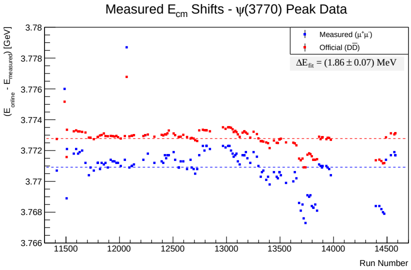
Name	E_{cm} [GeV]	$\mathcal{L}$
On-Peak $\psi(3770)^\dagger$	3.773	$2.93\,\mathrm{fb}^{-1}$
XYZ-Scan	3.810	$50.54\,\mathrm{pb}^{-1}$
R-Scan	3.850	$7.95\,\mathrm{pb}^{-1}$

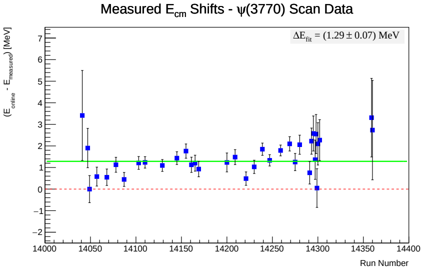
†Analysis of $D\overline{D}$ cross section performed independently

Center-of-Mass Energy

Accurate E_{cm} required for precise determination of $M^{\psi(3770)}$

- Measure E_{cm} using M_{inv} of 'On-Peak $\psi(3770)$' $e^+e^- \to \mu^+\mu^-$ events
- Compare results to separate, trustworthy procedure using $D\overline{D}$ events
  - Difference in average values determines correction to $\mu^+\mu^-$ procedure
- Measure E_{cm} for scan data using $\mu^+\mu^-$ procedure
  - Shift values by correction from $D\overline{D}$ procedure to get final results





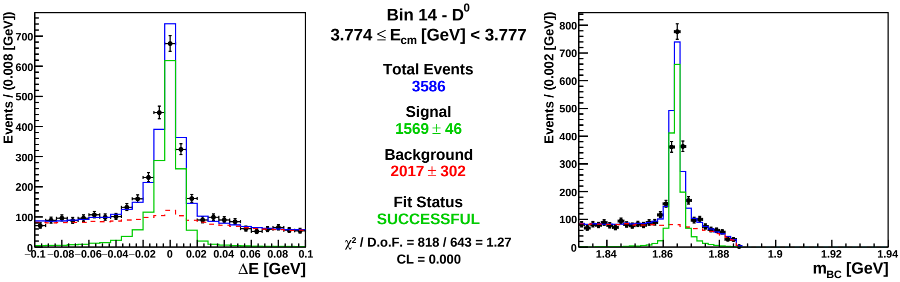
Monte Carlo Generation

- Generate MC samples to help identify signal and background rates
  - Signal: $\psi(3770) \to D^0\overline{D^0}$, $\psi(3770) \to D^+D^-$
  - Background: $q\bar{q}$, $\tau^+\tau^-$, $\gamma J/\psi$, $\gamma\psi(2S)$
  - Events per sample of $\sim 10^6$-10^7 depending on decay type
  - Decays simulated using run-dependent E_{cm} and accelerator conditions

- Samples of $\psi(3770) \to D\overline{D}$ generated using our cross section results
  - Use Born cross section from final fit results to improve MC generator
  - Requires iteration of MC generation to properly reflect true shape
    - Performed 5 iterations of input shapes for analysis

Signal Determination

- Measure $D^0\overline{D^0}$ / D^+D^- yields separately with 2D fit
  - Use D-tagging code to identify candidates in each sample (data / MC)
  - Extract ΔE and m_{BC} distributions and arrange MC samples into groups
    (1) Proper D-tags
    (2) Improper D-tags
    (3) $q\bar{q}$
    (4) $\tau^+\tau^- + \gamma J/\psi + \gamma\psi(2S)$
  - Float normalizations of each group to match data distributions (χ^2)



Efficiency Correction

- Correct for D reconstruction efficiency to determine total production
  - Average MC candidate amounts (N_{prop} vs. N_{gen}) over decay modes

$$\epsilon_D = \sum_i \epsilon_{i\ \text{rec}} \mathcal{B}_i = \sum_i \left(\frac{N_{i\ \text{prop}}}{N_{i\ \text{gen}}} \right) \mathcal{B}_i$$

Decay Mode (i)	PDG $\mathcal{B}_i$ [%]	MC Efficiency $\epsilon_{i\ \text{rec}}$
$D^0 \to K^- \pi^+$	3.89 ± 0.05	0.7002 ± 0.0011
$D^0 \to K^- \pi^+ \pi^0$	13.93 ± 0.50	0.3794 ± 0.0004
$D^0 \to K^- \pi^+ \pi^+ \pi^-$	8.11 ± 0.21	0.3988 ± 0.0006
$\epsilon_{D^0} = (11.245 \pm 0.020)\%$		
$D^+ \to K^- \pi^+ \pi^+$	9.13 ± 0.19	0.5471 ± 0.0007
$D^+ \to K^- \pi^+ \pi^+ \pi^0$	5.99 ± 0.18	0.2739 ± 0.0006
$D^+ \to K^0_S \pi^+$	1.47 ± 0.07	0.3883 ± 0.0014
$D^+ \to K^0_S \pi^+ \pi^0$	6.99 ± 0.27	0.2079 ± 0.0005
$D^+ \to K^0_S \pi^+ \pi^+ \pi^-$	3.12 ± 0.11	0.2237 ± 0.0007
$D^+ \to K^+ K^- \pi^+$	0.95 ± 0.03	0.4317 ± 0.0018
$\epsilon_{D^+} = (9.770 \pm 0.063)\%$		

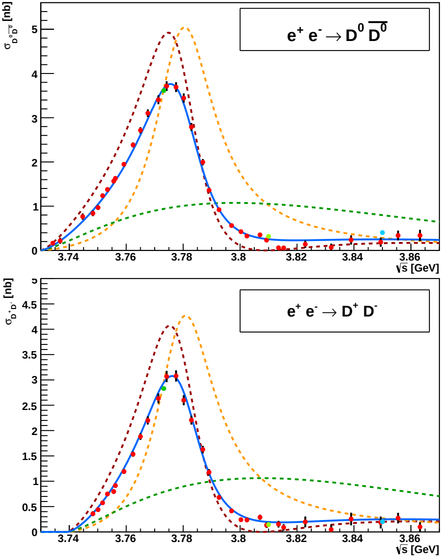
Cross Section Fitting

- Use signal amount, efficiency, and luminosity to find cross sections:
  - Include factor of 2 to correct for double counting (D vs. $D\overline{D}$)

$$\sigma^{RC}_{D\overline{D}}(E_i) = \frac{N_D(E_i)}{2\,\epsilon_D(E_i)\,\mathcal{L}(E_i)}$$

- Fit to theoretical formulation to determine $\psi(3770)$ parameters
  - $M^{\psi(3770)}$ $\Gamma^{\psi(3770)}$ $\Gamma_{ee}^{\psi(3770)\to D\overline{D}}$ $\phi^{\psi(3770)}$
  - Use $\Gamma_{ee}^{\psi(3770)\to D\overline{D}}$ in place of known $\mathcal{B}_{nD\overline{D}}$ or $\Gamma_{ee}^{\psi(3770)}$
- Two additional fit parameters depending on form factor choice
  - Exponential: F_{NR} a_{NR} VDM: $\Gamma^{\psi(2S)}$ F_0
- Minimize sum of χ^2 distributions for D^0 and D^+

Exponential Results



Exponential Fit Results

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

$$M^{\psi(3770)} = (3.7821 \pm 0.0003)$$

$$\Gamma^{\psi(3770)} = (2.6004 \pm 0.0597) \times 10^{-2}$$

$$\Gamma^{\psi(3770)}_{ee} = (2.3313 \pm 0.1016) \times 10^{-7}$$

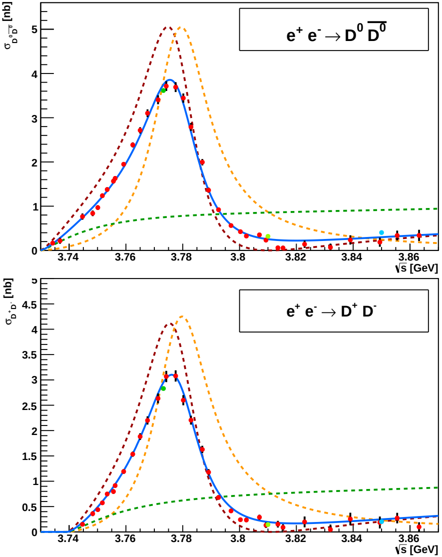
$$\phi^{\psi(3770)} = (3.7455 \pm 0.0388)$$

$$F_{NR} = (2.0844 \pm 0.0752) \times 10$$

$$a_{NR} = (4.2701 \pm 0.1336) \times 10^{-1}$$

$$\chi^2 \text{ / D.O.F.} = 110 / 59 = 1.86$$

Vector Dominance Model Results



VDM Fit Results

- Data
- Fit $\sigma^{RC}_{D\overline{D}}$
- σ_{Born}
- Resonant - $\psi(3770) \to D\overline{D}$
- Non-resonant - $\psi(2S)$
- BESIII On-peak Data [2.92 fb^{-1}]
- BESIII XYZ Scan Data
- BESIII R Scan Data

$$M^{\psi(3770)} = (3.7808 \pm 0.0002)$$

$$\Gamma^{\psi(3770)} = (2.4098 \pm 0.0534) \times 10^{-2}$$

$$\Gamma^{\psi(3770)}_{ee} = (2.1583 \pm 0.0867) \times 10^{-7}$$

$$\phi^{\psi(3770)} = (3.6149 \pm 0.0435)$$

$$\Gamma^{\psi(2S)} = (1.1491 \pm 0.1236) \times 10^{-2}$$

$$F_0 = (-2.8845 \pm 0.4462)$$

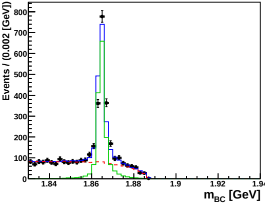
$$\chi^2 \,/\, \text{D.O.F.} = 124 / 59 = 2.11$$

Results Overview

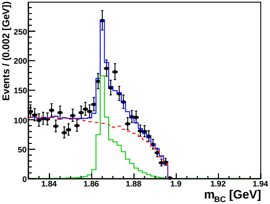
- Both form factor choices show generally good agreement
  - Excess in χ^2 largely due to two D^0 points just above 3.81 GeV
  - Could indicate need for improved model in higher energy region
- Values for $\psi(3770)$ parameters primarily dependent on peak region
  - Consistent shape in this region emphasizes quality of results
- Inteference related to behavior of Born level cross section
  - Reappearance of Born level events is strong indication of interference
  - Impossible to reproduce with two non-interfering Breit-Wigner shapes

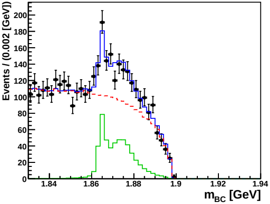
Born Level Event Contribution in m_{BC}

At $\psi(3770)$ Peak

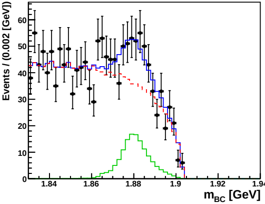


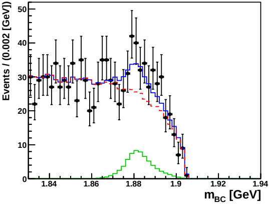
Approaching Born Minimum





At Born Minimum





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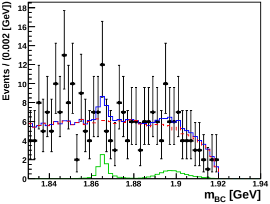
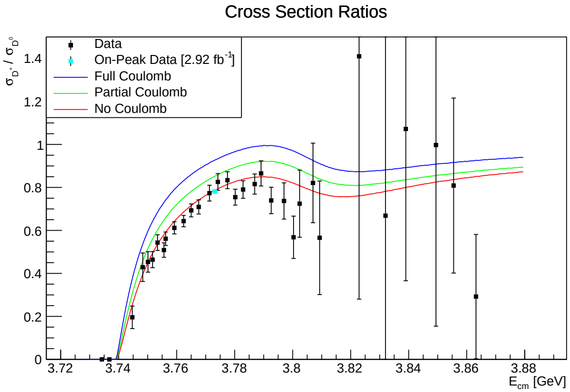


Coulomb Interaction

- Significantly worse results when including value for $z_{D^+D^-}$ ($\chi^2 \approx 5$)
  - Results shown previously use $z_{D^+D^-} = 1$ for calculations
- Ratio of cross sections ($\sigma_{D^+}/\sigma_{D^0}$) prefers lack of value
  - Unclear explanation for behavior, but consistent with $\Upsilon \to B\overline{B}$ studies



Systematic Uncertainties

- Examine uncertainty on parameters involved throughout procedure
  - Individually increase / decrease value by the uncertainty of each
  - Re-fit cross section with altered values and take maximal variation
- Many uncertainties adjust overall scale of cross section normalization
  - Only affects the value of $\Gamma_{ee}^{\psi(3770)\to D\overline{D}}$

Name	Change	Description
Luminosity	$\mathcal{L}$	1.0 %
$\pi^{\pm}/K^{\pm}$ Tracking	$\epsilon_{i\ \mathrm{rec}}$	1.0 % per $\pi^{\pm}$ or $K^{\pm}$ in the mode
π^0 Tracking	$\epsilon_{i\ \mathrm{rec}}$	2.0 % per π^0 in the mode
K_S^0 Tracking	$\epsilon_{i\ \mathrm{rec}}$	1.5 % per K_S^0 in the mode
Single Tag Fits	N_D	Adjust by fit difference (small)
PDG Branching Fractions	$\epsilon_{i\ \mathrm{rec}}$	Adjust by PDG errors

Systematic Uncertainties

- **Meson Radii**
  - Adjust values of $R_{\psi(2S)}$ and $R_{\psi(3770)}$ by 25 % (from KEDR)
  - Take max variation over all four combinations of up / down on each
  - Accounts for most significant source of systematic uncertainty
- **MC Iteration** (negligible)
  - Take difference in parameters before / after Born level modification
- **MC ISR Generation** (negligible)
  - Take difference in fit results with KKMC vs. ConExc generators
- **Intermediate Resonances** (negligible)
  - Examine effects of $\rho^0 \to \pi^+\pi^-$ in the mode $D^+ \to K^-\pi^+\pi^+$
  - Take difference in $K\pi$ vs. $\pi\pi$ invariant mass splits using 'On-Peak' data

Systematic Uncertainties

- Uncertainties summed in quadrature (assumed independent)
- Total contribution similar to statistical error for most parameters
  - Value for $M^{\psi(3770)}$ is small, but has very small statistical error

Systematic	$M^{\psi(3770)}$ [%]	$\Gamma^{\psi(3770)}$ [%]	$\Gamma_{ee}^{\psi(3770)\to D\overline{D}}$ [%]	$\phi^{\psi(3770)}$ [%]
Luminosity	0.000	0.004	1.005	0.014
$K^{\pm}/\pi^{\pm}$ Tracking	0.000	0.008	2.646	0.033
π^0 Tracking	0.000	0.012	0.746	0.028
K_S^0 Tracking	0.000	0.004	0.260	0.019
Single Tag Fits	0.000	0.012	0.213	0.008
PDG Errors	0.000	0.017	2.840	0.036
Meson Radii	0.016	2.411	3.512	1.477
Total [%]	0.016	2.411	5.389	1.479
Relative Stat. Error [σ]	3.000	1.088	1.342	1.229

Form Factor Uncertainty

- Substantial contribution from choice of non-resonant form factor
- Use difference between Exponential and VDM values as uncertainty
  - Follows example of KEDR with model-dependent uncertainty

Form Factor	$M^{\psi(3770)}$ [GeV]	$\Gamma^{\psi(3770)}$ [MeV]	$\Gamma_{ee}^{\psi(3770)\to D\overline{D}}$ [eV]	$\phi^{\psi(3770)}$ [°]
VDM	3.7821	26.004	233.13	214.60
VDM	3.7808	24.098	215.83	207.12
Difference	0.0013	1.906	17.30	7.48

Final Results

- Results limited by systematics and model-dependency

$M^{\psi(3770)}$	$3780.8 \pm 0.2 \pm 0.6 \pm 1.3$	[MeV]
$\Gamma^{\psi(3770)}$	$24.1 \pm 0.5 \pm 0.6 \pm 1.9$	[MeV]
$\Gamma_{ee}^{\psi(3770)\to D\overline{D}}$	$216 \pm 9 \pm 11 \pm 17$	[eV]
$\phi^{\psi(3770)}$	$207 \pm 3 \pm 3 \pm 7$	[°]

Errors are statistical, systematic, and model-dependent, respectively

- Results consistent with KEDR and very inconsistent with PDG

Method	$M^{\psi(3770)}$ [MeV]	$\Gamma^{\psi(3770)}$ [MeV]	$\Gamma_{ee}^{\psi(3770)\to D\overline{D}}$ [eV]
Exponential	$3782.1 \pm 0.3 \pm 0.6$	$26.0 \pm 0.6 \pm 0.7$	$233 \pm 10 \pm 13$
VDM	$3780.8 \pm 0.2 \pm 0.6$	$24.1 \pm 0.6 \pm 0.6$	$216 \pm 9 \pm 12$
KEDR	$3779.2^{+1.8+0.5+0.3}_{-1.7-0.7-0.3}$	$24.9^{+4.6+0.5+0.2}_{-4.0-0.6-0.9}$	$154^{+79+17+13}_{-58-9\ -25}$, $414^{+72+24+90}_{-80-26-10}$
PDG	3773.15 ± 0.33	27.2 ± 0.9	$[262 \pm 18] \times \mathcal{B}_{D\overline{D}}$

Measurement of the Non-$D\overline{D}$ Branching Fraction

Procedure

Event Selection
Hadron Cut Methods
Signal Counting Fits
MC Background Subtraction
Efficiency Extrapolation
$D\overline{D}$ Multiplicity Correction
Examination of Results for $\psi(3770)$ Data
Background Investigation
Examination of Results for Scan Data

Data Samples

Show 3650 Data Sets
Mention energy measurement

Event Selection

Charged Track Selection
Neutral Track Selection
Background Rejection

Hadronic Selection

Show SHAD, LHAD, and THAD cut tables

Signal Counting

Show signal counting fits for data

Background Subtraction

List MC samples considered (and note those excluded)
Relate to total number of hadrons found for future extrapolation

Efficiency Extrapolation

Repeat procedure for new continuum data
Extrapolate efficiency based on E_{cm}
Show extrapolation plots for SHAD, LHAD, and THAD

Procedure for $\psi(3770)$ Data

Repeat procedure for $\psi(3770)$ data
Introduction of new backgrounds and $D\overline{D}$ component

$D\overline{D}$ Correction

Create multiplicity distributions from single-tag events
Obtain correction factors for R1 and R2 separately
Example plots for D^0 and D^+ of R1

Reconstruction Efficiencies

Show example backgrounds for SHAD
Describe correction used for $\gamma\psi(2S)$ events
Point out cross sections used by Derrick for $\psi(3770)$ data

Initial Attempt - $\psi(3770)$ Data

Show cross section / branching fractions
Point out likely high values due to $\psi(2S)$ shape

Background Investigation - Part I

Describe alternate estimation for $\psi(2S)$ events
Show branching fraction results with estimation

Background Investigation - Part II

Describe alternate estimation ignoring $\psi(2S)$ events
Show branching fraction results with estimation

Procedure for Scan Data

Using best information available from $\psi(3770)$ results
Show hadronic cross section over region

Results for Scan Data

Show non-$D\overline{D}$ cross section over region
Show non-$D\overline{D}$ branching fraction over region

Conclusion

Conclusion

Show overview of measurements for $D\overline{D}$ cross section and non-$D\overline{D}$ branching fraction
List results of parameters for $\psi(3770)$
List branching fraction range for non-$D\overline{D}$

Backup Slides

Monte Carlo Generators

- KKMC
  - Used to model electroweak interactions: $e^+e^- \to f\bar{f} + (n)\gamma$
    $f = \{\mu^-,\ \tau^-,\ u,\ d,\ s,\ c,\ b\}$ and $(n)\gamma =$ (additional photons)
  - Decays $f\bar{f}$ pair based on involved fermions (TAUOLA, PYTHIA)
  - Takes into account initial- and final-state radiation (ISR / FSR)
    - For resonances, only handles ISR, then passes off γ^* to BesEvtGen
- BesEvtGen
  - Handles resonance decay as well as radiative effects
    - Reduced E_{cm} such that only lower mass resonances can be produced
- Babayaga
  - Used to model QED processes: $e^+e^- \to \{e^+e^-,\ \mu^+\mu^-,\ \gamma\gamma\}$
  - Very accurate results; estimated theoretical uncertainty of 0.1 %
    - High precision required for determination of integrated luminosity

Selection Cuts

$\pi^\pm$ and $K^\pm$ Selection

Vertex (xy)	$V_{xy} < 1\,\mathrm{cm}$
Vertex (z)	$\lvert Vz \rvert < 10\,\mathrm{cm}$
MDC Angle	$\lvert \cos\theta \rvert < 0.93$
Pion Probability	$P(\pi) > 0, \quad P(\pi) > P(K)$
Kaon Probability	$P(K) > 0, \quad P(K) > P(\pi)$

γ Selection

Min. Energy (Barrel)	$E_{\mathrm{EMC}} > 25\,\mathrm{MeV}$	$(\lvert \cos\theta \rvert < 0.80)$
Min. Energy (Endcap)	$E_{\mathrm{EMC}} > 50\,\mathrm{MeV}$	$(0.84 < \lvert \cos\theta \rvert < 0.92)$
TDC Timing	$(0 \le t \le 14) \times 50\,\mathrm{ns}$	

	$\pi^0 \to \gamma\gamma$ Selection	$K^0_S \to \pi^+\pi^-$ Selection
Nominal Mass	$115 < m_{\pi^0}[\mathrm{MeV}] < 150$	$487 < m_{K^0_S}[\mathrm{MeV}] < 511$
Fit Quality	$\chi^2 < 200$, Converged	$\chi^2 < 100$, Converged

Derivation of $\sigma(\psi(3770) \to D\overline{D})$

- $\mathcal{F}(x, W^2) = \beta\, x^{\beta-1}\left[1 + \frac{\alpha}{\pi}\left(\frac{\pi^2}{3} - \frac{1}{2}\right) + \frac{3}{4}\beta + \beta^2\left(\frac{37}{96} - \frac{\pi^2}{12} - \frac{L}{72}\right)\right] = \beta\, x^{\beta-1} F(W^2), \qquad \beta = \frac{2\alpha}{\pi}(L-1), \qquad L = \log\left(\frac{W^2}{m_e^2}\right)$

CP Violation Correction

Quickly list process of correcting for CP