Measurements of $BF(\psi(3770) \rightarrow D^0 \bar{D}^0, D^+ D^-)$ & $BF(\psi(3770) \rightarrow \text{non} - D \bar{D})$
and search for $\psi(3770)$ exclusive $\text{non} - D \bar{D}$ decays

Jiangchuan Chen
(for BES Collaboration)

Institute of High Energy Physics, Beijing 100049, P.R. China

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Introduction

$BF(\psi(3770) \rightarrow \text{non} - D \bar{D})$ with $R$ & $\sigma_{DD}^{obs}$

$BF(\psi(3770) \rightarrow D^0 \bar{D}^0, D^+ D^-, D \bar{D})$

by fitting $\sigma_{\text{had}}(E_i)$ and $\sigma_{DD}(E_i)$ with scan data.

Search for exclusive $\psi(3770) \rightarrow \text{non} - D \bar{D}$

Summary
Introduction
The Beijing Electron Positron Collider (BEPC)

$L \sim 1 \times 10^{31} / \text{cm}^2 \cdot \text{s}$ at $\psi(3770)$ peak

$E_{\text{cm}} \sim 2-5 \text{ GeV}$

One of the two $e^+e^-$ machines in the world in the $\tau$-charm energy region
BESII Detector

VC: $\sigma_{xy} = 100 \, \mu$m  
TOF: $\sigma_T = 180 \, \text{ps}$  
$\mu$ counter: $\sigma_{r\phi} = 3 \, \text{cm}$

MDC: $\sigma_{xy} = 220 \, \mu$m  
BSC: $\Delta E/\sqrt{E} = 22 \%$  
$\sigma_z = 5.5 \, \text{cm}$

$\sigma_{dE/dx} = 8.5 \%$  
$\sigma_\phi = 7.9 \, \text{mr}$  
$\Delta p/p = 1.7\% \sqrt{1+p^2}$  
$\sigma_z = 3.1 \, \text{cm}$

B field: 0.4 T
ψ(3770) data sample

~18 pb\(^{-1}\) of data taken at 3.773 GeV
~7 pb\(^{-1}\) of data taken in the region from 3.768 GeV to 3.778 GeV
~8 pb\(^{-1}\) of data taken in the energy region from 3.665 to 3.878 GeV

about 33 pb\(^{-1}\) of data collected around 3.773 GeV in total.
World $\psi(3770)$ Samples (pb$^{-1}$)

Largest sample from CLEO-c by Summer, 2005

$\psi(3770)$

MARK-I  DELCO  MARK-II  MARK-III  BES-II  CLEO-c
◆ **ψ(3770) resonance**

It is believed to be a mixture of $1^3D_1$ and $2^3S_1$ states of the system, and it is thought to decay almost entirely to pure DD-bar.

◆ **BUT**

Long-standing puzzle of ψ(3770) production and decays:

- Previously published data indicate that more than 30% of ψ(3770) does not decay to DD-bar? This conflicts with theoretical prediction.

Cross section at peak (PDG04 parameters)

- $\sigma^{prd}_{\psi(3770)} = \frac{12\pi}{M^2_{\psi(3770)}} \times BF(\psi(3770) \rightarrow e^+e^-) = 11.6 \pm 1.8 \text{ nb}$

- $\sigma^{obs}(e^+e^- \rightarrow D\bar{D}) = 5.0 \pm 0.5 \text{ nb (Mark-III)}$

- $\sigma^{prd}(e^+e^- \rightarrow D\bar{D}) = 7.1 \pm 0.7 \text{ nb}$

Before BES-II & CLEO-c
How to solve the problem?

1. Directly measure the branching fractions for the decays 
   \( \psi(3770) \rightarrow D^0 \bar{D}^0, D^+ D^-, D \bar{D} \) and \( \psi(3770) \rightarrow non-D \bar{D} \)

2. Simultaneously measuring both \( \sigma_{D \bar{D}} \) and \( \sigma_{\psi(3770)} \) could solve the problem or may uncover the puzzle, since there is no systematic uncertainty in normalization (luminosity or eff.).

3. Search for some exclusive non-DD-bar decays of \( \psi(3770) \)

4. ....
BF(ψ(3770) → non-DD) determined with R & $\sigma_{DD}$
$L = 17.3 \text{ pb}^{-1}$ of data @ 3.773 GeV

Using Kinematic fit method to improve momentum resolution and select the singly tagged D meson

Single tag analysis

$$\sigma_{DD}^{obs} = \frac{N_{D_{tag}}}{2 \times L \times Br \times \epsilon}$$

From Monte Carlo

PDG04 Br

Requiring $M_{fit} = M_{\tilde{X}}$
Observed cross sections for DD-bar production at 3.773 GeV

\[ \sigma_{D^0D^0}^{obs} = 3.58 \pm 0.09 \pm 0.31 \text{ nb} \]

\[ \sigma_{D^+D^-}^{obs} = 2.56 \pm 0.08 \pm 0.26 \text{ nb} \]

\[ \sigma_{DD}^{obs} = 6.14 \pm 0.12 \pm 0.50 \text{ nb} \]
pQCD calculates the R ratio

Experimentally, one measures

\[ R \equiv \frac{\sum Q_f^2}{\left(1 + \delta\right)} \]

\[ N_{\text{had}} : \text{# of hadronic events} \]
\[ L : \text{Luminosity} \]
\[ \varepsilon_{\text{had}} : \text{Eff.} \]

\[ \sigma_{\text{Born}} = \frac{\sigma_{\text{had}}^{\text{obs}}}{\left(1 + \delta\right)} \]

\[ \sigma_{\text{obs}}^{\text{had}} = \frac{N_{\text{had}}}{L \cdot \varepsilon_{\text{had}}} \]

\[ R = \frac{\sigma_{\text{Born}}^{\text{had}}}{\sigma_{\mu + \mu -}} \]

\[ \sigma_{e^+e^- \to \mu^+\mu^-} = \frac{86.8544 \text{ nb}}{E_{\text{cm}}^2 \text{ (GeV)}^2} \]
Including the contribution from high order processes

<table>
<thead>
<tr>
<th>$E_{CM}$ [GeV]</th>
<th>$\sigma^{obs}_{\text{had}}$</th>
<th>$R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.650</td>
<td>$18.98 \pm 0.23$</td>
<td>$2.24 \pm 0.03$</td>
</tr>
<tr>
<td>3.665</td>
<td>$18.30 \pm 0.28$</td>
<td>$2.18 \pm 0.04$</td>
</tr>
<tr>
<td>3.773</td>
<td>$27.68 \pm 0.31$</td>
<td>$3.75 \pm 0.04$</td>
</tr>
</tbody>
</table>

$\sigma^\gamma(e^+e^- \rightarrow \text{hadrons})$

$\overline{R}_{uds} = 2.22 \pm 0.02 \pm 0.09$

$R = 3.75 \pm 0.04 \pm 0.19$ @ 3.773 GeV

$\overline{R}_{uds} \big|_{\text{fit to } \sigma_{\psi(3686)} \& \sigma_{\psi(3770)}} = 2.21 \pm 0.13$

$\overline{R}_{uds} \big|_{2.0 \text{ to } 3.0 \text{ GeV}} = 2.26 \pm 0.14$

Obtaining by fitting to the $R$ values measured by BES in the range from 2.0 to 3.0 GeV

BES contribution paper to Lepton-photon 2005

Stat. & p-to-p systematic error

See below
Taking the $R$ for light hadron production to be a constant, then

$$R_{\psi (3770)} = R(\frac{E_{cm}}{E_{cm}}} = 3.773 \text{ GeV} - R_{uds}$$

We obtain

$$R_{\psi (3770)} = 1.53 \pm 0.05 \pm 0.13$$

$$\sigma_{\psi (3770)}^{\text{Born}} = 9.35 \pm 0.29 \pm 0.80 \text{ nb}$$

It is consistent with

$$\sigma_{\psi (3770)}^{\text{Born}} = \frac{12 \pi}{(1 + \delta_{VP}) M_{\psi (3770)}^2} \times BF (\psi (3770) \rightarrow e^+ e^-) = 11.08 \pm 1.74 \text{ nb}$$

$$(1 + \delta_{VP}) = (1.047 \pm 0.024)$$

obtained based on PDG04 $\psi (3770)$ resonance parameters
Determination of branching fractions with

\[ \sigma_{\text{obs}}^{DD} \quad \text{and} \quad \sigma_{\psi(3770)}^{\text{Born}} \]

\[
BF (\psi(3770) \rightarrow D \bar{D}) = \frac{N_{\text{prd}}^{DD}}{N_{\psi(3770)}^{\text{prd}}} = \frac{\sigma_{\psi(3770)}^{\text{Born}}}{\sigma_{\psi(3770)}^{\text{Born}}} = \frac{\sigma_{\text{obs}}^{DD}}{\sigma_{\psi(3770)}^{\text{Born}}} \]

Radiative correction

Assuming that \( \psi(3770) \) decay exclusively into \( DD \)

\[ \sigma_{\text{obs}}^{DD}(s) = \int_{0}^{1} \frac{dx}{4M_{D}^{2} / s} f(x, s) \sigma_{B}^{s(1-x)} |1 - \Pi(s(1-x))|^{-2} \]

\[ |1 - \Pi(s(1-x))|^{-2} = (1 + \delta_{vp}) = 1.047 \pm 0.024 \]

\[ \sigma_{B}^{s}(s) = \frac{12 \pi \Gamma_{ee} \Gamma_{f}^{s}(s)}{(s - M^{2})^{2} + M^{2} \Gamma_{\text{tot}}^{s}(s)} \]

Radiative correction factor \( g = \frac{\sigma_{\text{obs}}^{DD}}{\sigma_{B}^{s}} \)

\[ g_{\text{BES-II}} = 0.764 \pm 0.020 \]
Results of branching fractions

\[ BF(\psi(3770) \rightarrow D^0 \bar{D}^0) = (50.1 \pm 1.3 \pm 3.9)\% \]
\[ BF(\psi(3770) \rightarrow D^+ D^-) = (35.9 \pm 1.1 \pm 3.5)\% \]
\[ BF(\psi(3770) \rightarrow D \bar{D}) = (86.0 \pm 1.7 \pm 6.0)\% \]
\[ BF(\psi(3770) \rightarrow non-D \bar{D}) = (14.0 \pm 1.7 \pm 6.0)\% \]

These results are preliminary!
BF(ψ(3770) → D⁰D⁰, D⁺D⁻, DD̅) determined by fitting $\sigma_{\text{had}}(E_i) & \sigma_{DD}(E_i)$ line-shape with scan data.

◆ Cross section scan experiment

We use energy dependent inclusive hadronic cross sections and DD-bar cross sections to determine the branching fraction $BF(\psi(3770) \rightarrow \text{non} - D\bar{D})$.

◆ Monte Carlo

Developed a inclusive hadronic event generator with high order ISR corrections to simulate the hadronic event production in the full energy region.
MC generator & simulation

Full energy range ISR $e^+e^- \rightarrow$ hadrons Generator

\[ \sqrt{s} = 3.78 \text{ GeV} \]

<table>
<thead>
<tr>
<th>$\psi(3770)$</th>
<th>$\psi(3686)$</th>
<th>$\rho(1700)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega \phi$</td>
<td>$J/\psi$</td>
<td>$\rho$</td>
</tr>
</tbody>
</table>

Density [nb/GeV]

Effective energy [GeV]

- Nch
- KNO
- $\phi$
- Thrust
- Oblateness
- $\cos\theta$
- Sphericity
- Aplanarity
- Jet axis $\cos\theta$
- $x$
- $\eta$
- $\gamma$
- $P_t$
- $<P_{\text{in}}^2>$
- $<P_{\text{out}}^2>$
- $\text{NGOOD}$
- $\text{NCHIG}$
- $\text{NEU}$
**Observed cross section**

\[
\sigma_{\text{had}}^{\text{obs}}(E_{\text{cm}}) = \frac{n_{\text{had}}}{L(E_{\text{cm}}) \varepsilon_{\text{had}}(E_{\text{cm}}) \varepsilon_{\text{trg}}} 
\]

\[
\sigma_{\text{had}}^{\text{expect}}(s) = \int_0^1 dx \ f(x,s) \ \sigma^B(s(1-x)) 
\]

\[
\sigma^B(s) = \frac{12 \pi \Gamma_{ee} \Gamma_f(s)}{(s-M^2)^2 + M^2 \Gamma_{tot}^2(s)} 
\]

\[f(x,s) \text{ is sampling function} \]

(Kuraev and Fadin)

![Hadron efficiency vs C.M. energy](image)

**FIG. 4:** The efficiencies for detection of the inclusive hadronic events vs the nominal center-of-mass energies.
To get right resonance parameters, the two resonance production and decays should be considered simultaneously. In this way the “correct” QED background \( R_{uds} \) can be determined correctly!
Energy dependent cross sections

\[ \sigma_{\text{DD}}^{\text{obs}}(E_{\text{cm}}) = \frac{N_{\text{D singletag}}(E_{\text{cm}})}{2L\varepsilon_{\text{D single tag}}B(D \rightarrow \text{mode})} \]
Observed cross sections

Inclusive hadrons

Observed cross sections for hadron production [nb]

Center-of-mass energy (GeV)

Observed DD-bar cross section (nb)
Fit to the observed cross sections

Fitting the observed inclusive hadron and DD-bar production cross sections to the theoretical cross sections, one obtains the branching fractions

\[ \sigma_B^{\psi(3770)} = \frac{12 \pi \Gamma_{ee}^0 \Gamma_{tot}^2 (s)}{(s - M^2) + M^2 \Gamma_{tot}^2 (s)} \]

\[ \sigma_{D\bar{D}}^B = \frac{12 \pi \Gamma_{ee}^0 \Gamma_{D\bar{D}}^2 (s)}{(s - M^2) + M^2 \Gamma_{tot}^2 (s)} \]

\[ \Gamma_{tot}^2 (s) = \Gamma_{D^0\bar{D}^0}^2 (s) + \Gamma_{D^+D^-}^2 (s) + \Gamma_{non-D\bar{D}}^2 (s) \]

\[ \Gamma_{D^0\bar{D}^0}^2 (s) = \Gamma_0 \theta(E_{cm} - 2M_{D^0}) \frac{1 + (r p_{D^0})^2 (p_{D^0})^3}{1 + (r p_{D^0})^2 (p_{D^0})^3} B(\psi(3770) \rightarrow D^0 \bar{D}^0) \]

\[ \Gamma_{D^+D^-}^2 (s) = \Gamma_0 \theta(E_{cm} - 2M_{D^+}) \frac{1 + (r p_{D^+})^2 (p_{D^+})^3}{1 + (r p_{D^+})^2 (p_{D^+})^3} B(\psi(3770) \rightarrow D^+ D^-) \]

\[ \Gamma_{non-D\bar{D}}^2 (s) = \Gamma_0 (1 - B(\psi(3770) \rightarrow D^0 \bar{D}^0) - B(\psi(3770) \rightarrow D^+ D^-)) \]

\[ \chi^2 = \sum \left( \frac{\sigma_{obs}^{had}(i) - \sigma_{exp}^{had}(i)}{\Delta_{had}(i)} \right)^2 + \sum \left( \frac{\sigma_{obs}^{D^0\bar{D}^0}(j) - \sigma_{exp}^{D^0\bar{D}^0}(j)}{\Delta_{D^0\bar{D}^0}(j)} \right)^2 + \sum \left( \frac{\sigma_{obs}^{D^+D^-}(j) - \sigma_{exp}^{D^+D^-}(j)}{\Delta_{D^+D^-}(j)} \right)^2 \]

\[ 24 \]
Line shape of the cross sections for hadron and DD-bar production

\[ \sigma_{\text{obs}} \]

Inclusive hadrons

\[ E_{cm} \quad [\text{GeV}] \]

\[ \sigma_{\text{had}} \]

\[ \sigma_{\text{DD}} \]

\[ \sigma_{\text{DD}} \]

\[ E_{cm} \quad [\text{GeV}] \]

\[ D^0 \bar{D}^0 \]

\[ D^+ D^- \]
After subtracting the backgrounds from $J/\psi$ and $\psi(2S)$ radiative tails and QED continuum.
Branching fractions

Obtained from fitting to the inclusive hadron and the DD-bar production cross sections simultaneously.

Considered the correlation between the two branching fractions for the two modes

\begin{align*}
BF (\psi (3770) \rightarrow D^0 \overline{D}^0) &= (46.8 \pm 5.2 \pm 3.2) \% \\
BF (\psi (3770) \rightarrow D^+ D^-) &= (37.0 \pm 4.1 \pm 3.5) \% \\
BF (\psi (3770) \rightarrow D \overline{D}) &= (83.8 \pm 6.8 \pm 6.4) \% \\
BF (\psi (3770) \rightarrow non - D \overline{D}) &= (16.2 \pm 6.8 \pm 6.4) \% \\
BF (\psi (3770) \rightarrow non - D \overline{D}) &< 31.1\% \text{ at 90\% C.L.}
\end{align*}

where the first error is statistical and second systematic, which arises from the un-canceled systematic uncertainties in hadron cross sections (~3.4 %), neutral DD-bar cross sections (~6.2 %) and charged DD-bar cross sections (~8.6 %).

These results are preliminary!
Search for exclusive decay $\psi(3770) \rightarrow \text{non-D}\bar{D}$
Evidence for $\psi^\prime \rightarrow J/\psi \pi^+ \pi^-$

Analysis of the fitted dilepton masses of $l^+l^-\pi^+\pi^-$

Open histogram is for $e^+e^-$ channel, histogram in yellow is for $\mu^+\mu^-$ channel

$\psi^\prime$ production due to ISR

The histogram is $\psi(3686)$, while error bars are the $\psi(3686) + \psi(3770)$

Data MC 20 times larger than the data

$\psi(3686) \rightarrow J/\psi\pi^+\pi^-$ mainly

$17.8_{-4.8}^{+8.1} \text{ signal events obtained}$

$6.0_{-0.8}^{+8.17} \text{ signal events of } \psi(3770) \rightarrow J/\psi\pi^+\pi^-$

$N(\psi(3770) \rightarrow J/\psi\pi^+\pi^-) = 11.8_{-4.8}^{+8.4}$
Previous observations of non-DD-bar decays

BES observed 12 signal events for the decay $\psi(3770) \rightarrow \text{non} - D\overline{D}$ and measured the branching fraction to be

$$BF(\psi(3770) \rightarrow J/\psi \pi^+\pi^-) = (0.34 \pm 0.14 \pm 0.09)\%$$

CLEO confirmed BES observation of the decay, and measured the branching fractions to be

$$BF(\psi(3770) \rightarrow J/\psi \pi^+\pi^-) = (0.189 \pm 0.020 \pm 0.020)\%$$

BES searched for $\psi(3770) \rightarrow \rho\pi$, and determined the limits region

$$BF(\psi(3770) \rightarrow \rho\pi) \in (6.0 \times 10^{-6}, 2.4 \times 10^{-3})$$

CLEO also searched for some other non-DD-bar exclusive decay modes...
Search For $\psi(3770)$ decay to $\Phi \pi^0$ and $\Phi \eta$

Ecm around 3.773 GeV (L=33 pb$^{-1}$)

Ecm=3.65GeV (L=6.5 pb$^{-1}$)

<table>
<thead>
<tr>
<th>Ecm [GeV]</th>
<th>N($\Phi \pi^0$)</th>
<th>N($\Phi \eta$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>around 3.773</td>
<td>0</td>
<td>5.2±2.5</td>
</tr>
<tr>
<td>3.65</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Search For $\psi(3770)$ decay to $\Phi \pi^+\pi^-$, $\Phi K^+K^-$ and $\Phi p\bar{p}$

- **Ecm around 3.773 GeV (L=33 pb⁻¹)**
  - $\Phi \pi^+\pi^-$
  - $\Phi K^+K^-$
  - $\Phi p\bar{p}$

- **Ecm = 3.65 GeV (L=6.5 pb⁻¹)**
  - $\Phi \pi^+\pi^-$
  - $\Phi K^+K^-$
  - $\Phi p\bar{p}$

<table>
<thead>
<tr>
<th>Ecm</th>
<th>$N(\Phi \pi^+\pi^-)$</th>
<th>$N(\Phi K^+K^-)$</th>
<th>$N(\Phi p\bar{p})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Around 3.773 GeV (L=33 pb⁻¹)</td>
<td>6.0 ±3.5</td>
<td>27.3 ±5.8</td>
<td>2</td>
</tr>
<tr>
<td>3.65 GeV (L=6.5 pb⁻¹)</td>
<td>2</td>
<td>4.9 ±2.6</td>
<td>0</td>
</tr>
</tbody>
</table>
Search For $\psi(3770)$ decay to multi-body decays containing $\pi^0$ or $\eta$

Around 3.773GeV, $E_{cm}=3.65GeV$

- 2($\pi^+\pi^-)\pi^0$
- $KK\pi^+\pi^-\pi^0$
- $pp\pi^0$
- $pp\pi^+\pi^-\pi^0$

Around 3.773GeV, $E_{cm}=3.65GeV$ (L=33 pb$^{-1}$)

- 2($K^+K^-)\pi^0$
- $3(\pi^+\pi^-)\pi^0$

DDbar events have been removed.
# Observed Cross Sections

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma_{e^+e^- \rightarrow f}^{\text{3.773GeV}}$ (pb)</th>
<th>$\sigma_{e^+e^- \rightarrow f}^{\text{3.65GeV}}$ (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi \pi^0$</td>
<td>&lt; 1.8 (C.L. = 90%)</td>
<td>&lt; 9.0 (C.L. = 90%)</td>
</tr>
<tr>
<td>$\phi \eta$</td>
<td>7.1 ± 3.4 ± 0.5</td>
<td>&lt; 17.8 (C.L. = 90%)</td>
</tr>
<tr>
<td>$\phi \pi^+ \pi^-$</td>
<td>3.7 ± 2.2 ± 0.3</td>
<td>&lt; 20.2 (C.L. = 90%)</td>
</tr>
<tr>
<td>$\phi K^+ K^-$</td>
<td>17.4 ± 3.7 ± 1.6</td>
<td>15.3 ± 8.1 ± 1.4</td>
</tr>
<tr>
<td>$\phi p\bar{p}$</td>
<td>&lt; 3.8 (C.L. = 90%)</td>
<td>&lt; 8.4 (C.L. = 90%)</td>
</tr>
<tr>
<td>$2(\pi^+ \pi^-)\pi^0$</td>
<td>77.2 ± 8.3 ± 8.1</td>
<td>130.2 ± 21.2 ± 13.8</td>
</tr>
<tr>
<td>$K^+ K^- \pi^+ \pi^- \pi^0$</td>
<td>159.4 ± 16.0 ± 17.1</td>
<td>198.8 ± 33.1 ± 21.3</td>
</tr>
<tr>
<td>$p\bar{p}\pi^0$</td>
<td>7.8 ± 1.3 ± 0.9</td>
<td>9.3 ± 3.3 ± 1.0</td>
</tr>
<tr>
<td>$p\bar{p}\pi^+ \pi^- \pi^0$</td>
<td>60.6 ± 7.6 ± 8.3</td>
<td>30.0 ± 10.8 ± 4.1</td>
</tr>
<tr>
<td>$2(K^+ K^-)\pi^0$</td>
<td>12.4 ± 4.4 ± 1.3</td>
<td>&lt; 20.2 (C.L. = 90%)</td>
</tr>
<tr>
<td>$3(\pi^+ \pi^-)\pi^0$</td>
<td>102.6 ± 18.2 ± 14.9</td>
<td>117.2 ± 41.6 ± 17.0</td>
</tr>
<tr>
<td>$2(\pi^+ \pi^-)\eta$</td>
<td>103.1 ± 23.3 ± 10.8</td>
<td>75.1 ± 35.0 ± 7.9</td>
</tr>
</tbody>
</table>

Preliminary!
SUMMARY

◆ BES measured $R$ at 3.773 GeV and around 3.666 GeV with average uncertainties of $\sim 5\%$

$$R = 3.75 \pm 0.04 \pm 0.19 \quad @ \quad \sqrt{s} = 3.773 \ \text{GeV}$$

$$\overline{R}_{uds} = 2.22 \pm 0.02 \pm 0.09 \quad @ \quad \sqrt{s} \approx 3.66 \ \text{GeV}$$

$$\overline{R}_{uds} = 2.21 \pm 0.13 \quad @ \quad \text{in the range from 3.67 to 3.89 GeV}$$

Obtained from fitting to $\psi(3686)$ and $\psi(3770)$

$$\sigma_{\psi (3770)}^{\text{Born}} = 9.35 \pm 0.29 \pm 0.80 \ \text{nb}$$

◆ BES measured the energy dependent DD-bar cross sections, and the cross section at 3.773 GeV

$$\sigma_{DD}^{\text{obs}} = 6.14 \pm 0.12 \pm 0.50 \ \text{nb}$$  
Singly tagged D analysis

$$\sigma_{DD}^{\text{obs}} = 5.93 \pm 0.46 \pm 0.35 \ \text{nb}$$  
Doubly tagged D analysis
◆ BES measured the branching fractions for inclusive non-DD-bar decays of $\psi(3770)$ using two different data sample and two different methods

\[
\begin{align*}
BF (\psi (3770) \rightarrow D^0 \bar{D}^0) &= (50.1 \pm 1.3 \pm 3.9)\% \\
BF (\psi (3770) \rightarrow D^+ D^-) &= (35.9 \pm 1.1 \pm 3.5)\% \\
BF (\psi (3770) \rightarrow D \bar{D}) &= (86.0 \pm 1.7 \pm 6.0)\% \\
BF (\psi (3770) \rightarrow \text{non} - D \bar{D}) &= (14.0 \pm 1.7 \pm 6.0)\% \\
\end{align*}
\]

Determined from analysis of R values and DD-bar cross sections

Obtained from fitting to the inclusive hadron and the DD-bar production cross sections simultaneously.

◆ We searched for some exclusive multi-hadronic final state at $E_{cm}=3.773$ GeV and $E_{cm}=3.65$ GeV. We did not observe obvious cross section discrepancy at the two energy points.
Thank You
Comparison with those measured by CLEO-c

BES-II

\[ BF(\psi(3770) \to non-D\bar{D}) = (16.2 \pm 6.8 \pm 6.4)\% \]

Taking \( \sigma_{\psi(3770)}^{obs} \approx 7\) nb

\[ \sigma_{\psi(3770) \to non-D\bar{D}} \approx 1.1 \pm 0.7\) nb \]

(the error in \( \sigma_{\psi(3770)}^{obs} \) is ignored)

Method:

Based on inclusive hadron and DD cross section scan data.

Fitting the observed inclusive hadron and DD production cross sections line-shape to the theoretical cross sections to obtain the branching fractions.

Both results are not contradiction.

CLEO-c (hep-ex/0512038)

\[ \sigma_{\psi(3770) \to hadrons}^{obs} = 6.38 \pm 0.08^{+0.41}_{-0.30}\) nb \]

CLEO-c directly counted the number of hadronic events observed at 3.773 GeV, and subtracted the backgrounds from the J/ψ, ψ(2S) tails and QED continuum.

CLEO-c averaged the efficiencies for the DD decay (0.8) and ψ(2S) decay (0.68) to estimate the efficiency for the decay \( \psi(3770) \to non-DD \) hadrons. CLEO-c considered the possible effect of Interferences between the final states of resonance decays and non-resonant annihilation, assumed the amplitude for \( \gamma \to qq \to hadrons \) interfere in the same way as one for \( \gamma \to \mu^+\mu^- \).
Comparison with those measured by CLEO-c

**BES-II**

\[ \sigma_{DD}^{obs} = 6.14 \pm 0.12 \pm 0.50 \text{ nb} \]

\[ BF(\psi(3770) \rightarrow non - D \overline{D}) = (14.0 \pm 1.7 \pm 6.0)\% \]

Taking \( \sigma_{\psi(3770)}^{obs} \approx 7 \text{ nb} \)

\[ [\sigma_{\psi(3770)}^{obs} = (9.35 \times 0.764 + 6.8)/2 = 6.95 \text{ nb}] \]

\[ \sigma_{\psi(3770)} \rightarrow non - D \overline{D} \approx 1.0 \pm 0.44 \text{ nb} \]

Based on measured R values.

**Method:**

BES measured \( R_{uds} \) near \( D \overline{D} \) threshold and \( R \) at 3.773 GeV with traditional method, then calculate the Born order cross section for \( \psi(3770) \) production. By comparing the cross sections for \( DD \) and \( \psi(3770) \) production, BES obtained the branching fraction. BES used an generator which included ISR to simulate the decay \( \psi(3770) \rightarrow \text{hadrons} \).

**CLEO-c**

\[ \sigma_{DD}^{obs} = 6.39 \pm 0.10^{+0.17}_{-0.08} \text{ nb} \]

\[ \sigma_{\psi(3770) \rightarrow \text{hadrons}}^{obs} = 6.38 \pm 0.08^{+0.41}_{-0.30} \text{ nb} \]

\[ \sigma_{\psi(3770)} \rightarrow non - D \overline{D} = -0.01 \pm 0.08^{+0.41}_{-0.30} \text{ nb} \]

**Discussion:**

If BES considered the interference effect between \( RES \rightarrow \gamma^* \rightarrow qq \rightarrow \text{hadrons} \) and \( e^+e^- \rightarrow \gamma^* \rightarrow qq \rightarrow \text{hadrons} \), we obtain:

\[ BF(\psi(3770) \rightarrow non - D \overline{D}) \approx (10.0 \pm 1.7 \pm 6.0)\% \]

\[ \sigma_{\psi(3770) \rightarrow non - D \overline{D}} \approx 0.7 \pm 0.44 \text{ nb} \]

In this case, if we take \( \sigma_{DD} = 6.39 \text{ nb} \),

\[ \sigma_{\psi(3770) \rightarrow non - D \overline{D}} \approx 0.4 \text{ nb} \]

These results are not contradiction.
Comparison of measurements of the cross sections for DD-bar production

- MARK-II (Single Tag): (5.39 +/- 0.40) nb
- MARK-I (Single Tag): (4.82 +/- 0.59) nb
- BES-II (Single Tag): (6.14 +/- 0.59) nb
- MARK-III (Double Tag): (5.00 +/- 0.52) nb
- BES-II (Double Tag): (5.93 +/- 0.58) nb
- CLEO (Double Tag): (6.39 +/- 0.16) nb

$\sigma_{DD}^{obs}$ [nb]