Symposium on 30 years of BES Physics

# Initial ψ(3770) Program at BES


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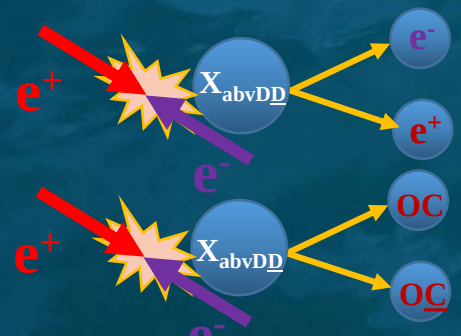
5 September, 2019

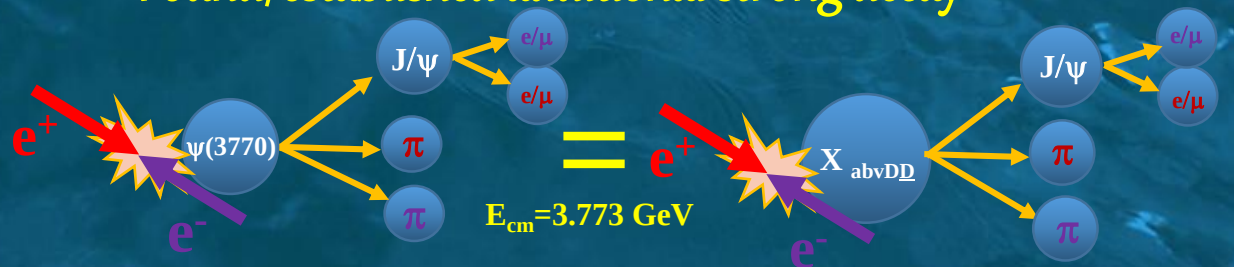
Standard pictures of $X_{SabvD\bar{D}}$ decays




$E_{cm}$>3.73 GeV

Before 2002

Found/established additional strong decay




$E_{cm}$=3.773 GeV

June 2002

Finding new $c\bar{c}$ and non-$c\bar{c}$ states, $X_{abvD\bar{D}}$, by means of searching for $J/\psi\pi\pi$ in the final states of $X_{abvD\bar{D}}$

After June 2002

# Outline

- ψ(3770) project
  - History of ψ(3770) physics at BES-I and BES-II
  - QCD and $X_{abv D\bar{D}}$ states
  - ψ(3770) physics and international competition
  - Innovation leads the future
- Total measurements at BES-II
- Several examples of measurements at BES-II
  - Discovery of ψ(3770)→$J/\psi\pi^+\pi^-$
  - Finds 15% of ψ(3770) decay into non-$D\bar{D}$
  - …
  - Absolute measurements of $f_{D+}$, $f_+^K(0)$ and $f_+^\pi(0)$
  - Solving a long-standing puzzle in D decays
- Measurements naturally extended to BES-III
- Summary

# History of the ψ(3770) program

- **Proposals for taking ψ(3770) data at BES-I were not approved**
  - D physics at 3.773 proposed by Prof. Hitlinng in 1991
  - D physics at 3.773 proposed by Prof. Yan in 1992
  - D physics at 3.773 proposed by some others in 1993 ?
- **BES-I accumulated 24 $pb^{-1}$ of data at 4.03 and 4.14 GeV for $Ds^+$ physics**
  - $D_s^+$ physics at ψ(4030) proposed by Profs. Zhang/Toki at the BES-I was approved in1991
  - During 1992 -- 1993, 22.3 $pb^{-1}$ of data were collected at 4.03 GeV
    1.5 $pb^{-1}$ of data were collected at 4.14 GeV
- **BES-II collected 7.4 $pb^{-1}$ of data in two test-runs for ψ(3770) data taking**
  - In 2001, ~2 $pb^{-1}$ of data were collected at energies from 3.67 to 3.89 GeV; ~1.3 $pb^{-1}$ of data were collected at 3.773 GeV
  - In April 2002, ~5.3 $pb^{-1}$ of data were collected at 3.773 GeV
- **Began to study decays of $X_{abvD\underline{D}}$ [ψ(4030), ψ(4140), non-c$\underline{c}$ states, ψ(3770),…] in 1995**
  - Study D-meson decays
  - Focus on studying no-open-charm-pair (NOCP) decays of $X_{abvD\underline{D}}$ states
  - Search for non-c$\underline{c}$ state by studying NOCP decays of $X_{abvD\underline{D}}$, which might easily decay to NOCP FS.

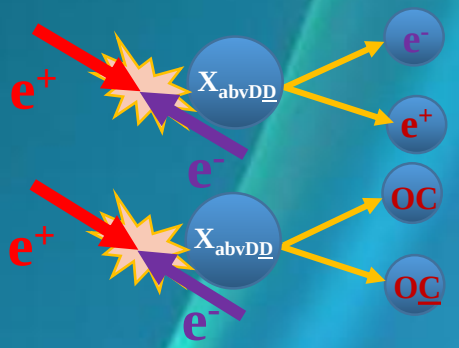
# QCD and $X_{abvD\underline{D}}$[$X_{abvD\underline{D}}$=ψ(3770) at 3.773 GeV]

## ➢ Test of QCD in lower energy

- QCD predicts existing non-c$\underline{c}$ states $S_{abvD\underline{D}}$ lying above D$\underline{D}$ threshold (abvD$\underline{D}$)
- QCD effective theories expect decay rates of c$\underline{c}$ state $R_{abvD\underline{D}}$ to exclusive final states
- Finding $S_{abvD\underline{D}}$ and measuring the rates of $R_{abvD\underline{D}}$ decays are important tests of QCD theory
- Precise measurements of decay constant and form factors of D mesons are crucial test of LQCD

## ➢ Bottleneck of finding new state $S_{abvD\underline{D}}$ and new decays of $R_{abvD\underline{D}}$

- Before 2002, neither $S_{abvD\underline{D}}$ nor NOCP (non-open-charm-pair) decays of $R_{abvD\underline{D}}$ was observed since few experimental physicists studied NOCP decays of $X_{abvD\underline{D}}$ (here X stands for S or R)
- At that time, experimental physicists believed 100% of $X_{abvD\underline{D}}$ decay into OCP final state, which had become a bottleneck of discovering new state $X_{abvD\underline{D}}$ and new kinds of decays of $X_{abvD\underline{D}}$




$E_{cm}$>3.73 GeV
Before 2002

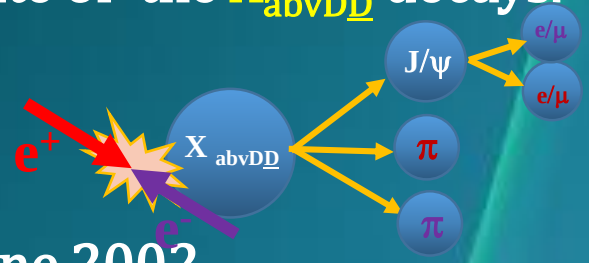
## ➢ The goal of ψ(3770) or $X_{abvD\underline{D}}$ physics at BES-II

- To find NOCP decays of $X_{abvD\underline{D}}$, to break through the bottleneck, …
- To find new state by means of studying the NOCP decays of $X_{abvD\underline{D}}$
- To study D-meson decays: measuring $f_D$, hadronic form factors, and test of conservation law, …

# Evidence for $\psi(3770)\to J/\psi\pi^+\pi^-$ & Proposal for $\psi(3770)$ physics

## ➢ Results of $\psi(3770)$ & D decays from available data

- We studied more than 30 NOCP final states from these data, and find some possible NOCP final states. Among these $J/\psi\pi^+\pi^-$ is the most sensitive NOCP final state of the $X_{abvD\underline{D}}$ decays.
- We found $6.8\pm3$ $J/\psi\pi^+\pi^-$ from the data taken ~3.773 GeV, found $(24\pm13\pm14)\%$ of $\psi(3770)$ decay into NOCP final states, ...
- These were reported at the BES Collaboration 2002 Meeting held in June 2002.




## ➢ Proposal for $\psi(3770)$ physics program

At BES Collaboration 2002 Meeting we propased for taking $\psi(3770)$ data [Note].

- Study NOCP decays of $\psi(3770)$ or $X_{abvD\underline{D}}$
  - ✓ Precisely measure Br[$\psi(3770)\to J/\psi\pi^+\pi^-$]
  - ✓ Precisely measure Br[$\psi(3770)\to$non-D$\underline{D}$]
  - ✓ Finding more $\psi(3770)\to$light-hadrons decays
  - ✓ Searching for new state(s), ...
- Study D-meson decays
  - ✓ Measurement of $f_D$
  - ✓ Measurement of FF $f_+^K(q^2)$, $f_+^\pi(q^2)$
  - ✓ Test Isospin symmetry in D SL decays
  - ✓ ...

Note: Because six experiments in the world had been studying both the Charmonium and D-meson decays, some friends in the Collaboration strongly opposed taking $\psi(3770)$ data since they believe that it is difficult for BES to publish significant papers based on the $\psi(3770)$ data in any International Journal due to the highly hot competition with other experiments in both the $\psi(3770)$ and D physics .

# Competition with other experiments

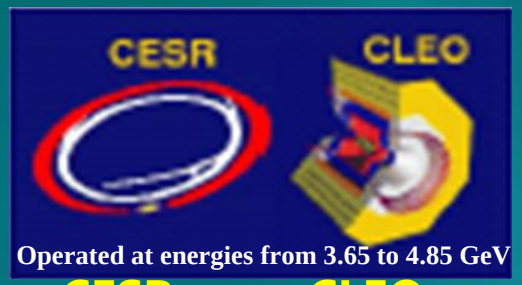


## ➢ ψ(3770) physics

- In 2003, seven experiments [BaBar, BELLE, CDF, D0 and FOCUS, CLEO-c, BES-II] had been studying both the Charmonium and D physics
- The performances of these six detectors are much better than that of the BES-II.


BEPC


BES-II

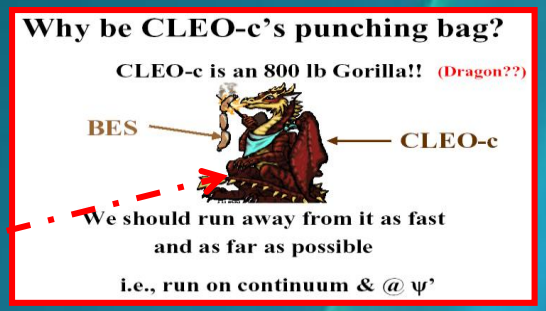



CESR CLEO-c

- CLEO-c is going to collect 1 $fb^{-1}$ of data at 3.773 GeV
- Comparing to BES-II, CLEO-c is really too strong !
- American friends withdrew from paper publications based on ψ(3770) data because of existing CLEO-c

人们普遍认为，B factories 可以做精密的粲偶素物理研究，并可以取代低能近阈的粲物理研究






Prof. Olsen kindly presented this cartoon at the BES Collaboration Meeting held in June 2002, which image to compare the actual strength of the BES-II and CLEO-c, advising the BES collaborators not to take ψ(3770) data, instead taking data at ψ(3686) peak and 3.65 GeV, so that BES could run away from the CLEO-c AF&AFSP!

**Studies of ψ(3770) and D physics were very competitive in the world 16 years ago !**

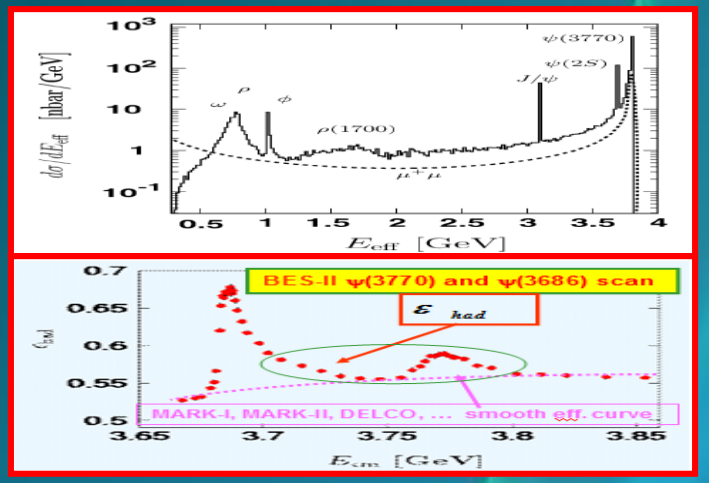
# Innovative methods/techniques and program

## How to win the competition ?

- Rely on soft strength; make an unique program on study of ψ(3770) or $X_{abvD\underline{D}}$ physics;
- Develop some innovative methods and MC techniques for the physics

## Innovative methods and MC techniques

- Techniques to separately different kinds of events
- Codes for analyzing observed cross sections in full energy region
- Fully MC simulated ISR-VP correction generators
- The ISR and VP correction programs, …




## Proposal approved & four months ψ(3770) data taking

- As well prepared software for the project, our proposal was approved in Nov., 2002
- ~25 $pb^{-1}$ of data (cross-section scan + data taking at 3.773 GeV) were accumulated in 2003

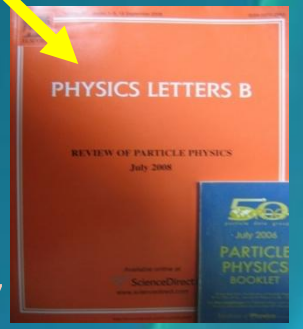
## Global strategy and direction

- Take globally analyzing $\sigma(e^+e^- \rightarrow hadrons)$ as a means to an end
- Grasp the systematic studies of NOCP decays of $X_{abvD\underline{D}}$ as the breakthrough direction
- Take finding some more sensitive NOCP final states of $X_{abvD\underline{D}}$ decays as A Breakthrough .

**The BES finally won the competition with the other experiments in ψ(3770) physics**

# Summary of total Measurements/Cited by PDG

- Measured more than170 physical quantities, including decay branching fractions of ψ(3770), $D^0$ and $D^+$ mesons, resonance parameters of ψ(3686) and ψ(3770), …
- Measured ~50-channel cross sections for $e^+e^-$→LH and $e^+e^-$→D$\underline{D}$ at 3.65 and ~3.773 GeV
- Measured $R_{uds}$, $R_{\psi(3770)}$ and $R_{had}$ at energies from 3.6 to 3.9 GeV.
- More than 140 measurements are included in the Review of Particle Physics -- PDG
  - 63 of these are the first measurements
  - 45 of these are the most precision measurements
  - 33 of these are general measurements
  - Our the world's best measurements of ψ(3686) and ψ(3770) resonance parameters dominate the weighted-average values in PDG editions after 2007

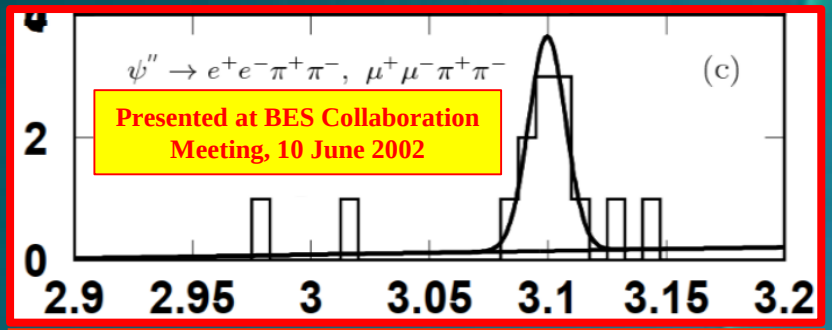


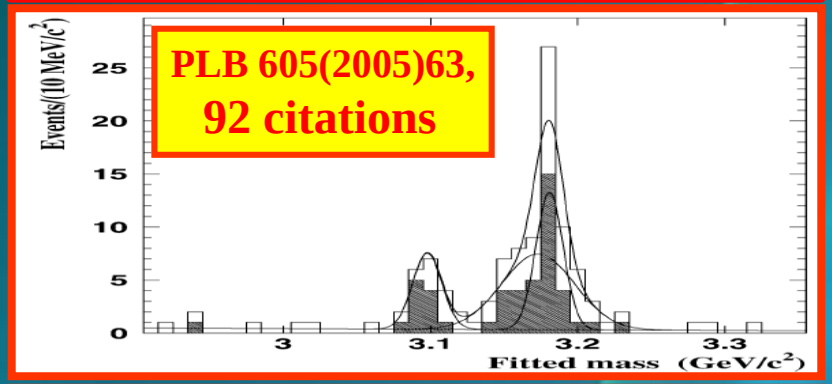

- 25 measurements of ψ(3686) in PDG are improved by re-normalizing with our measurements
- Published 35 papers in PRL, PRD, … which have been cited by more than 1000 times
- More than 31 invited talks were presented at International Conference/Workshop till 2009
- Wrote ψ(3770) non-D$\underline{D}$ decays in 《Heavy Quarkonium Physics》 published in EPJC , and ψ(3770) physics and D physics in a book entitled 《 $e^+e^-$ Collision Physics 》 published in China

**As an example, several discoveries/measurements are presented below:**

# Discovery #1: $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$

- BES discovers the first NOCP decay of $X_{abvD\underline{D}}\rightarrow J/\psi\pi^+\pi^-$ for the first time, which is assigned to be $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$.
- This discovery reveals that the particles $X_{abvD\underline{D}}$ lying above $D\underline{D}$ threshold can decay into NOCP final states
- It overturns the conventional knowledge that 100% of $X_{abvD\underline{D}}$ decay into OCP final states, thereby breaking through the Bottleneck of finding new states $X_{abvD\underline{D}}$.
- BES finds a 'golden' NOCP final state -- $J/\psi\pi^+\pi^-$ which can be used to find and study NOCP decays of other $X_{abvD\underline{D}}$.




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

- The news of this discovery reported at BES Collaboration 2002 Meeting spread quickly outside of the Collaboration, inspiring a lot of physicists to find the decays of $X_{abvD\underline{D}}\rightarrow J/\psi\pi^+\pi^-$, leading to the discovery of new particles, such as XYZ in a short time scale after 2002.
- This discovery and measurement of Br[$\psi(3770)\rightarrow J/\psi\pi^+\pi^-$] can be used to test the QCD multipole-expansion approaches in calculations of $\psi(3770)$ hadronic transition.

# International repercussions: Discovery of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$



- **Discovery of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ by BES was widely questioned in the world**

  After BES discover this decay, CLEO-c began to find $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ in their data. But they did not observe it, then the BES discovery was widely questioned in the world

  - **2003 Lepton and Photon Interaction Conf., 11—16 Aug., 2003**

Prof. Skwarnicki from the CLEO collaboration claimed that they did not see any event of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$

  - **Hadron 2003**

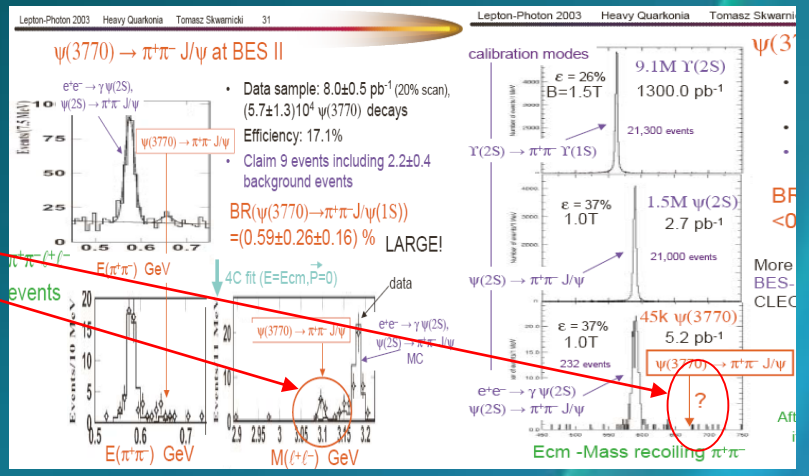
The CLEO Spokesperson, Prof. Cassel claimed in the Conference Summary Talk that CLEO-c did not observe $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$. He also said the CLEO-c detector is much better than the BES-II, why did the BES-II discover it, but the CLEO-c did not observe it?

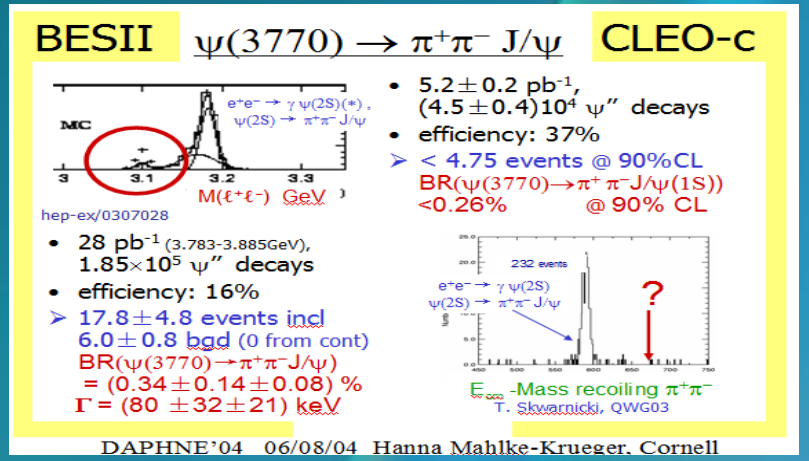
  - **DAPHNE 2004, Aug., 2004**

Prof. Hanna from Cornell University claimed that the CLEO-c did not observed any $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$

  - **A set of Conferences/workshops held during 2003--2005**

A lot of physicists from different Nations called in questions for $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ discovered by the BES



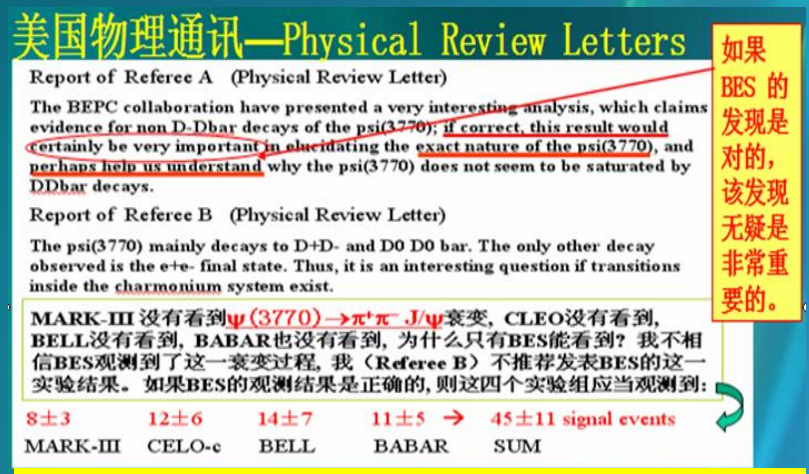
# International repercussions: Discovery of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$

- **The BES-II $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ is challenged by the CLEO-c**
  - ✓ A lot of particle physicists pointed out that it is a terribly hard measurement to search for this typical $J/\psi\pi^+\pi^-$ final state, or it is impossible to observe this transition.

  - ✓ Prof. Quigg (the head of theoretical physics division of Feimi national Laboratory) said "it is a terribly hard measurement, but a precise normalization for the 1D properties is urgently needed… [hep-ph/0403187]"

  - ✓ Prof. Eichten said in his published-paper that "$\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ discovered by the BES is seriously challenged by the CLEO-c.

- **The paper was rejected by PRL**
  - ✓ Referee A said, "If correct this result would certainly be very important in elucidating the exact nature of $\psi(3770)$,...
  - ✓ Referee B said MARK-III did not observe $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$, CLEO-c did not observe this decay, BELLE did not observe it, and BaBar did not observe this decay. Why only the BES can observe this decay? I do not believe the BES result! I do not recommend to publish the BES result.

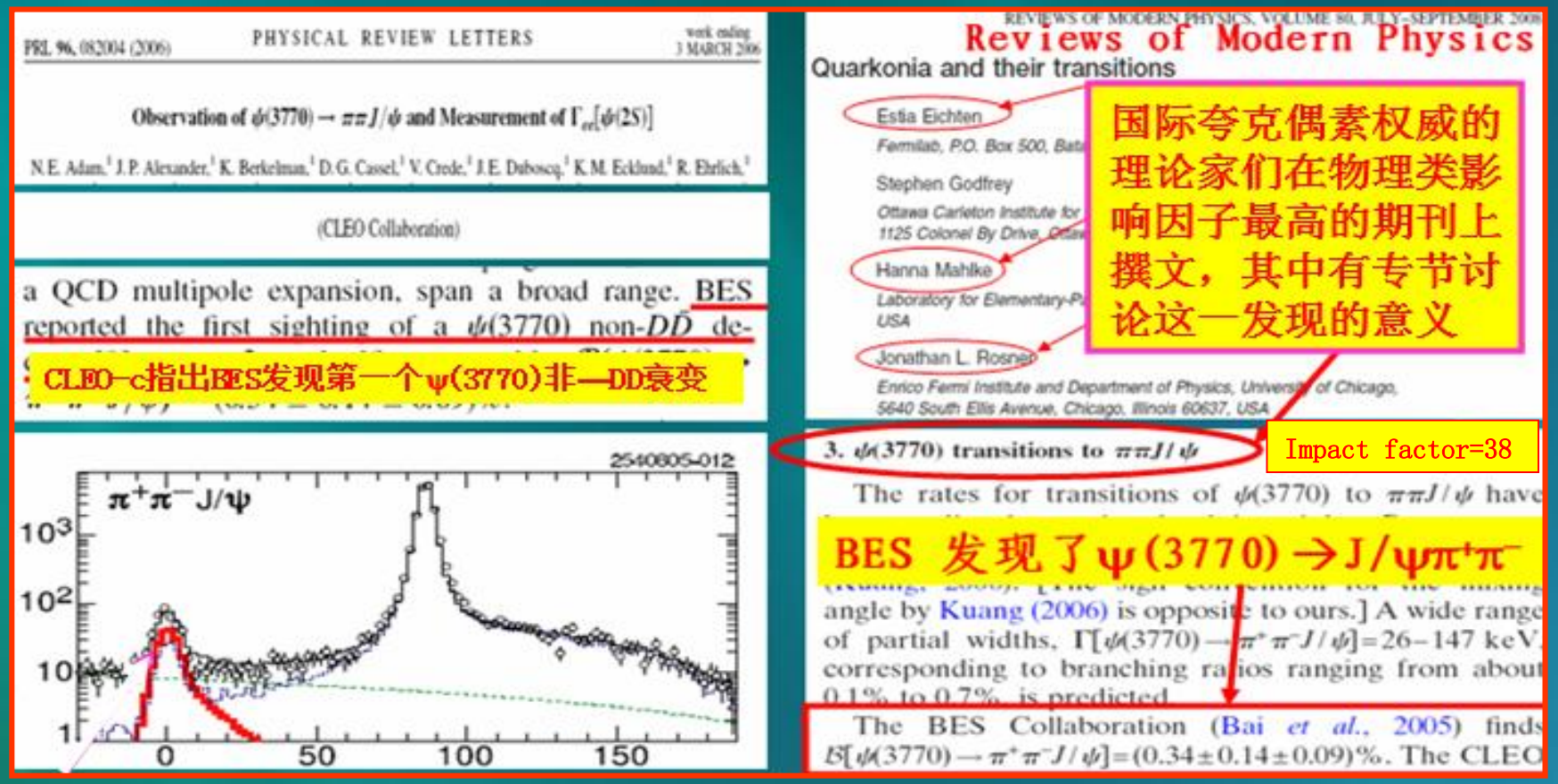



$\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ is published in both the HEP&NP and PLB 605(2005)63; has been cited by more than 93 times

# International repercussions: Discovery of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$

- **After more than two years efforts, CLEO-c finally observe $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$**

  In the world-wide highly hot debate/controversy about this discovery, the physicists from CLEO-c discussed the analysis with us in very details by e-mails for many times. After improving their event selection criteria to prevent rejecting signal of $J/\psi\pi^+\pi^-$ in suppressing backgrounds, … two years latter (Aug., 2005), CLEO-c finally observed the $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$

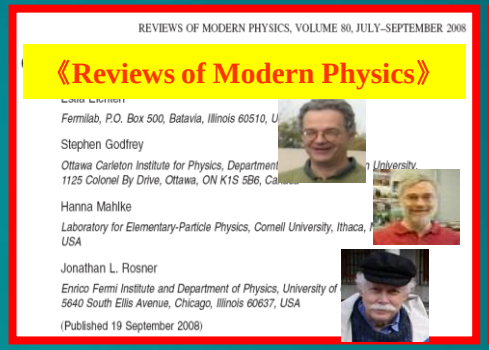


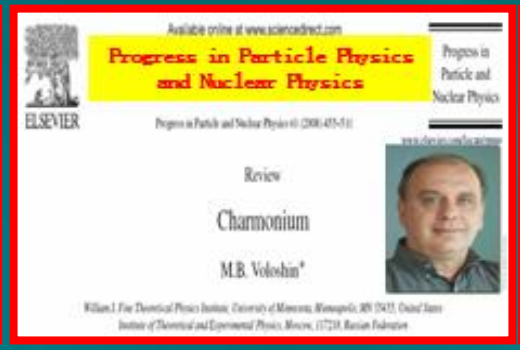

**Up to August 2005, the world-wide highly hot debate/controversy about the discovery of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ had come to a close.**

**The debate lasted over two years!**

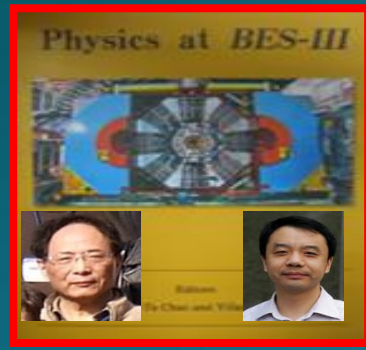
# Effect of discovery of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ on physics

- $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ is included in the most famous Journal
  - As a transition law, $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ is included in "Review of Moden Physics", and so on, in which the transition is discussed in a spectral section or a paragraph



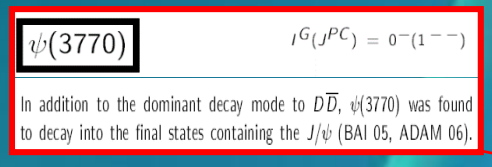


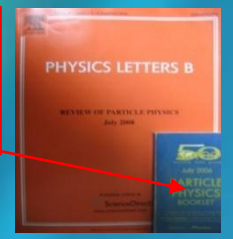


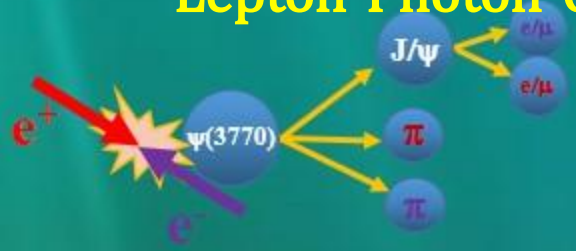

80多位国际正负电子物理专家、教授和学者合著

  - The <<Particle Physics BOOKLET>> annotates this discovery. It is written that 'In addition to dominant decay mode to $D\bar{D}$, $\psi(3770)$ was found to decay into the final states containing the $J/\psi$.' Making this kind commentary and annotation on one decay mode in the BOOKLET is very rare in the last 40 years.

- From 2003 to 2008, in plenary talks presented at the ICHEP and Lepton-Photon-Conference, $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ were always mentioned/discussed



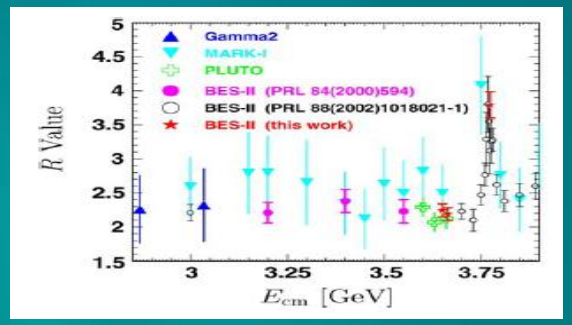




All of these indicate that the discovery of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ is very important for helping us understand the strong interaction inside of the Charmonium system

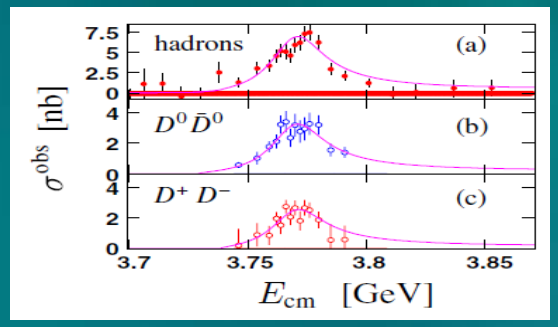
# Discovery #2: 15% of ψ(3770) decay into non-D$\underline{D}$

- Based on three independent data samples and four analysis methods, BES finds that (14.7±3.2)% of ψ(3770) decays into NOCP for the first time in the world, elucidating that branching fractions of particles $X_{abv D\underline{D}}$ decay into NOCP final states could be large

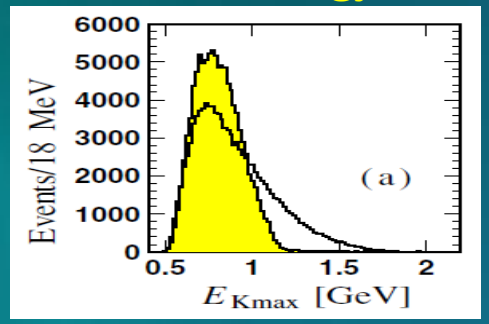
1. R-value measurements



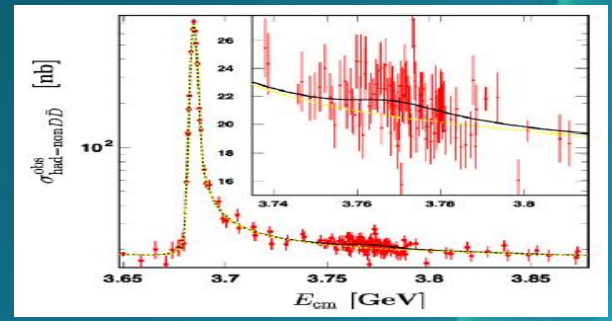

2. Cross-section scan




3. K-max energy CS




4. K-max energy CS scan




ELSEVIER Physics Letters B 641 (2006) 145–155 www.elsevier.com/locate/physletb

Measurements of the cross sections for $e^+e^- \to$ hadrons at 3.650, 3.6648, 3.773 GeV and the branching fraction for $\psi(3770) \to$ non-$D\bar{D}$

PRL 97, 121801 (2006) PHYSICAL REVIEW LETTERS week ending 22 SEPTEMBER 2006

Measurements of the Branching Fractions for $\psi(3770) \to D^0\bar{D}^0$, $D^+D^-$, $D\bar{D}$, and the Resonance Parameters of $\psi(3770)$ and $\psi(2S)$

M. Ablikim,[1] J

PHYSICAL REVIEW D 76, 122002 (2007)

Direct measurements of the non-$D\bar{D}$ cross section $\sigma_{\psi(3770)\to\text{non-}D\bar{D}}$ at $E_{cm} = 3.773$ GeV and the branching fraction for $\psi(3770) \to$ non-$D\bar{D}$

M. Ablikim,[1] J. Z. Bai,[1]

ELSEVIER Physics Letters B 659 (2008) 74–79 www.elsevier.com/locate/physletb

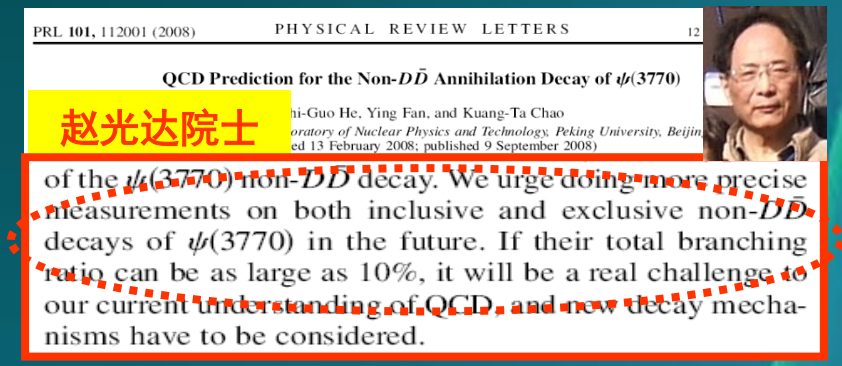
Direct measurements of the cross sections for $e^+e^- \to$ hadrons$|_{\text{non-}D\bar{D}}$ in the range from 3.65 to 3.87 GeV and the branching fraction for $\psi(3770) \to$ non-$D\bar{D}$

BES Collaboration

**These papers have been cited by 314 times**

# International repercussions : 15% of ψ(3770) decay into non-DD̄

- The Chinese Academician of CAS, Prof. K.T. Zhao pointed out: "If the branching fraction for ψ(3770)→ non-DD̄ can be as large as 10%, it will be a real challenge to our understanding of QCD, and new decay mechanisms have to be considered."


PRL 101, 112001 (2008) PHYSICAL REVIEW LETTERS 12

QCD Prediction for the Non-$D\bar{D}$ Annihilation Decay of $\psi(3770)$

赵光达院士

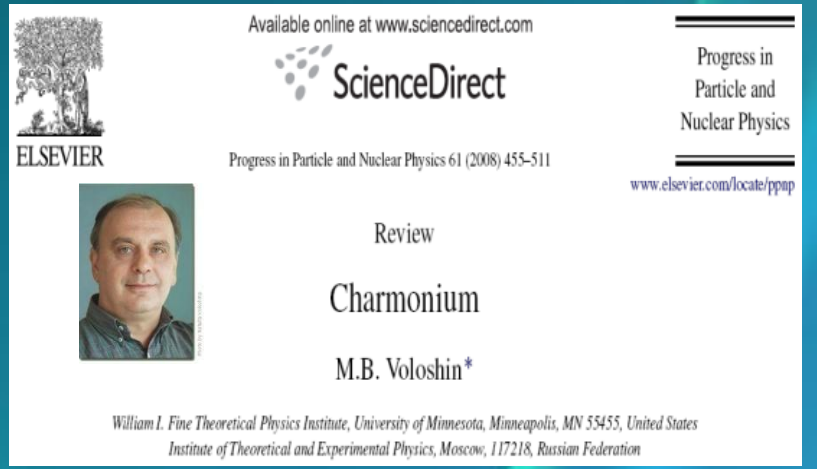
...i-Guo He, Ying Fan, and Kuang-Ta Chao

...oratory of Nuclear Physics and Technology, Peking University, Beijin...

...ed 13 February 2008; published 9 September 2008)

of the $\psi(3770)$ non-$D\bar{D}$ decay. We urge doing more precise measurements on both inclusive and exclusive non-$D\bar{D}$ decays of $\psi(3770)$ in the future. If their total branching ratio can be as large as 10%, it will be a real challenge to our current understanding of QCD, and new decay mechanisms have to be considered.

- Prof. M. B. Voloshin pointed out: "BES measurements of branching fractions for ψ(3770)→DD̄ and ψ(3770)→non-DD̄ all indicate that the branching fraction for ψ(3770) decay into non-DD̄ are large, which means ψ(3770) is not pure cc̄ state， instead containing 4-quark components in its wave function.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Progress in Particle and Nuclear Physics 61 (2008) 455–511

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Review

Charmonium

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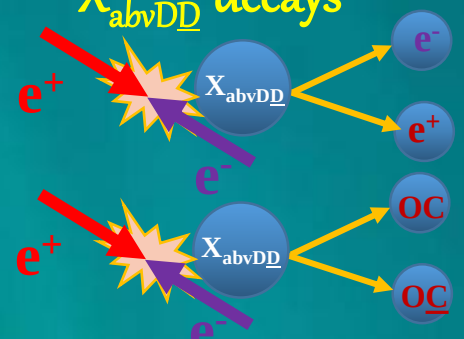
Institute of Theoretical and Experimental Physics, Moscow, 117218, Russian Federation

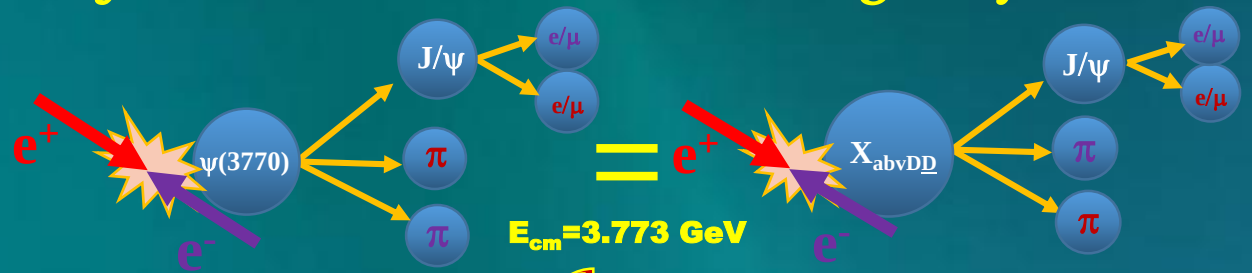
# Effects of discoveries of $\psi(3770)\to J/\psi\pi^+\pi^-$, non-D$\underline{D}$ on $X_{avbD\underline{D}}$ Physics

*Standard pictures of $X_{abvD\underline{D}}$ decays*

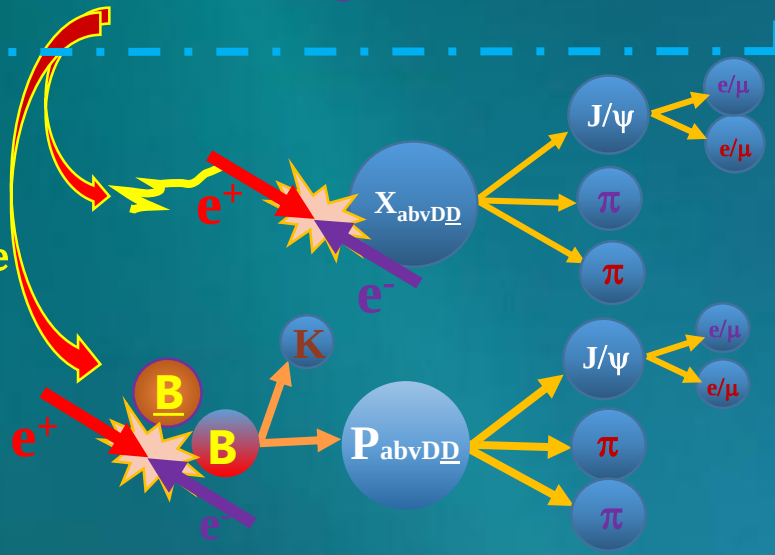



$E_{cm}$>3.73 GeV
Before 2002

*BES found/established additional strong decay in 2002*




From $\psi(3770)\to J/\psi\pi^+\pi^-$, these 2 kinds processes (on right) are naturedly expected. So there must be $J/\psi\pi^+\pi^-$ final states coming from other $X_{abvD\underline{D}}$ or $P_{abvD\underline{D}}$. Studying the $J/\psi\pi^+\pi^-$ final state at other high energy experiments probably find new non-c$\underline{c}$ states, ...




$P_{abvD\underline{D}}$ could be a vector or another kinds of state

Finding new c$\underline{c}$ and non-c$\underline{c}$ states, $X_{abvD\underline{D}}$, by means of searching for $J/\psi\pi\pi$ in the final states of these states decays

**discovery of XYZ states**

After June 2002

BES-II开辟了实验研究DD阈上粒子$X_{abvD\underline{D}}$非粲介子衰变的新研究方向和新研究领域，引领了利用$J/\psi\pi^+\pi^-$作为搜寻目标，研究$X_{abvD\underline{D}}\to J/\psi\pi^+\pi^-$的衰变，引发国际高能物理界的物理学家寻找、研究DD阈上粒子非粲介子对衰变的热潮。

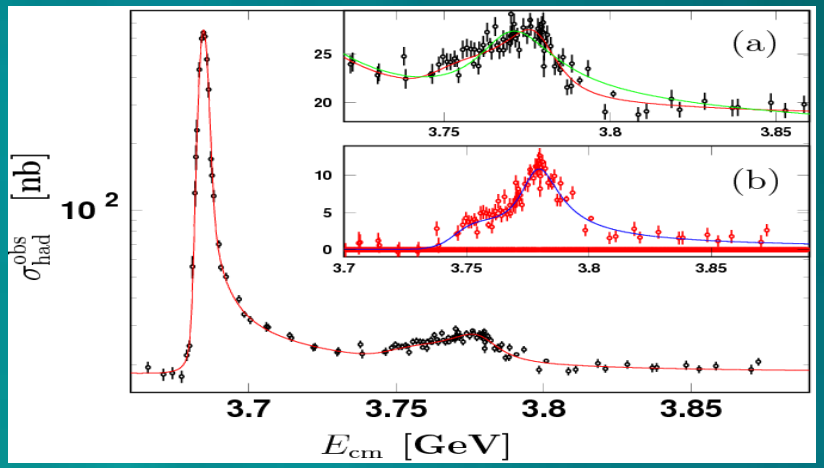
$\psi(3770)\to J/\psi\pi^+\pi^-$的发现揭示了DD阈粒子可以通过强作用衰变到$J/\psi\pi^+\pi^-$的物理规律；在国际上引起很大反响，带动了国际高能物理界研究DD阈粒子的非粲介子对衰变，以$J/\psi\pi^+\pi^-$作为搜寻目标，寻找DD阈上粒子非粲介子对衰变的热潮。…

摘引《两次创造跨越奇迹的BEPC》
--中国科学院大装置办公室

# Discovery #3: Anomalous line-shape of $\sigma(e^+e^-\rightarrow hadrons)$



- The BES finds an anomalous line-shape of $\sigma(e^+e^-\rightarrow hadrons)$, which is more likely a Di-structures around 3.773 GeV.




Di-structure parameters **PRL101 (2008) 102004**

Parameters under one ψ(3770) assumption

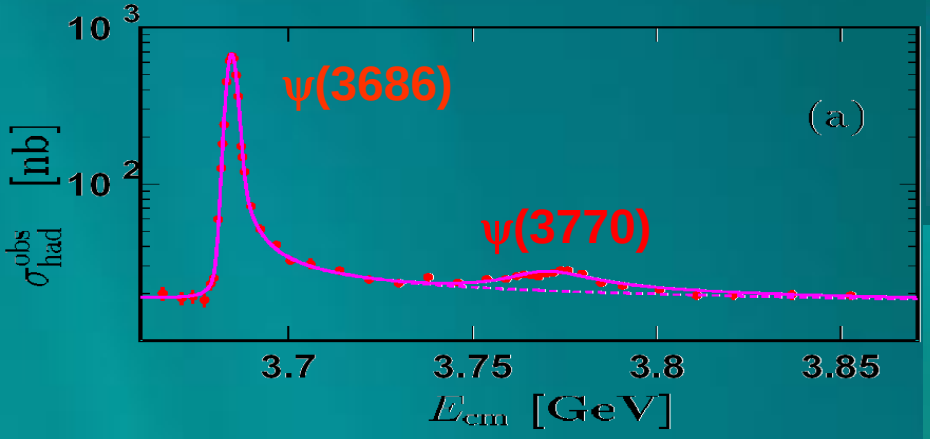
| Quantity | two AM (Solution 1) | two AM (Solution 2) | one AM | ψ(3770) and G(3900) AM (Solution 3) |
|---|---|---|---|---|
| $\chi^2$/(ndof) | 125/103 = 1.21 | 112/102 = 1.10 | 182/106 = 1.72 | 170/104 = 1.63 |
| $M_{\psi(3686)}$ [MeV] | 3685.5 ± 0.0 ± 0.5 | 3685.5 ± 0.0 ± 0.5 | 3685.5 ± 0.0 ± 0.5 | 3685.5 ± 0.0 ± 0.5 |
| $\Gamma^{tot}_{\psi(3686)}$ [keV] | 312 ± 34 ± 1 | 311 ± 38 ± 1 | 304 ± 36 ± 1 | 293 ± 36 ± 1 |
| $\Gamma^{ee}_{\psi(3686)}$ [keV] | 2.24 ± 0.04 ± 0.11 | 2.23 ± 0.04 ± 0.11 | 2.24 ± 0.04 ± 0.11 | 2.23 ± 0.04 ± 0.11 |
| $M_1$ [MeV] | 3765.0 ± 2.4 ± 0.5 | 3762.6 ± 11.8 ± 0.5 | 3773.3 ± 0.5 ± 0.5 | 3774.4 ± 0.5 ± 0.5 |
| $\Gamma^{tot}_1$ | 28.5 ± 4.6 ± 0.1 | 49.9 ± 32.1 ± 0.1 | 28.2 ± 2.1 ± 0.1 | 28.6 ± 2.3 ± 0.1 |
| $\Gamma^{ee}_1$ [eV] | 155 ± 34 ± 8 | 186 ± 201 ± 8 | 260 ± 21 ± 8 | 264 ± 23 ± 8 |
| $M_2$ [MeV] | 3777.0 ± 0.6 ± 0.5 | 3781.0 ± 1.3 ± 0.5 | ... | 3943.0 (fixed) |
| $\Gamma^{tot}_2$ [MeV] | 12.3 ± 2.4 ± 0.1 | 19.3 ± 3.1 ± 0.1 | ... | ... |
| or $\sigma_G$ [MeV] | ... | ... | | 54 (fixed) |
| $\Gamma^{ee}_2$ [eV] | 93 ± 26 ± 9 | 243 ± 160 ± 9 | ... | ... |
| or C | ... | ... | ... | 0.243 (fixed) |
| $\phi$ [deg] | ... | (158 ± 334 ± 5) | ... | (150 ± 23 ± 5) |
| $f$ | 0.4 ± 5.6 ± 0.6 | 5.2 ± 2.5 ± 0.6 | 0.0 ± 0.5 ± 0.6 | 0.0 ± 1.2 ± 0.6 |

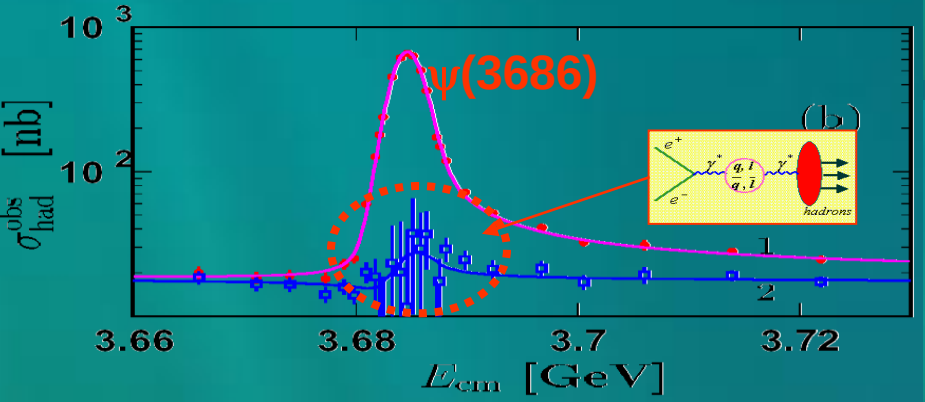
- At 7σ statistical significance level, the assumption that there is only one simple ψ(3770) at the energies from 3.73 to 3.78 is ruled out

- Prof. M.B. Voloshin interprets the 'Anomalous line-shape of $\sigma(e^+e^-\rightarrow hadrons)$' as a Diresonance. In his paper, he said "the multi-quarks state lying threshold energy would affect the nature of the "well known" resonance, which is very similar to what we reported in the BES published paper. He suggests to investigate the nature of the "well known" resonance

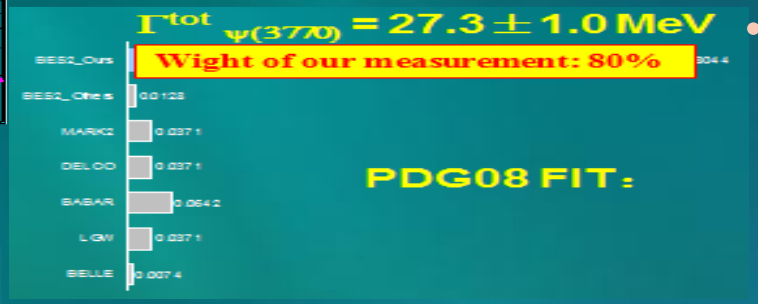
# Example #4 : Precise measurements of ψ(3686) and ψ(3770) parameters

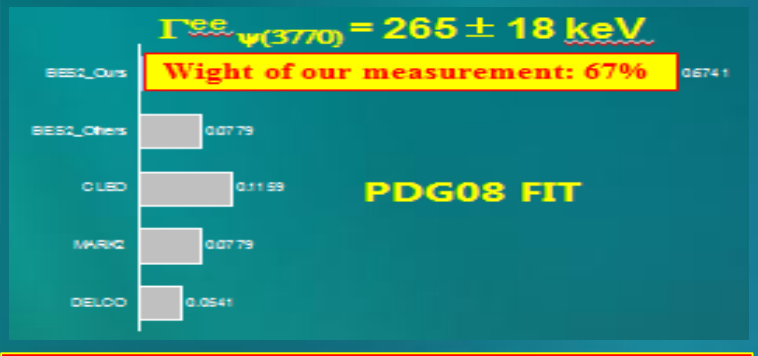
- We developed a new method to precisely measure the resonance parameters of ψ(3686) and ψ(3770)



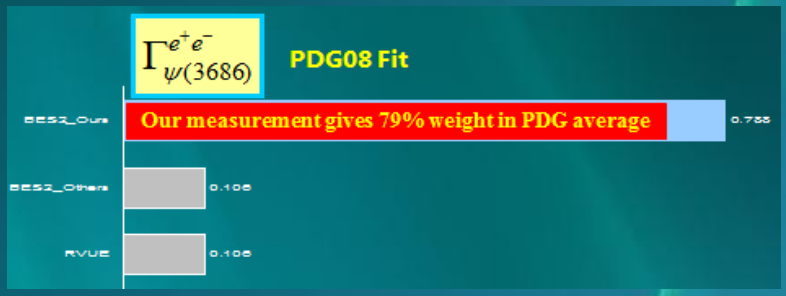




- We considered this VP correction for the first time in $e^+e^-$ experiments to get unbiased values of the parameters


These measurements contribute ~80% weights in PDG averages




- We first directly observed the effects of vacuum polarization correction on the cross sections of continuum light hadron production, which modifies the values of the parameters. We considered these effects in analysis of cross sections and solved the problems with difference in the values measured at $e^+e^-$ and $p\bar{p}$ experiments.

PRL 97 (2006) 121801, cited by 103 times

# Measurements #6: $\sigma(e^+e^-\rightarrow LH)$ at 3.65, 3.773 GeV; $Br(\psi(3770)\rightarrow LH)$



- We measured more than 50-channel cross sections for $e^+e^-\rightarrow$LH (light-hadron) at 3.65 and 3.773 GeV
- We set more than 50 upper limits on branching fractions for $\psi(3770)$ decay into light-hadrons final states, which filled the empty blocks in Particle Physics Book for these corresponding measurements

| $e^+e^-\rightarrow$ | $\sigma_{obs}$ [pb] (3.773 GeV) | $\sigma_{obs}$ [pb] (3.650 GeV) |
|---|---|---|
| $K_S^0K^-K^+\pi^+$ | 28.0±12.1±4.1 | 34.2±19.4±4.9 |
| $K_S^0K^-\pi^+\eta$ | 52.6±24.6±6.2 | <122.4 |
| $K_S^0K^-\pi^+\pi^+\pi^-\eta$ | <325.1 | <284.1 |
| $K_S^0K^-K^+K^+\pi^-\eta$ | <152.1 | <397.8 |
| $K_S^0K^-K^+K^+\pi^-\pi^0$ | <204.8 | <326.8 |
| $K_S^0K^-\rho^+$ | 45.9±14.9±5.4 | 39.9±19.6±4.7 |
| $K_S^0K^-\pi^+\rho^0$ | 93.8±43.4±13.5 | 116.8±60.3±18.2 |

| $e^+e^-\rightarrow$ | $\sigma_{obs}$ [pb] (3.773 GeV) | $\sigma_{obs}$ [pb] (3.650 GeV) |
|---|---|---|
| $\pi^+\pi^-\eta$ | 14.5±6.3±1.7 | 25.4±11.5±2.6 |
| $K^+K^-\eta$ | <21.1 | <17.4 |
| $pp\eta$ | 4.4±2.5±0.5 | <11.0 |
| $\rho^0\pi^+\pi^-\eta$ | 126.0±23.1±14.5 | 80.0±32.9±9.9 |
| $K^+K^-\pi^+\pi^-\eta$ | 63.0±24.6±7.7 | 39.2±33.3±5.3 |
| $pp\pi^+\pi^-\eta$ | 14.8±7.4±1.9 | 26.3±15.9±3.2 |
| $ppK^+K^-\pi^0$ | <8.2 | <27.3 |
| $ppK^+K^-\eta$ | <46.6 | <736.7 |

| $\psi(3770)\rightarrow$ | $\sigma_{obs}$ [pb] | Br [$\times10^{-3}$] |
|---|---|---|
| $K_S^0K^-K^-K^+\pi^+$ | <33.5 | <4.9 |
| $K_S^0K^-\pi^+\eta$ | <85.4 | <13.0 |
| $K_S^0K^-\pi^+\pi^+\pi^-\eta$ | <325.1 | <48.0 |
| $K_S^0K^-K^-K^+\pi^+\eta$ | <152.1 | <22.0 |
| $K_S^0K^-K^-K^+\pi^+\pi^0$ | <204.8 | <30.0 |
| $K_S^0K^-\rho^+$ | <44.6 | <6.6 |
| $K_S^0K^-\pi^+\rho^0$ | <108.3 | <16.0 |

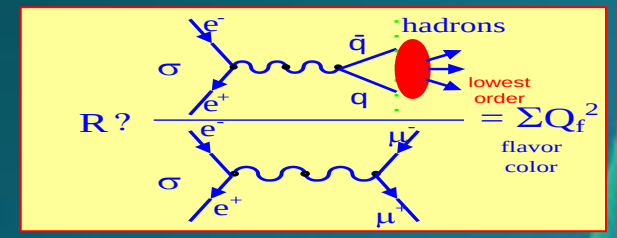
| $\psi(3770)\rightarrow$ | $\sigma_{obs}$ [pb] | Br [$\times10^{-3}$] |
|---|---|---|
| $\pi^+\pi^-\eta$ | <15.8 | <2.3 |
| $K^+K^-\eta$ | <21.1 | <3.1 |
| $pp\eta$ | <7.7 | <1.1 |
| $\rho^0\pi^+\pi^-\eta$ | <98.3 | <14.5 |
| $K^+K^-\pi^+\pi^-\eta$ | <84.0 | <12.4 |
| $pp\pi^+\pi^-\eta$ | <22.2 | <3.3 |
| $ppK^+K^-\pi^0$ | <8.2 | <1.2 |
| $ppK^+K^-\eta$ | <46.6 | <6.9 |

| | | |
|---|---|---|
| 14 | PDG2008.1027 | $\Gamma(K_SK_L)/\Gamma_{total}$ |
| 15 | PDG2008.1028 | $\Gamma(3(\pi^+\pi^-))/\Gamma_{total}$ |
| 16 | PDG2008.1028 | $\Gamma(3(\pi^+\pi^-)\pi^0)/\Gamma_{total}$ |
| 17 | PDG2008.1028 | $\Gamma(\rho^0\pi^+\pi^-)/\Gamma_{total}$ |
| 18 | PDG2008.1028 | $\Gamma(\eta_c2(\pi^+\pi^-))/\Gamma_{total}$ |
| 19 | PDG2008.1028 | $\Gamma(\phi\pi^0)/\Gamma_{total}$ |
| 20 | PDG2008.1028 | $\Gamma(4(\pi^+\pi^-))/\Gamma_{total}$ |
| 21 | PDG2008.1028 | $\Gamma(4(\pi^+\pi^-)\pi^0)/\Gamma_{total}$ |
| 22 | PDG2008.1028 | $\Gamma(K\bar{K}\rho\pi^0)/\Gamma_{total}$ |
| 23 | PDG2008.1028 | $\Gamma(K\bar{K}\rho\pi^+$c.c.$)/\Gamma_{total}$ |
| 24 | PDG2008.1028 | $\Gamma(\phi\pi^+\pi^0)/\Gamma_{total}$ |

| | | |
|---|---|---|
| 25 | PDG2008.1028 | $\Gamma(K^{*0}\bar{K}^{*0}\pi^+\pi^0+$c.c.$)/\Gamma_{total}$ |
| 26 | PDG2008.1028 | $\Gamma(K^{*0}\bar{K}^{*0}\pi^+\pi^-+$c.c.$)/\Gamma_{total}$ |
| 27 | PDG2008.1028 | $\Gamma(K\bar{K}2(\pi^+\pi^-))/\Gamma_{total}$ |
| 28 | PDG2008.1028 | $\Gamma(K\bar{K}2(\pi^+\pi^-)\pi^0)/\Gamma_{total}$ |
| 29 | PDG2008.1028 | $\Gamma(\rho^0K^+K^-)/\Gamma_{total}$ |
| 30 | PDG2008.1028 | $\Gamma(2(K\bar{K})\pi^+\pi^-)/\Gamma_{total}$ |
| 31 | PDG2008.1028 | $\Gamma(K^{*0}\bar{K}^{*0}\pi^+$c.c.$)/\Gamma_{total}$ |
| 32 | PDG2008.1029 | $\Gamma(pp^{-bar}\pi^0)/\Gamma_{total}$ |
| 33 | PDG2008.1029 | $\Gamma(\Lambda\bar{\Lambda}^{-bar}\pi^0)/\Gamma_{total}$ |
| 34 | PDG2008.1029 | $\Gamma(pp^{-bar}2(\pi^+\pi^-))/\Gamma_{total}$ |
| 35 | PDG2008.1029 | $\Gamma(\rho^0pp^{-bar})/\Gamma_{total}$ |
| 36 | PDG2009 | $\Gamma(D^+\rightarrow\mu^+X)/\Gamma_{total}$ |
| 37 | PDG2009 | $\Gamma(2(\pi^+\pi^-\pi^0))/\Gamma_{total}$ |
| 38 | PDG2009 | $\Gamma(3(\pi^+\pi^-\pi^0))/\Gamma_{total}$ |
| 39 | PDG2009 | $\Gamma(\pi^+\pi^-2\pi^0))/\Gamma_{total}$ |
| 40 | PDG2009 | $\Gamma(K^+K^-2\pi^0))/\Gamma_{total}$ |
| 41 | PDG2009 | $\Gamma(K^+K^-\pi^+\pi^-2\pi^0))/\Gamma_{total}$ |
| 42 | PDG2009 | $K_S^0K^-\pi^+$c. c. |
| 43 | PDG2009 | $K_S^0K^-\pi^+\pi^0$c. c. |
| 44 | PDG2009 | $K_S^0K^-\pi^+\pi^+\pi^-$c. c. |
| 45 | PDG2009 | $K_S^0K^-\pi^+\pi^+\pi^-\pi^0$c. c. |
| 46 | PDG2009 | $K_S^0K^-\pi^+\pi^+\pi^-\pi^-\pi^+$c. c. |
| 47 | PDG2009 | $K_S^0K^-\pi^+\pi^0\pi^0$c. c. |

# Example #7 : Measurements of Diff. kind of R-values at $E_{cm}$>3.63 GeV

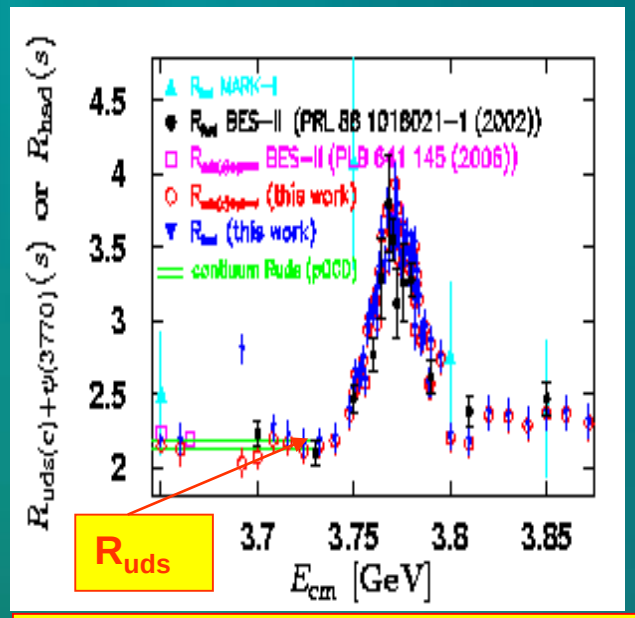
- **Previously measured R-values in the world are all $R_{had}$**
  $R_{had}$ could not be used to directly compare with pQCD calculations since $R_{had}$ includes contributions from all resonances decays

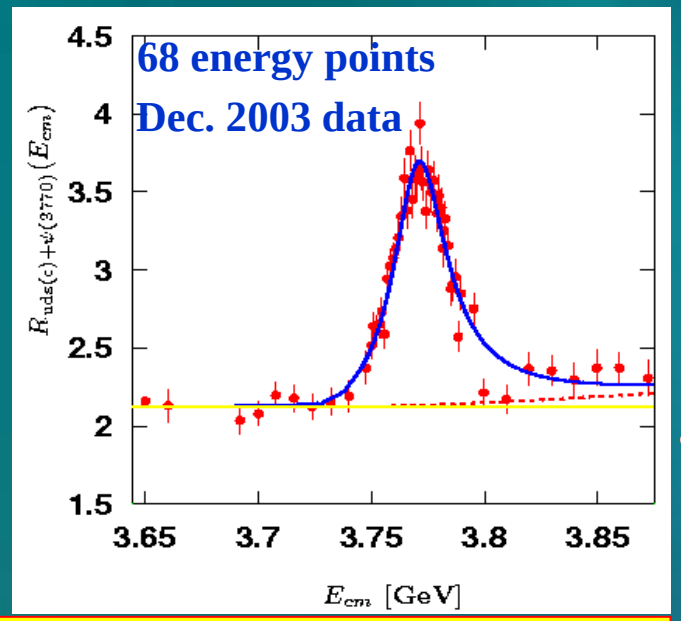



- **Different R-values**

不同成分的R值也是研究ψ(3770)非-DD衰变的一座桥梁，首先要架桥！

We developed the new Monte Carlo generator built in both the ISR and Vacuum Polarization corrections. The ISR correction is based on the Structure-function approach.
We separately measured the $R_{uds(c)}$, $R_{\psi(3770)}$ and $R_{had}$ for the first time in this energy region




PRL 97, 262001 (2006); PLB 652 (2007) 238, cited by 82 records

- Considering the effects of all vector states on the R-values at energies from 3.6 to 3.87 GeV
- Determine different kinds of R-values in the energy region for the first time
- Pinpoint out that different R-values are used to calculate different quantities; $R_{uds}$ is used to calculate $\alpha_s$ (s), $R_{had}$ is used to calculate $\alpha_{QED}$(s) and (g-2)

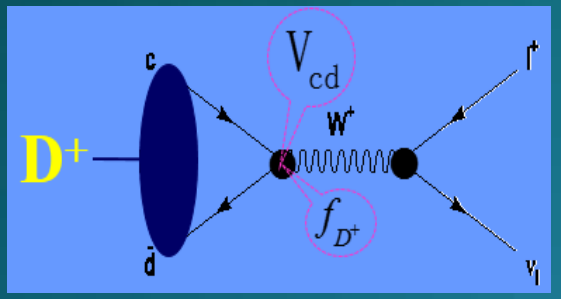
# Example #9 : Measurement of decay constant $f_D$



BES-II

- **Observed 3 leptonic decay events of $D^+ \to \mu^+\nu$**

Before CLEO-c, we found 3 leptonic decay events of $D^+ \to \mu^+\nu$, which is the first statistically significant observation of the purely leptonic $D^+$ decays, and measured decay constant




$$f_{D^+} = (371^{+129}_{-119} \pm 25)\ \text{MeV}$$

PLB610(2005)183, 39 Citations

'04 Electroweak Interactions and Unified Theories, p404, March, 2004;

**At the BES-III, we made the world's best measurement of $f_{D+}$**

- **Scientific significance**

$f_D$ is an important constant . Precision measurement of $f_D$ is a crucial test of the Lattice QCD techniques used to compute important heavy quark processes in the D and B mesons leptonic decays, then help physicists more precisely test the SM

BES-III

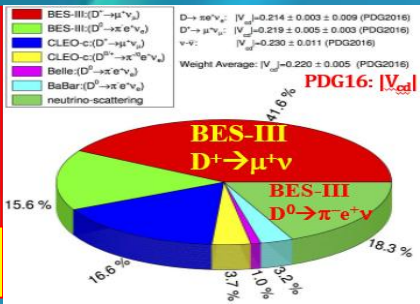
In 1999, we translated all of the single and double $D^{+/-}$ tag software packages from the BES-II experiment to the BES-III. At the BES-III experiment, we then made the world's best measurements of the decay constant $f_D$ and the quark-mixing-matrix element $|V_{cd}|$

$B(D^+ \to \mu^+\nu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$

$f_{D+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$

PRD 89, 051104(R) (2014); 52 Citations



# Example #10 : Measurements of $D^0 \to K(\pi)\, e^+\nu$ form factors

BES-II

L~0.028 fb$^{-1}$ (~3.773 GeV)

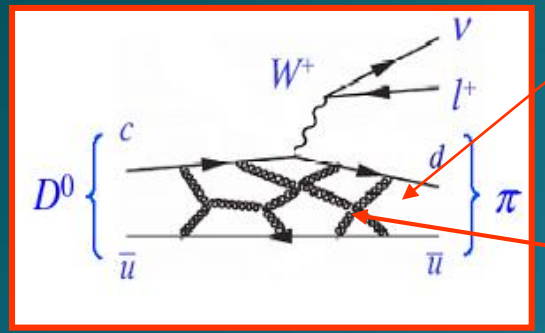
## ➢ $D^0 \to K^- e^+ \nu$ and $D^0 \to \pi^- e^+ \nu$

We absolutely measure the hadronic FFs for $D^0 \to K^- e^+ \nu$ and $D^0 \to \pi^- e^+ \nu$ decays for the first time in the world

$f_+^K(0) = 0.78 \pm 0.05$ $\quad$ $f_+^\pi(0) = 0.73 \pm 0.15$

(relative error is 0.64%)

PLB597(2004)39, 93 citations




$f_+^\pi(q^2)$

低能强作用的理论(LQCD)可以描述

These results are widely cited by theoretical physicists to validate their LQCD calculations of FFs.

At the BES-III, we made the world's best measurement of these form factors FFs

## ➢ Scientific significance

These form factor results can be used to validate the LQCD (and QCD sum rule) calculations of the form factors, help physicists better understand the strong interaction at lower energies.

BES-III

L=2.93 fb$^{-1}$ (3.773 GeV)

In 1999, we translated all of the single and double D tag software packages from the BES-II to the BES-III. In 2015, at the BES-III, we made the world's best measurements of these form factors and $|V_{cd}|$ and $|V_{cs}|$:

PRD 92, 072012 (2015); 59 Citations

$f_+^K(0) = 0.7368 \pm 0.0026 \pm 0.0036$ (relative error is 0.6%)

$f_+^\pi(0) = 0.6372 \pm 0.0008 \pm 0.0044$

$f_+^\pi(0)/f_+^K(0) = 0.8649 \pm 0.0112 \pm 0.0073$

$|V_{cs}| = 0.9601 \pm 0.0003 \pm 0.0047 \pm 0.0239_{\text{Thr.}}$

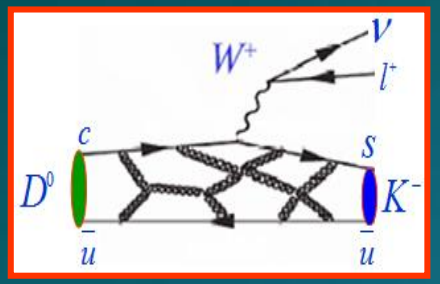
$|V_{cd}| = 0.2155 \pm 0.0027 \pm 0.0014 \pm 0.0094_{\text{Thr.}}$

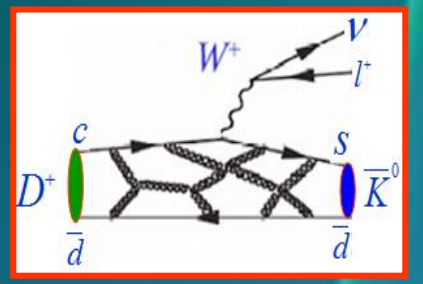
$|V_{cd}|/|V_{cs}| = 0.238 \pm 0.004 \pm 0.002 \pm 0.011_{\text{Thr.}}$

# Example #11 : Solved a puzzle: "Isospin is not conserved in D decays"



- **PDG2014 $\Gamma(D^0\to K^-e^+\nu)/\Gamma(D^+\to \text{anti-}K^0e^+\nu)$**




Before 2005, world average of decay ratio (PDG2004):

$\Gamma(D^0\to K^-e^+\nu)/\Gamma(D^+\to \text{anti-}K^0e^+\nu)=1.4\pm0.2$,

which conflicts with the SM prediction, and indicates "Isospin conservation is not held in $D^0$ and $D^+$ semi-leptonic decays". This is a long-standing Puzzle

**Phys.Lett.B608(2005)24, Phys.Lett.B644(2007)20, Cited by 133 records**

- **BES-II mesurement**

$\Gamma(D^0\to K^-e^+\nu)/\Gamma(D^+\to \text{anti-}K^0e^+\nu)=1.08\pm0.22\pm0.07$,

indicating that Isospin conservation is held in D semi-leptonic decays, thereby solved the long-standing puzzle --- "the Isospin conservation is not held in D semi-leptonic decays".

At the BES-III, we made the world's best measurement of this ratio again

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In 2017, with the BES-III data, we made the world's best measurement:

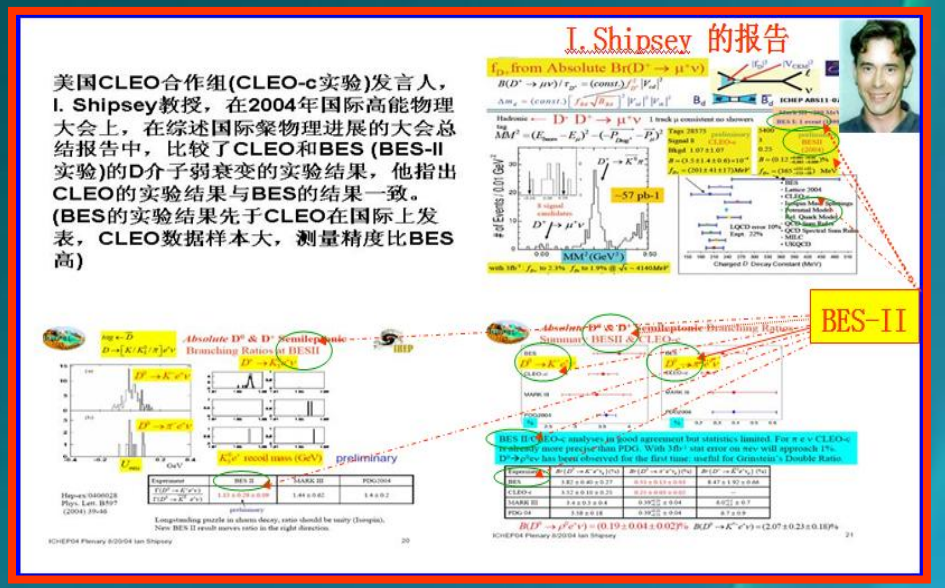
$\Gamma(D^0\to K^-e^+\nu)/\Gamma(D^+\to \text{anti-}K^0e^+\nu)=1.03\pm0.01\pm0.02$

**PRD96, 012002(2017)**

# International repercussions: $f_D$ and FFs $f_+^K(0)$, $f_+^K(0)$



- **BES D physics results are widely cited by researchers from other collaborations**
  - In a plenary talk presented at ICHEP04, Prof. Shipsey (CLEO-c spokesperson) pointed out that the absence of accurate charm data against which to test lattice techniques is changing with the BES-II run at ψ(3770)
  - Prof. Shipsey cited more than 10 BES D physics results to discuss the experimental test of the SM in his talk.
  - Prof. Shipsey pointed out BES solved a long-standing puzzle that 'Isospin conservation is not held in $D^0$ and $D^+$ semi-leptonic decays'.




  - At a set of International Conferences/Workshops, a lot of physicists from CLEO and other Collaborations all claimed that their measurements on D-mesons decays are in good agreement with BES-II measurements.
  - In published papers, a lot of theoretical physicists report that their calculated form factors based on the LQCD or QCD techniques are in very good agreement with the BES-II measurements of these form factors

# National Review of the BES-II Physics


The 5 Chinese Academician

王乃彦　方守贤　张焕乔　何多慧　赵光达

On 17 December, 2008


- **The review committee**

  5 Academician of CAS and 8 Professors (李学潜, 常进，马建平，陈裕启，陈宏芳，罗民兴，赵维琴，郑阳恒, 梁作堂) from research institutions & Universities in China

- **The results of the National Review**

  On 17 December 2007, the review committee awards the BES-II ψ(3770) Physics as the only one particularly outstanding project in the BES-II Physics containing 5 physics projects

专家组的专家们一致认为：该项目[ BES-II ψ(3770) Project] 取得了许多突破性进展和重要科学成果，其中包括在国际上首次发现了 ψ(3770) →J/ψπ⁺π⁻ 和发现 ~15% ψ(3770) 衰变到非-DD̄ 末态等，取得了一批国际关注的重要物理结果。**该项目为保持中国在粲物理研究领域的国际领先地位做出了贡献**。总体水平达到国际先进，评定等级为 特优（五个物理课题中, 只有一个被评定为特优）。

# ψ(3770) Project Winning NNS Award in 2010

- The BES-II ψ(3770) Project was honored with second-prizes of the National Natural Science Awards in 2010


- The ψ(3770) Project was judged the particularly outstanding project by National Natural Science Foundation of China in 2011


To summarize, owing to over 150 Chinese Scientists and Engineers' great efforts on the project, BES won the competition with other Collaborations in studies of both the ψ(3770) and D physics. On behalf of the ψ(3770) Physics Group/Project at the BES-II experiment, I would like to thank all of them and the IHEP leadership for strongly supporting this ψ(3770) project 17 years ago.

**ψ(3770) or $X_{abvD\underline{D}}$ Physics Project is naturally extended to the NOCP decays of $X_{abvD\underline{D}}$ and D Physics at the BES-III experiment**

# Study of $X_{abvDD}$ Physics at the BES-III



- **we suggested/proposed to search for new states by energy scan at BES-III experiment**
  - We proposed to find new states by studying line-shape of cross sections for $e^+e^-\rightarrow J/\psi X$ , $\psi(3686)X$, ($X=\pi\pi$, or anything) and studying the $J/\psi\pi\pi$ final states from data taken at energies from 3.73 to 4.5 GeV in the talk/paper presented at an International workshop in Oct., 2009
  - We proposed to study Y(4260) and search for new state by studying line-shape of cross sections for $e^+e^-\rightarrow$hadron, $J/\psi$ X($X=\pi\pi$, or anything), … at energies from 3.7 to 4.5 GeV. This proposal was presented at BESIII Collaboration 2009 Winter Meeting held in Nankai University, 7—10 Nov. 2009.

2009年10月，项目组成员在国际会议上建议BES-III在3.7~4.5 GeV能量区间多点采集数据，通过研究$J/\psi\pi\pi$等非-DD末态，寻找新强子态。

Talk given at International Workshop on $e^+e^-$ Collison from $\phi$ to $\psi$, Beijing, Oct., 13-16, 2009

CPC(HEP & NP), 2010, 34(6): 785–791 Chinese Physics C Vol. 34, No. 6, Jun., 2010

CPC, Vol. 34 Num. 6 June 2010 http://cpc-hepnp.ihep.ac.cn

Physics program of open charm and heavy $c\bar{c}$ states at the BES-III experiment*

RONG Gang(荣刚)1)

…

With the data to be taken in the energy region from 3.7 to 4.5 GeV with the BES-III detector, the BES-III collaboration has an opportunity to search for some new structure(s) in the resonance regions of the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ conventional $c\bar{c}$ states or coming from these resonances decays. Searching for the new structure(s) can be performed by examining the line shapes of the cross sections for $e^+e^-$ → hadrons, open-charm-pair, $J/\psi$ X, $\psi(3686)$ X, $K^0$ X, $\phi$ X, $\eta$ X, and so on. The direct measurements of the non-charmed decay branching fractions of the heavy states give us another method to search for the new structure(s) and to understand the production and decay dynamics of the heavy states.

We suggested to find new states by analyzing line-shape of cross sections for $e^+e^-\rightarrow J/\psi X$, $\psi(3686)X$, open-charm-pair, … at energies from 3.9 to 4.5 GeV

## Proposal for Finer Energy Scan in the Open Charm Energy Region

G. RONG [1] X.Y. Zhang [2] J.C. Chen [1]
D.H. Zhang [1] H.L. Ma [1]

[1] Institute of High Energy of Physics
[2] Shandong University

BES-III Annual Meeting, November 7—10, 2009, Nankai University

## Physics Goal

- Measurement of $\Gamma^{ee}_{X(4260)}$

  There are some uncertainties in interpretation of the X(4260) state. No $\Gamma^{ee}_{X(4260)}$ is available currently.

  Measurement of the $\Gamma^{ee}_{X(4260)}$ can help interpretation of the X(4260) state.

- …

In view of these physics potentials in the open charm energy region, we propose to operate two phases of energy scan experiments

## Proposal

We propose to make a finer energy scan in the open charm energy region, which can be divided into two stages

The first stage:

Energy scan in the range from 3.645 to 3.890 GeV, which was already approved by the Collaboration in last January. This energy scan was planned to be operated in this December or before the next May.

The second stage:

Energy scan in the range from 3.890 to 4.500 GeV. We suggest to operate this energy scan sometimes before 2013.

## Conclusion

With 100 $pb^{-1}$ of data taken in first phase of energy scan

- make sure whether there is any new structure or some new physics effects reflecting $D\bar{D}$ production and decays.
- solve the puzzle about $\psi(3770)$ non-$D\bar{D}$ decays and search for new state(s) in energy rang from 3.7—3.9 GeV

With 200 $pb^{-1}$ of data taken in second phase of energy scan

- measure $\Gamma_{ee}^{X(4260)}$, helping interpretation of X(4260)
- clear up the situation of the uncertainties in classification of the heavy $\psi$'s and search for new state in energy region between 3.9 and 4.5 GeV

With $J/\psi$, $\psi(3686)$ fast energy scan data sample and singly tagged D events, we can well calibrate the BEPC-II energy.

We propose to operate the first phase of energy scan experiment in this December and the second one sometimes before 2013

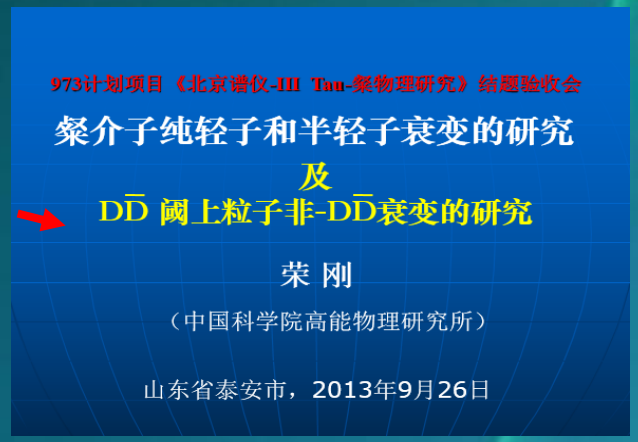
# $X_{abvD\bar{D}}$ and Charm Meson Physics at the BES-III

- **Two projects supported by the Chinese Governments**

Under the two projects associated with Professors from Universities and Institute in the BES-III Collaboration, we worked in two directions:

1. **Study NOCP decays of $X_{abvD\bar{D}}$ states**
   - ✓ Study NOCP decays of $X_{abvD\bar{D}}$ from the data taken at energies from 3.7 to 4.6 GeV
   - ✓ Measuring/analyzing cross-sections for $e^+e^- \rightarrow J/\psi X$, LH, $\mu^+\mu^-$ at energies from 3.7 to 4.6 GeV,
2. **Study charmed mesons (semi-)leptonic decays**
   - ✓ Made several the world's best measurements of charm meson (semi-)leptonic decays [ $f_D$, $f_+^K(0)$, $f^{+\pi}(0)$ ], which are crucial test of the Lattice techniques used to compute important heavy quark processes in D and B mesons decays.
   - ✓ Precisely determined the quark-mixing parameters $|V_{cd}|$ and $|V_{cs}|$ of the SM.

More than 20 papers (see publication list below) related to $X_{abvD\bar{D}}$ Physics and Charm Meson Physics have been published




# $X_{abvD\underline{D}}$ Physics at the BES-III



- Study NOCP decays of $X_{abvD\underline{D}}$ from data taken at energies from 3.7 to 4.6 GeV
  - NOCP decay of ψ(3770)

    $B[\psi(3770\rightarrow\gamma\chi_{\chi0}]=(6.88\pm0.28\pm0.67)\times10^{-3}$

    $\Gamma[\psi(3770\rightarrow\gamma\chi_{c0}]=(187\pm8\pm19)$ keV

    Phys. Letts. B 753, 103-109 (2016)

    $B[\psi(3770)\rightarrow\gamma\chi_{\chi1}]=(2.48\pm0.15\pm0.23)\times10^{-3}$

    $\Gamma[\psi(3770)\rightarrow\gamma\chi_{c1}]=(67.5\pm4.1\pm6.7)$ keV

    $B[\psi(3770)\rightarrow\gamma\chi_{c2}]=(0.25\pm0.21\pm0.18)\times10^{-3}$

    $\Gamma[\psi(3770)\rightarrow\gamma\chi_{c2}]<17.4$ keV

    Phys. Rev. D 91, 092009 (2015)

  - NOCP decay of ψ(4040)

    $B[\psi(3770)\rightarrow\Lambda\Lambda\pi^+\pi^-]<4.7\times10^{-4}$

    $B[\psi(3770)\rightarrow\Lambda\Lambda\pi^0]<0.7\times10^{-4}$

    $B[\psi(3770)\rightarrow\Lambda\Lambda\eta]<1.9\times10^{-4}$

    $B[\psi(3770)\rightarrow\Sigma^+\Sigma^-]<1.0\times10^{-4}$

    $B[\psi(3770)\rightarrow\Sigma^0\Sigma^0]<0.4\times10^{-4}$

    $B[\psi(3770)\rightarrow\Xi^+\Xi^-]<1.5\times10^{-4}$

    $B[\psi(3770)\rightarrow\Xi^0\Xi^0]<1.4\times10^{-4}$

    Phys. Rev. D 87, 112011 (2013)

As an example, show a few measurements only

- Measuring cross-sections for $e^+e^-\rightarrow$light-hadron at energies from 3.6 to 3.9 GeV
  - $e^+e^-\rightarrow p\bar{p}$ (Physikalisches Institute, ⋯)

    $\sigma[\psi(3770)\rightarrow p\bar{p}]=(0.059^{+0.070}_{-0.020}\pm0.012)$ pb $\quad \phi_1=(255.8^{+39.0}_{-26.6}\pm4.8)^o$

    $\sigma[\psi(3770)\rightarrow p\bar{p}]=(2.57^{+0.12}_{-0.13}\pm0.012)$ pb $\quad \phi_2=(266.9^{+6.1}_{-6.3}\pm0.9)^o$

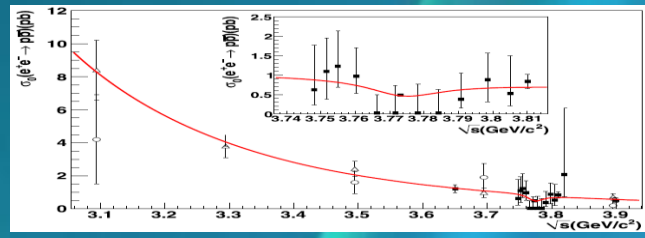
    PLB 735, 101-107 (2014)

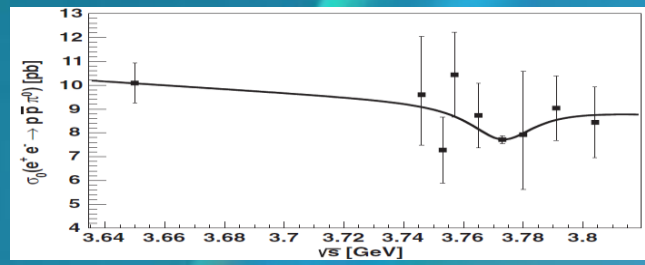
  - $e^+e^-\rightarrow p\bar{p}\pi^0$

    $\sigma[\psi(3770)\rightarrow p\bar{p}\pi^0]=(33.80\pm1.8\pm2.1)$ pb $\quad \phi_1=(269.7\pm2.3\pm0.3)^o$

    $\sigma[\psi(3770)\rightarrow p\bar{p}\pi^0]=(0.06^{+0.10}_{-0.04}\pm0.01)$ pb $\quad \phi_2=(266.8^{+52.4}_{-48.0}\pm11.0)^o$

    PRD 90, 032007 (2014)



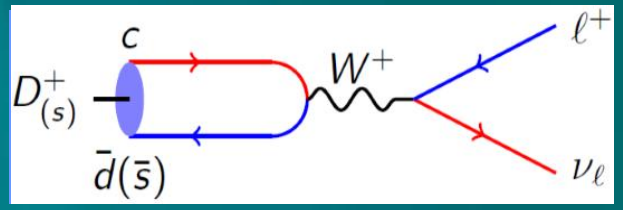
# $X_{abvDD}$ Physics at the BES-III

- Measurements of cross sections for $e^+e^- \rightarrow J/\psi X$, light-hadrons, hadrond, $\mu^+\mu^-$ at energies from 3.7 to 4.6 GeV
  - $\sigma(e^+e^- \rightarrow J/\psi X)$ at energies from 3.55 to 3.89 (4.6) GeV
    Analysis being reviewed within the BES-III Collaboration
  - $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ at energies from 3.81 to 4.60 GeV
    In this analysis, we observed some structure(s); Analysis is currently being reviewed within the BES-III Collaboration
  - $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ at energies from 3.55 to 3.9 GeV
    we observed a structure in this energy region; Analysis is still in progress
  - $\sigma(e^+e^- \rightarrow$ hadrons) at energies from 3.55 to 3.87 GeV
    In this analysis, we observed di-structure(s) as those observed at the BES-II; Analysis is still in progress
  - $\sigma(e^+e^- \rightarrow$ LH) at energies from 3.55 to 4.60 GeV
    Analysis of these are still in progress at the BES-III experiment

# Precision measurements of $f_{D^+}$ and $|V_{cd}|$ with $D^+ \to \mu^+\nu$



➢ $D^+ \to \mu^+\nu$




- Based on **2.93 fb$^{-1}$** of data taken with the BES-III detector at 3.773 GeV, we made the world's best measurements of Br., decay constant $f_D$ and $|V_{cd}|$.

$B(D^+ \to \mu^+\nu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$

$f_{D^+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$

- Measurement of $f_D$ is a crucial test of the Lattice QCD techniques used to compute important heavy quark processes in D and B mesons decays.

**$(170.3 \pm 0.3) \times 10^4$ $D^-$ tags**

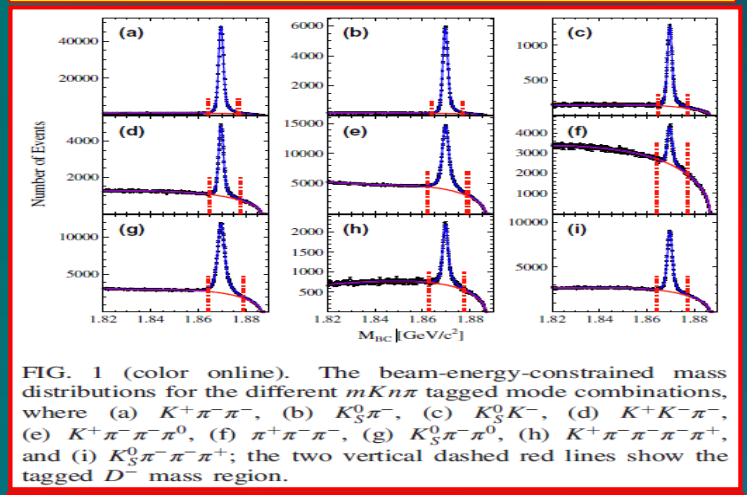
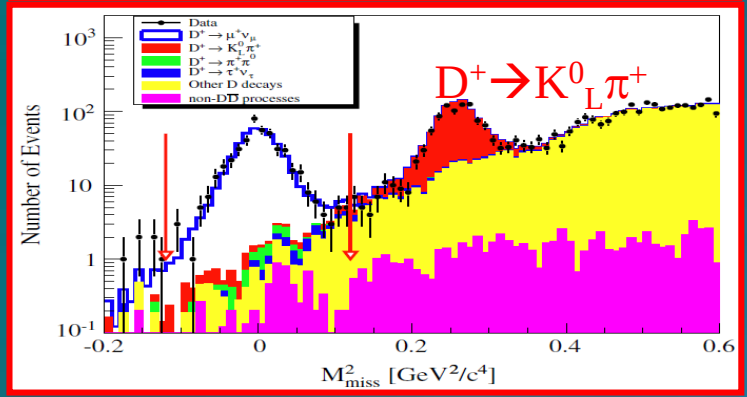
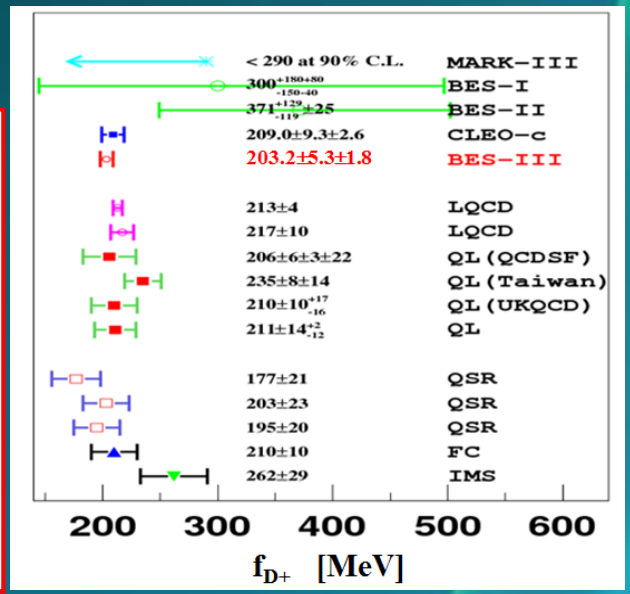
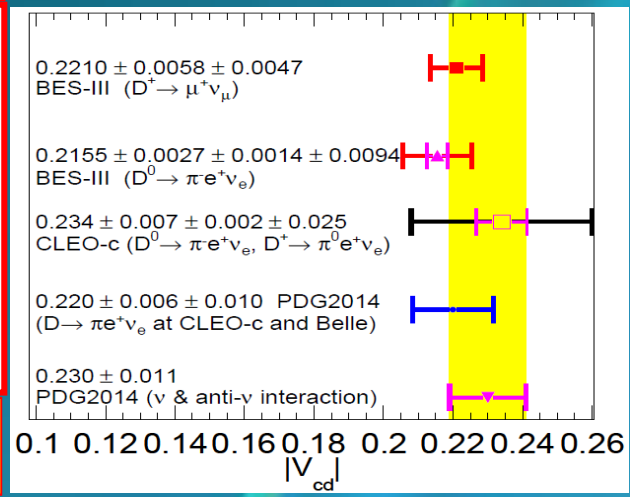



FIG. 1 (color online). The beam-energy-constrained mass distributions for the different $mKn\pi$ tagged mode combinations, where (a) $K^+\pi^-\pi^-$, (b) $K^0_S\pi^-$, (c) $K^0_SK^-$, (d) $K^+K^-\pi^-$, (e) $K^+\pi^-\pi^-\pi^0$, (f) $\pi^+\pi^-\pi^-$, (g) $K^0_S\pi^-\pi^0$, (h) $K^+\pi^-\pi^-\pi^-\pi^+$, and (i) $K^0_S\pi^-\pi^-\pi^+$; the two vertical dashed red lines show the tagged $D^-$ mass region.




**PRD 89, 051104(R) (2014)**




**Using measurement of $D^+ \to \mu^+\nu$ to determine $|V_{cd}|$ for the first time in the world**

# Precision measurements of FFs and $|V_{cd(s)}|$ with $D^0 \to K(\pi)^- e^+ \nu$



## ➢ $D^0 \to K^- e^+ \nu$ and $D^0 \to \pi^- e^+ \nu$

- We made the world's best measurements of Br., $|V_{cs}|$, $|V_{cd}|$, as well as $f_+^K(0)$ and $f_+^\pi(0)$.

$B(D^0 \to K^- e^+ \nu) = (3.505 \pm 0.014 \pm 0.033)\%$

$B(D^0 \to \pi^- e^+ \nu) = (0.295 \pm 0.004 \pm 0.003)\%$

PRD 92, 072012 (2015)

The relative systematic uncertainty is 0.94%, while the corresponding CLEO-c's uncertainty is 1.14%.

$|V_{cs}| = 0.9601 \pm 0.0003 \pm 0.0047 \pm 0.0239_{\text{Thr.}}$

$|V_{cd}| = 0.2155 \pm 0.0027 \pm 0.0014 \pm 0.0094_{\text{Thr.}}$

$|V_{cd}|/|V_{cs}| = 0.238 \pm 0.004 \pm 0.002 \pm 0.011_{\text{Thr.}}$

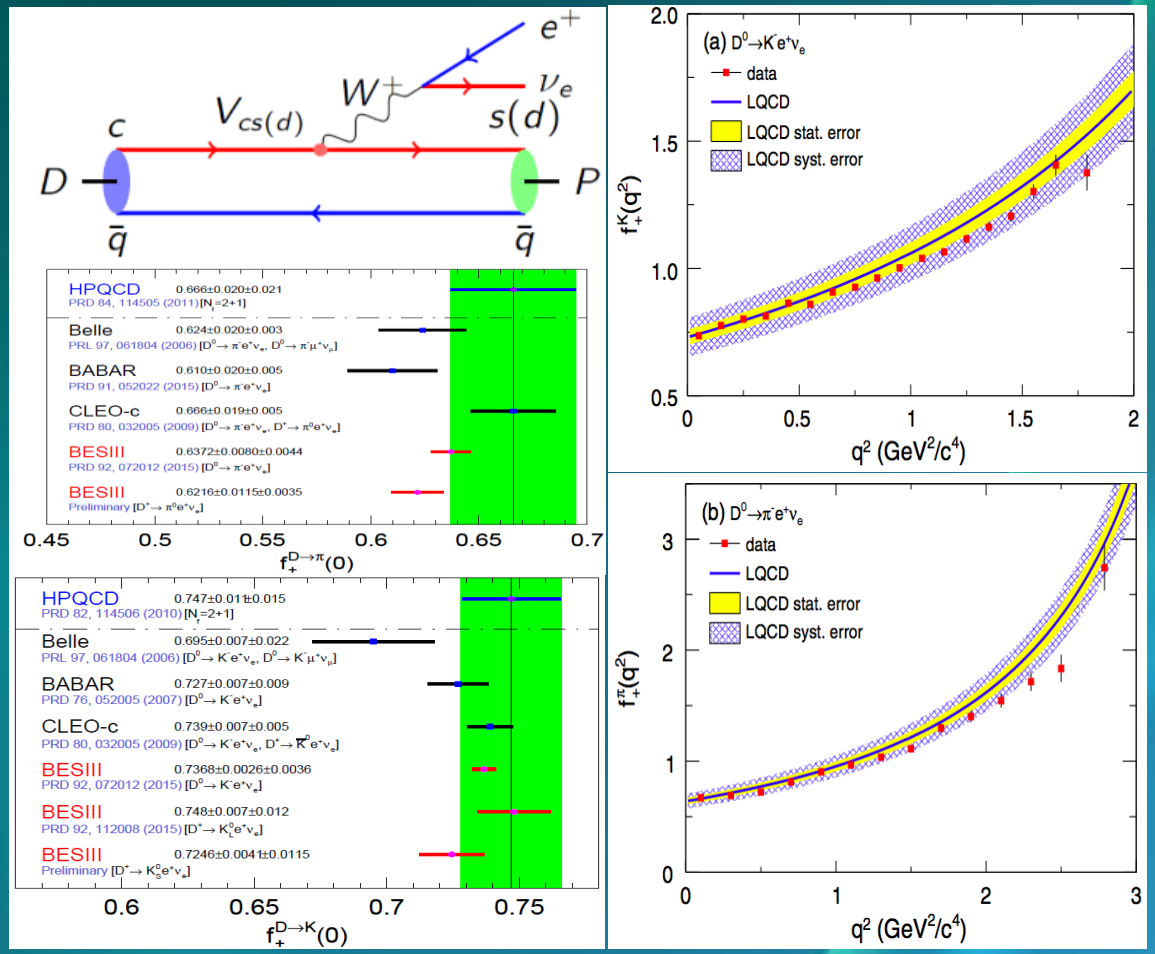
$f_+^K(0) = 0.7368 \pm 0.0026 \pm 0.0036$

Relative error is 0.6%

$f_+^\pi(0) = 0.6372 \pm 0.0008 \pm 0.0044$

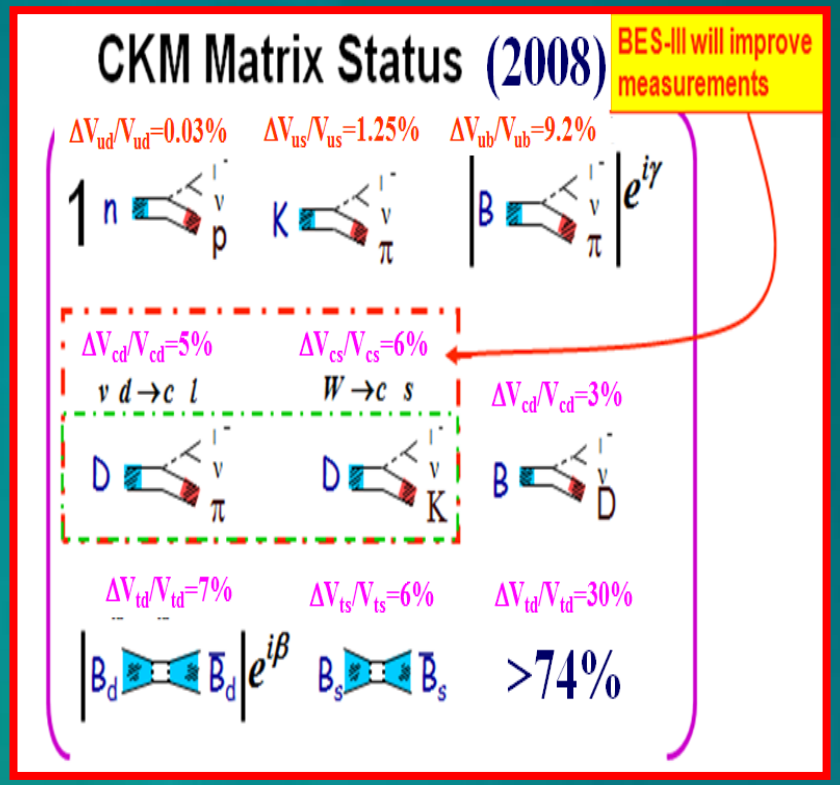
$f_+^\pi(0)/f_+^K(0) = 0.8649 \pm 0.0112 \pm 0.0073$

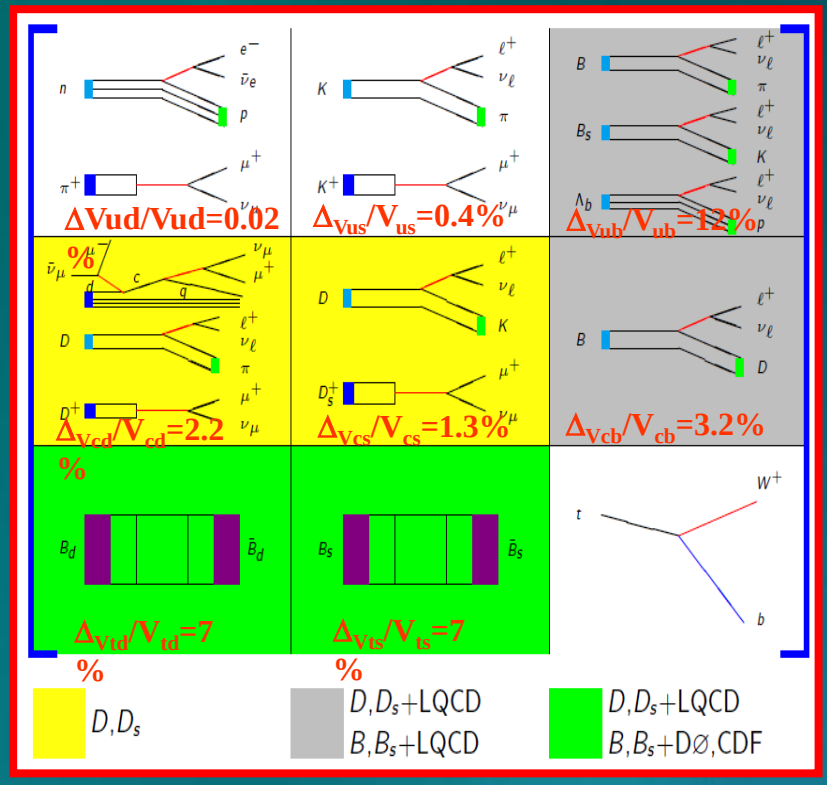
- For the same size of data samples , our reconstructed number of $D^0 \to K(\pi)^- e^+ \nu$ events is 40%(28%) more than that of CLEO-c.

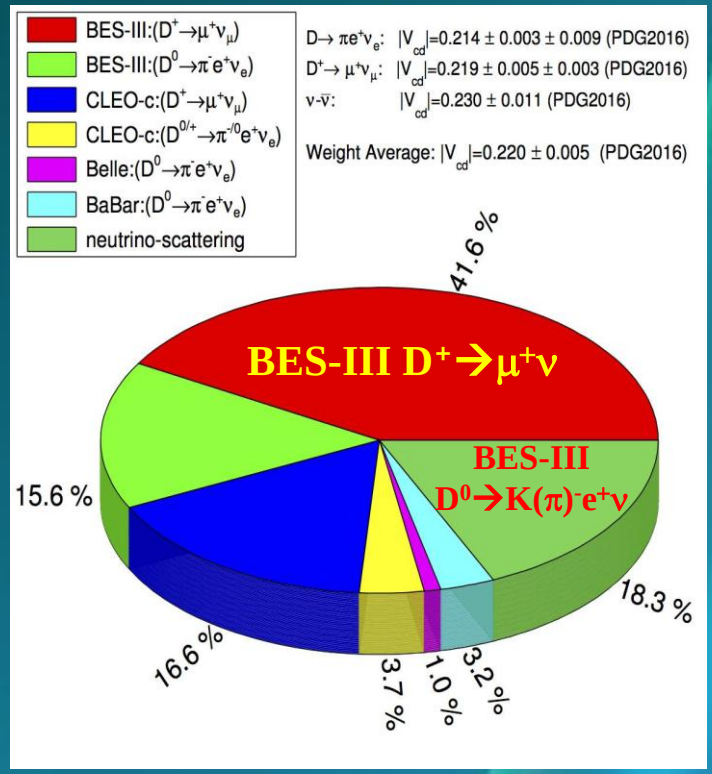



- The precision of these form factors (FFs) measured at BES-III experiment are four times higher than that of LQCD calculations.

# The CKM Matrix Status (2008 and 2016)




- Our measurements of values of $|V_{cd}|$ from both the leptonic and semileptonic D decays dominate (57% weight) the PDG16 value of $|V_{cd}|$
- The BES-III measurements improve the accuracies of the average values of the $|V_{cd}|$ and $|V_{cs}|$ given in PDG2014 by over 70% and 45%, respectively.

# Summary

- We began to study D-meson decays and NOCP (non-open-charm-pair) decays of $X_{abv\underline{DD}}$ [ψ(4030), ψ(4140), non-cc states,...] in 1995.
- The research work in both the D and $X_{abv\underline{DD}}$ physics at BES-I improved our soft strength and make it is possible to win the competition with other experiments in studies of these physics at BES-II
- With discoveries of $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$, $\psi(3770)\rightarrow$non-$D\underline{D}$, di-structures nearby 3.773 GeV, and systematic studies of $e^+e^-\rightarrow$NOCP at energies from 3.5 to 3.9 GeV, the bottleneck of finding NOCP decays of $X_{abv\underline{DD}}$ and discovering new states has been broken. Practice has proved that studying NOCP decays of $X_{abv\underline{DD}}$ are really more sensitive to find new non-$c\underline{c}$ states. The studying NOCP decays of $X_{abv\underline{DD}}$ have been naturally extended to higher energies at BES-III.
- Experience in study of charm physics at BES-I and BES-II has enabled us to make the world's best measurements of $f_D$, $f_+^K(q^2)$, $f_+^\pi(q^2)$ as well as $|V_{cd}|$ and $|V_{cs}|$ at the BES-III.
- We are still working on studying these physics at the BES-III to find something new, and to try to understand some interesting puzzles in the $X_{abv\underline{DD}}$ physics and in hadronic physics. ...

**Thank you!**

# Publication list (related to the two projects supported by the Chinese Government)

1. Precision measurements of B(D+→μ+νμ), the pseudoscalar decay constant fD+, and the quark mixing matrix element |Vcd|
   (BES III Collaboration), Phys.Rev. D89 (2014) no.5, 051104

2. Study of Dynamics of D0→K−e+νe and D0→π−e+νe Decays
   (BESIII Collaboration), Phys.Rev. D92 (2015) no.7, 072012

3. Measurement of the form factors in the decay D+→ωe+νe and search for the decay D+→ϕe+νe
   (BESIII Collaboration), Phys.Rev. D92 (2015) no.7, 071101

4. Meas urement of the absolute branching fraction of D+→K¯0e+νe via K¯0→π0π0
   (BESIII Collaboration), Chin.Phys. C40 (2016) no.11, 113001

5. Analysis of D+→K¯0e+νe and D+→π0e+νe semileptonic decays
   (BESIII Collaboration), Phys.Rev. D96 (2017) no.1, 012002

6. Study of D+→K−π+e+νe
   (BESIII Collaboration), Phys.Rev. D94 (2016) no.3, 032001

7. Measurements of the absolute branching fractions for D+s→ηe+νe and D+s→η′e+νe
   (BESIII Collaboration), Phys.Rev. D94 (2016) no.11, 112003

8. Measurements of the branching fractions for D+→K0SK0SK+, K0SK0Sπ+ and D0→K0SK0S, K0SK0SK0S
   (BESIII Collaboration), Phys.Lett. B765 (2017) 231-237

9. Improved measurement of the absolute branching fraction of D+→K¯0μ+νμ
   (BESIII Collaboration, Eur.Phys.J. C76 (2016) no.7, 369

10. Measurement of the branching fractions of D+s→η′X and D+s→η′ρ+ in e+e−→D+sD−s
    (BESIII Collaboration), Phys.Lett. B750 (2015) 466-474

11. Study of the D0→K−μ+νμ dynamics and test of lepton flavor universality with D0→K−ℓ+νℓ decays
    (BESIII Collaboration), Phys.Rev.Lett. 122 (2019) no.1, 011804

12. Measurement of B($\psi(3770)\to\gamma\chi c1$) and search for $\psi(3770)\to\gamma\chi c2$
(BESIII Collaboration), Phys.Rev. D91 (2015) no.9, 092009

13. Measurement of the branching fraction for $\psi(3770)\to\gamma\chi c0$
(BESIII Collaboration), Phys.Lett. B753 (2016) 103-109

14 Search for baryonic decays of $\psi(3770)$ and $\psi(4040)$
(BESIII Collaboration), Phys.Rev. D87 (2013) no.11, 112011

15. Study of $e^+e^-\to p\bar{p}\pi^0$ in the Vicinity of the $\psi(3770)$
(BESIII Collaboration), Phys.Rev. D90 (2014) no.3, 032007

16. Search for the radiative transitions $\psi(3770)\to\gamma\eta c$ and $\gamma\eta c(2S)$
(BESIII Collaboration), Phys.Rev. D89 (2014) no.11, 112005

17. Study of $e^+e^-\to p\bar{p}$ in the vicinity of $\psi(3770)$
(BESIII Collaboration), Phys.Lett. B735 (2014) 101-107

18. Search for the Y(4140) via $e^+e^-\to\gamma\phi J/\psi$ at $\sqrt{s}$=4.23 , 4.26 and 4.36 GeV
(BESIII Collaboration), Phys.Rev. D91 (2015) no.3, 032002

19. Measurement of the integrated luminosities of the data taken by BESIII at $\sqrt{s}$=3.650 and 3.773 GeV
(BESIII Collaboration), Chin.Phys. C37 (2013) 123001

20. Measurement of the integrated Luminosities of cross-section scan data samples around the $\psi(3770)$ mass region
(BESIII Collaboration), Chin.Phys. C42 (2018) no.6, 063001

# Backup Slides

# International repercussions: ψ(3770)→non-DD̄ decays

- At workshop DAPHNE 2004, Prof. Hanna summarized existing eleven hot topics and puzzles in the Heavy Quarkonia Physics.
- Two of these were originally from studies of ψ(3770) physics at the BES-II experiment. Questions about these were still open at that time
- In 2005, the BES gave a definite answer about ψ(3770)→J/ψπ⁺π⁻ .
- In 2006, the BES gave another definite answer about ψ(3770)→non-DD̄, i.e. ~15% of ψ(3770) decay into non-DD̄.

# International repercussions: ψ(3770)→non-DD̄ decays



- Before 2006, most international physicists still did not believe the BES results. For example, Prof. Voloshin would rather cite the CLEO-c's unpublished result than cite the BES published result in his papers

BES
$\sigma_{D\bar{D}}^{obs} = (6.14 \pm 0.12 \pm 0.50)$ nb,
PLB 603 (2004) 130

[2] Q. He *et al.* (CLEO Collaboration), Reports No. CLNS-05-1914 and No. CLEO-05-6, 2005 (unpublished).

PHYSICAL REVIEW D 71, 114003 (2005)

**$\bar{c}c$ purity of $\psi(3770)$ and $\psi'$ challenged**

M. B. Voloshin
*William I. Fine Theoretical Physics Institute, University of Minnesota, Minneapolis, Minnesota 55455, USA and Institute of Theoretical and Experimental Physics, Moscow, 117259, Russia*
(Received 6 May 2005; published 6 June 2005)

It is suggested that the resonance $\psi(3770)$ may contain a sizeable ($O(10\%)$ in terms of the probability weight factor) four-quark component with the up- and down-quarks and antiquarks in addition to the $c\bar{c}$ pair, which component in itself has a substantial part with isospin $I = 1$. Furthermore such a four-quark nent with extra $u\bar{u}$ and $d\bar{d}$ quark pairs. Namely, the data to be discussed are: the total cross section for $D\bar{D}$ pair production in $e^+e^-$ annihilation at the $\psi(3770)$ peak [2]

$$\sigma(e^+e^- \to D\bar{D}) = (6.39 \pm 0.10^{+0.17}_{-0.08})\ \text{nb}; \quad (1)$$

- After BES published 6 papers reporting ψ(3770)→non-DD̄ decays, the situation was totally changed. In 2008, in a paper to review Charmonium, Prof. Voloshin discuses the effects of the experimental measurements on Charmonium physics. He cited 6 BES papers in discussion of progress on Charmonium physics. He put the BES results at the first place in his discussion

- Prof. Voloshin gave a high level of evaluation of studies of ψ(3770) non-DD̄ decays at BES-II.

ELSEVIER
Progress in Particle and Nuclear Physics
Progress in Particle and Nuclear Physics 61 (2008) 455–511
www.elsevier.com/locate/ppnp

引用6篇BES-II文章讨论
其对QCD理论发展的影响

Review
Charmonium
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*William I. Fine Theoretical Physics Institute, University of Minnesota, Minneapolis, MN 55455, United States
Institute of Theoretical and Experimental Physics, Moscow, 117218, Russian Federation*

Recently the physics of charmonium regained a great renewed interest due to the massive dedicated investigation by BES and CLEO-c and the studies using decays of $B$ mesons and the radiative return technique at the B factories with a higher initial energy of the electron and positron beams. After a 'dry spell' of more than two decades during which no new states of charmonium have been found with any certainty, new observations discover charmonium and charmonium-related resonances at a rate that outpaces the ability of the theory to fit their properties in a consistent scheme. Furthermore, the data very strongly suggest that among the new resonances there are exotic four-quark states, possibly hybrid states with gluonic degrees of freedom in addition to the $c\bar{c}$ pair, and also loosely bound states of heavy hadrons – charmonium molecules. Thus it looks like that charmonium not only has provided us with a 'hadronic atomic physics' but quite possibly also with a 'hadronic chemistry', and in its mature age of 33 charmonium still offers us new intriguing puzzles.

$\sigma(e^+e^- \to D\bar{D}) = (6.57 \pm 0.04 \pm 0.10)$ nb. On the other hand, the BES measurement of the total cross section [148] gives $\sigma[e^+e^- \to \psi(3770)] = (7.25 \pm 0.27 \pm 0.34)$ nb, and their directly reported result [149] for the branching fractions: $\mathcal{B}[\psi(3770) \to D^0\bar{D}^0] = (46.7 \pm 4.7 \pm 2.3)\%$, $\mathcal{B}[\psi(3770) \to D^+D^-] = (36.9 \pm 3.7 \pm 4.2)\%$ and $\mathcal{B}[\psi(3770) \to \text{non} - D\bar{D}] = (16.4 \pm 7.3 \pm 4.2)\%$ leaves an ample room for non-$D\bar{D}$ decays of $\psi(3770)$ and their branching fraction for $\psi(3770) \to D\bar{D}$ is also in agreement with the CLEO result for $\sigma(e^+e^- \to D\bar{D})$.

**Prof. Voloshin 对BES-II ψ(3770)→non-DD̄ 研究结果认知态度的变化，形象地反映了国际高能物理界的理论和实验物理学家们，对 BES-II 实验结果 认知 态度的变化。BES-II ψ(3770) 物理研究结果改变了他们对 BES-II 物理研究的看法。**

# Example #5: Precisely measuring $\sigma(e^+e^-\to\psi(3770))$ and $Br[\psi(3770)\to e^+e^-]$

| Experiment | $\sigma^{dressed}[e^+e^-\to\psi(3770)]$ [nb] | $\sigma^{obs}[e^+e^-\to\psi(3770)]$[nb] | Note |
|---|---|---|---|
| BES (PLB 625 (2007) 238 | 10.0±0.3±0.5 | 7.2±0.2±0.4 | Data taken in Dec. 2003 |
| BES [PRL 97(2006)121801] | 9.6±0.7±0.4 | 6.9±0.5±0.3 | Data taken in Mar. 2003 |
| MARKII | | 9.3±1.4 | |

$\sigma^{obs}_{\psi(3770)} = 7.18 \pm 0.20 \pm 0.63$ [nb] BES-II PLB 641 (2006) 145

$\sigma^{obs}_{\psi(3770)} = 6.38 \pm 0.08^{+0.41}_{-0.30}$ [nb] CLEO-c PRL 96 (2006) 092002

Data taken at 3 or 2 energies

| Experiment | BES [PLB 652(2007) 238] | BES [PRL 97(2006)121801] | PDG08 |
|---|---|---|---|
| $B[\psi(3770)\to e^+e^-][\times10^{-5}]$ | 0.97±0.03±0.05 | 0.93±0.06±0.03 | 0.97±0.07 |

Dec. 2003 data

Mar. 2003 data

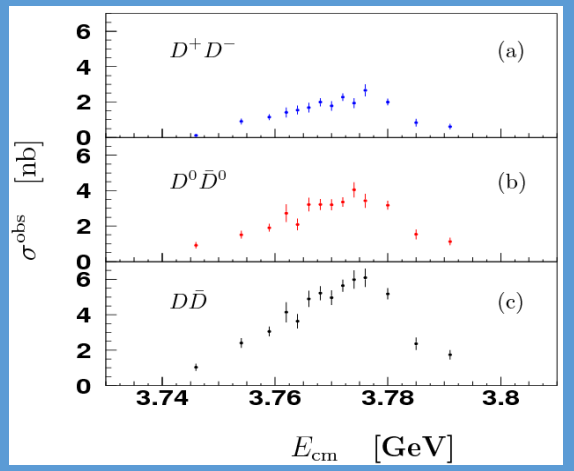
$(1.05\pm0.14)\times10^{-5}$ PDG06

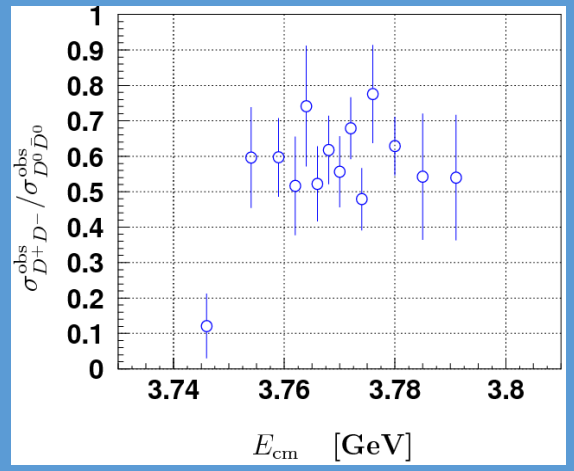
$(0.96\pm0.07)\times10^{-5}$ PDG18

**This PDG value is absolutely dominated by BES-II measurements**

# Example #8 : Measurements of shape of cross sections for $e^+e^-\rightarrow D\bar{D}$

- The BES measure the shape of cross sections for $e^+e^-\rightarrow D\bar{D}$ and ratio of the charged over the neutral $D\bar{D}$ cross sections at energies from 3.73 to 3.82 GeV for the first time in the world.
- These shapes of cross sections and ratios could help us understand the ψ(3770) production and decays, as well as help us search for other state $X_{abv D\bar{D}}$.




Response to the measurements

Charmonium:
Above the Open Charm Threshold

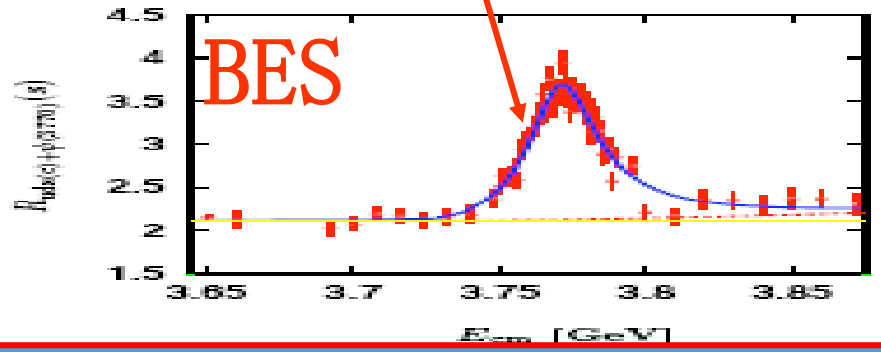
**Charm 07**

Estia Eichten
Fermilab

国际粲偶素权威理论家，势模型提出者

Two very important measurement:
(1) Resonance shape
(2) Ratio of charge to neutral DD final states

over the whole resonance region



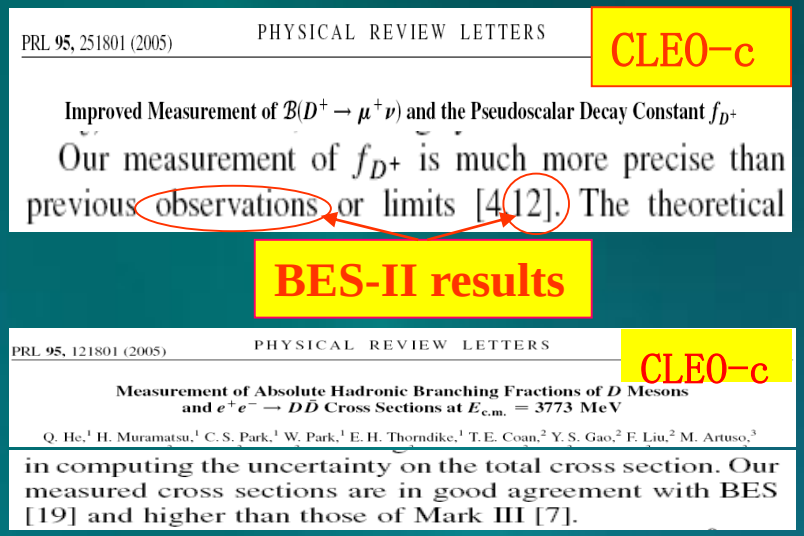

- At Charm07, Prof. Eichten pointed out that BES made two important measurements:

1. the line-shape of cross sections for $e^+e^-\rightarrow$hadrons;
2. the line-shape of the ratio of the charged over neutral $D\bar{D}$ cross sections.

**PLB 668,(2008) 263; PRL 101, (2008) 102004; cited by 67 times**

# Response to D Physics: Decay constant $f_D$ and FFs $f_+^K(0)$, $f_+^K(0)$

- The BES published results before CLEO-c did. In CLEO-c published papers, CELO-c pointes out that 'CLEO-c results are in good agreement with the BES measurements'.


PRL 95, 251801 (2005) PHYSICAL REVIEW LETTERS

CLEO-c

Improved Measurement of $\mathcal{B}(D^+ \to \mu^+\nu)$ and the Pseudoscalar Decay Constant $f_{D^+}$

Our measurement of $f_{D^+}$ is much more precise than previous observations or limits [4,12]. The theoretical

BES-II results

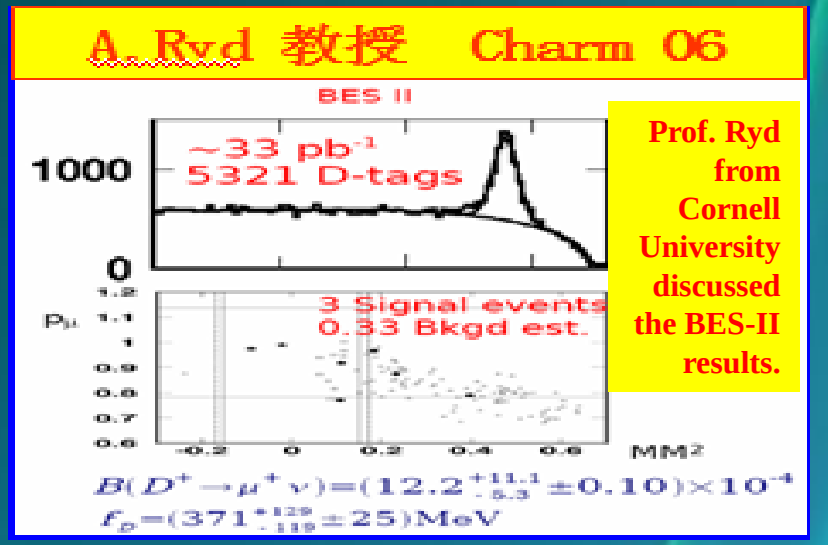
PRL 95, 121801 (2005) PHYSICAL REVIEW LETTERS

CLEO-c

Measurement of Absolute Hadronic Branching Fractions of $D$ Mesons and $e^+e^- \to D\bar{D}$ Cross Sections at $E_{\rm c.m.} = 3773$ MeV

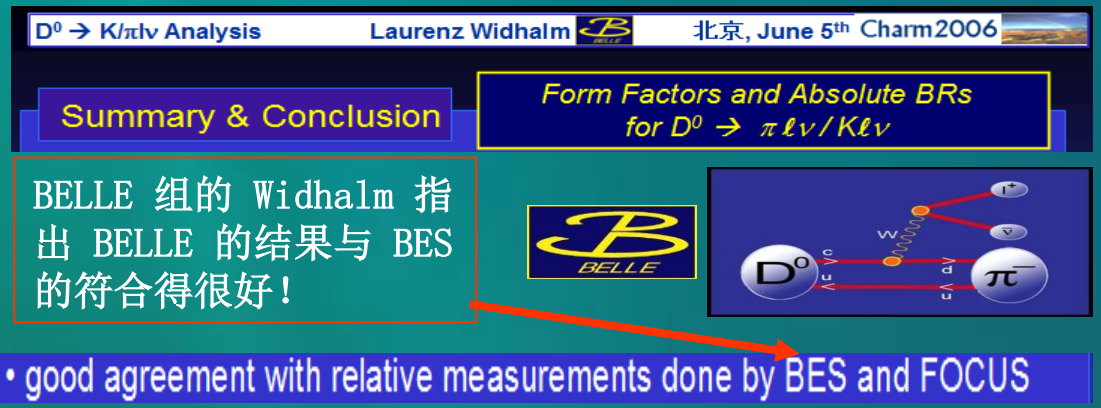
Q. He,[1] H. Muramatsu,[1] C. S. Park,[1] W. Park,[1] E. H. Thorndike,[1] T. E. Coan,[2] Y. S. Gao,[2] F. Liu,[2] M. Artuso,[3]

in computing the uncertainty on the total cross section. Our measured cross sections are in good agreement with BES [19] and higher than those of Mark III [7].

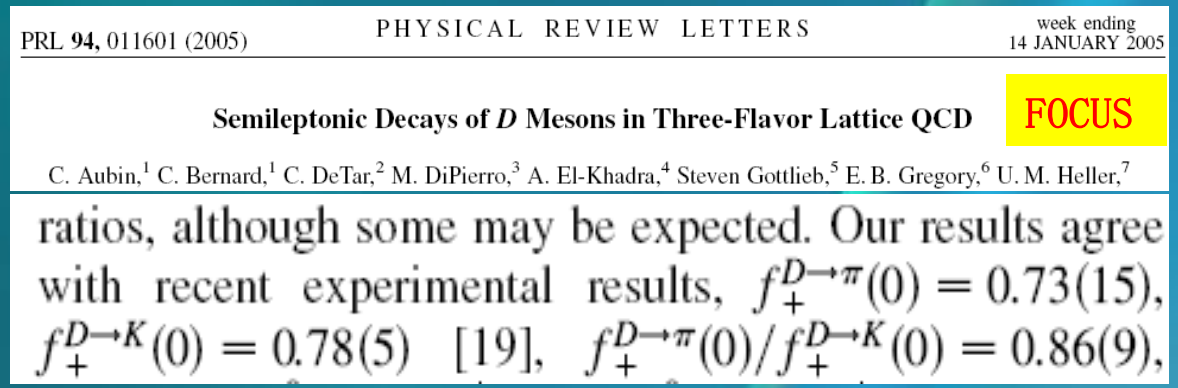



Prof. Ryd from Cornell University discussed the BES-II results.

- BELLE's speaker in talks/papers pointed out that the measurements are in good agreement with the BES measurements




- FOCUS's publications pointed out that 'our measurements agree with recent the BES experimental results, $f_+^\pi(0)$, $f_+^K(0)$, $f_+^\pi(0)/f_+^K(0)$


PRL 94, 011601 (2005) PHYSICAL REVIEW LETTERS week ending 14 JANUARY 2005

FOCUS

Semileptonic Decays of $D$ Mesons in Three-Flavor Lattice QCD

C. Aubin,[1] C. Bernard,[1] C. DeTar,[2] M. DiPierro,[3] A. El-Khadra,[4] Steven Gottlieb,[5] E. B. Gregory,[6] U. M. Heller,[7]

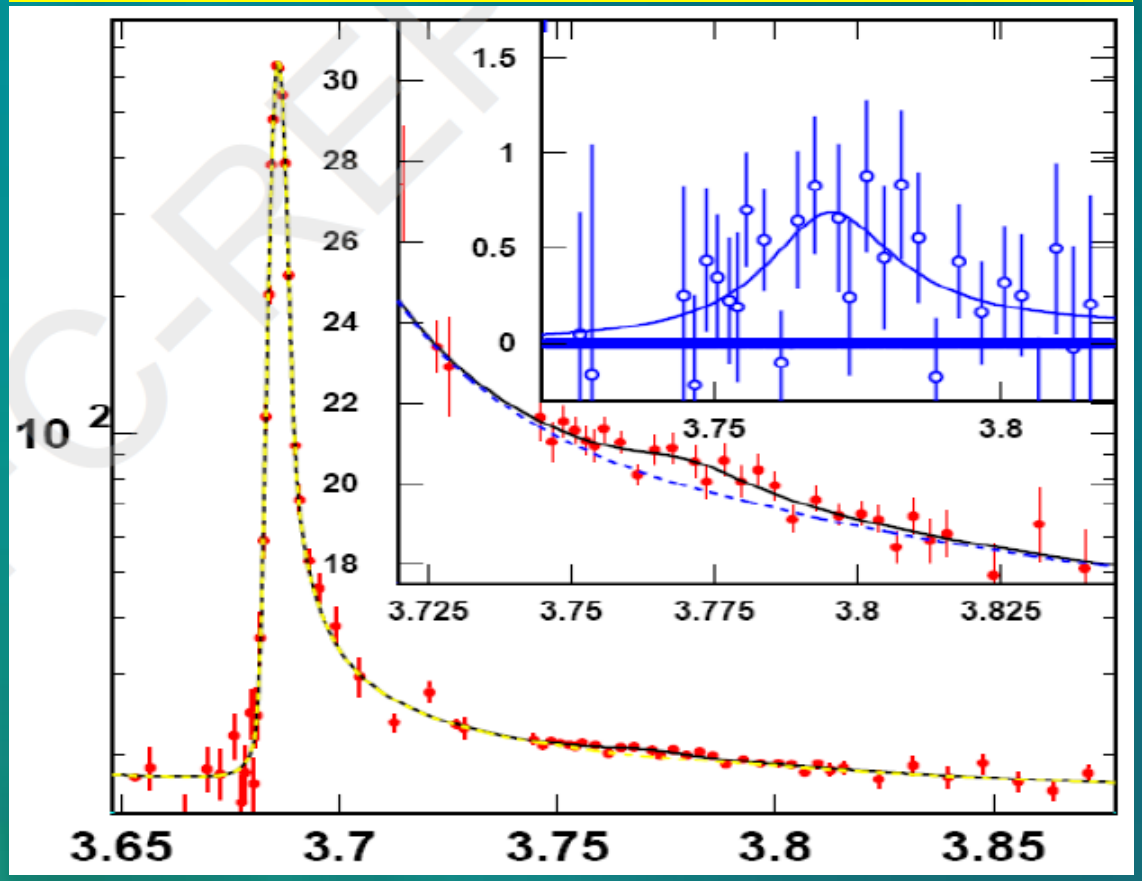
ratios, although some may be expected. Our results agree with recent experimental results, $f_+^{D\to\pi}(0) = 0.73(15)$, $f_+^{D\to K}(0) = 0.78(5)$ [19], $f_+^{D\to\pi}(0)/f_+^{D\to K}(0) = 0.86(9)$,

# BES-III B[ψ(3770)→non-DD̄]

## ➢ IHEP working group

We directly measure the branching fraction

$B[\psi(3770)\rightarrow \text{non-}D\bar{D}]=(10.1\pm3.5\pm\Delta_{sys})\%$

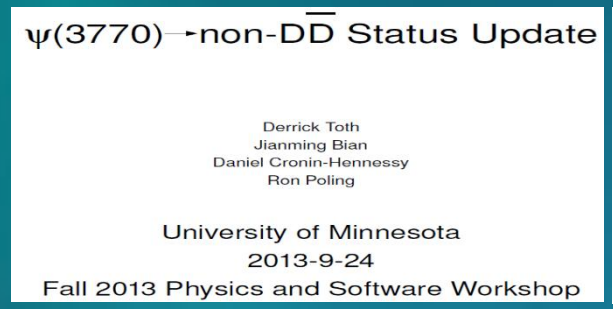



## ➢ UM working group

Daniel Cronin-Hennessy and Ron Poling are the members of the CLEO collaboration. They measured the branching fraction in September 2013

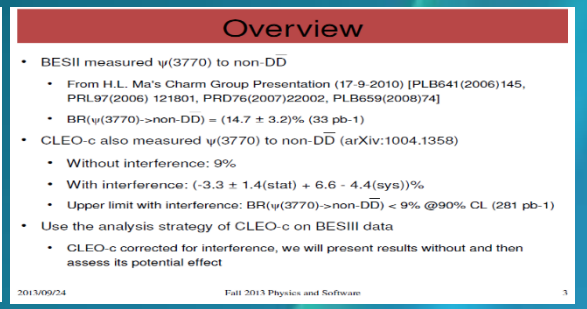
$BF[\psi(3770)\rightarrow \text{non-}D\bar{D}]=(9.6+-0.4+-2.8)\%$,

which is consistent within error with the BES-II measurements


ψ(3770)→non-DD̄ Status Update

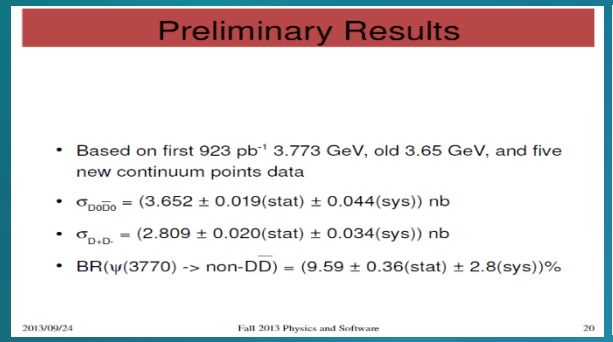
Derrick Toth
Jianming Bian
Daniel Cronin-Hennessy
Ron Poling

University of Minnesota
2013-9-24
Fall 2013 Physics and Software Workshop


Overview

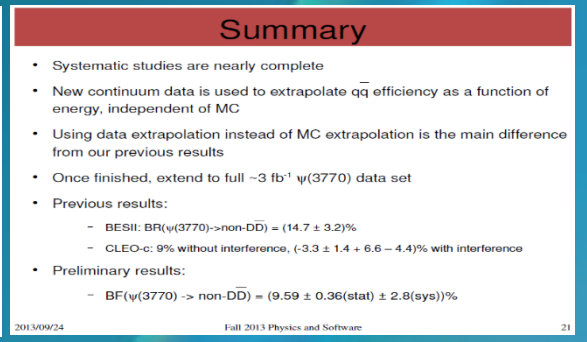
- BESII measured ψ(3770) to non-DD̄
  - From H.L. Ma's Charm Group Presentation (17-9-2010) [PLB641(2006)145, PRL97(2006) 121801, PRD76(2007)22002, PLB659(2008)74]
  - BR(ψ(3770)->non-DD̄) = (14.7 ± 3.2)% (33 pb-1)
- CLEO-c also measured ψ(3770) to non-DD̄ (arXiv:1004.1358)
  - Without interference: 9%
  - With interference: (-3.3 ± 1.4(stat) + 6.6 - 4.4(sys))%
  - Upper limit with interference: BR(ψ(3770)->non-DD̄) < 9% @90% CL (281 pb-1)
- Use the analysis strategy of CLEO-c on BESIII data
  - CLEO-c corrected for interference, we will present results without and then assess its potential effect

2013/09/24 Fall 2013 Physics and Software 3


Preliminary Results

- Based on first 923 pb$^{-1}$ 3.773 GeV, old 3.65 GeV, and five new continuum points data
- $\sigma_{D\bar{D}^0}$ = (3.652 ± 0.019(stat) ± 0.044(sys)) nb
- $\sigma_{D^+D^-}$ = (2.809 ± 0.020(stat) ± 0.034(sys)) nb
- BR(ψ(3770) -> non-DD̄) = (9.59 ± 0.36(stat) ± 2.8(sys))%

2013/09/24 Fall 2013 Physics and Software 20


Summary

- Systematic studies are nearly complete
- New continuum data is used to extrapolate qq̄ efficiency as a function of energy, independent of MC
- Using data extrapolation instead of MC extrapolation is the main difference from our previous results
- Once finished, extend to full ~3 fb$^{-1}$ ψ(3770) data set
- Previous results:
  - BESII: BR(ψ(3770)->non-DD̄) = (14.7 ± 3.2)%
  - CLEO-c: 9% without interference, (-3.3 ± 1.4 + 6.6 – 4.4)% with interference
- Preliminary results:
  - BF(ψ(3770) -> non-DD̄) = (9.59 ± 0.36(stat) ± 2.8(sys))%

2013/09/24 Fall 2013 Physics and Software 21

Issue about B[ψ(3770)→non-DD]

# CLEO-c 数据分析中存在的问题

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ScienceDirect

Physics Letters B 641 (2006) 145–155

PHYSICS LETTERS B

www.elsevier.com/locate/physletb

## Measurements of the cross sections for $e^+e^- \to$ hadrons at 3.650, 3.6648, 3.773 GeV and the branching fraction for $\psi(3770) \to$ non-$D\bar{D}$

BES Collaboration

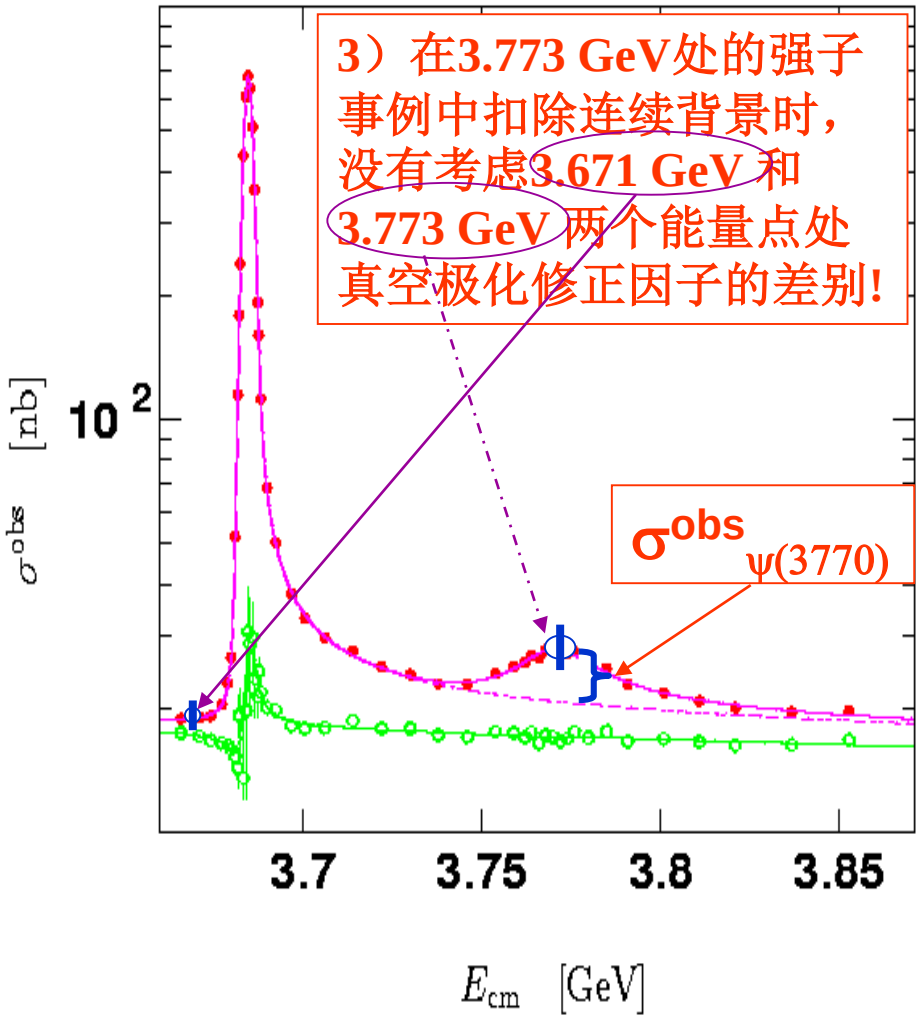
M. Ablikim [a], J.Z. Bai [a], Y. Ban [k], J.G. Bian [a], X. Cai [a], H.F. Chen [o], H.S. Chen [a], H.X. Chen [a],

[6] After BES submitting the paper to Phys. Lett. B, CLEO reported a measurement of $\sigma^{\rm obs}_{\psi(3770)}$ appeared in [32]. In CLEO's measurement of the $\sigma^{\rm obs}_{\psi(3770)}$, no correction for the difference of the ISR and vacuum polarization correction to the continuum hadron production at $E_{\rm cm} = 3.671$ GeV and $E_{\rm cm} = 3.773$ GeV is mentioned in the continuum background subtraction. This effect would systematically shift the measured $\sigma^{\rm obs}_{\psi(3770)}$ significantly. Moreover from CLEO's published paper, one find that the leptonic width of $\psi(2S)$ estimated based on the number of $N_{\psi(2S)} = 583\,000 \pm 6000$ at $E_{\rm cm} = 3.773$ GeV is $\Gamma^{ee}_{\psi(2S)} = 2.55$ keV which is larger than $\Gamma^{ee}_{\psi(2S)} = 2.330 \pm 0.036 \pm 0.110$ keV measured by BES Collaboration (see [31]) based on analysis of $\psi(2S)$ and $\psi(3770)$ cross section scan data. This difference would affect the observed cross section $\sigma^{\rm obs}_{\psi(3770)}$ by about 0.26 nb.

[32] CLEO Collaboration, D. Besson, et al., Phys. Rev. Lett. 96 (2006) 092002.

**Issue about B[ψ(3770)→non-DD]**

# CLEO-c 分析中至少存在三个问题




$$\sigma^{obs}_{had} = \frac{N_{had}}{\varepsilon\ L} \qquad \sigma^{obs}_{\psi(3770)} = \frac{N_{\psi(3770)}}{\varepsilon_{\psi(3770)}\ L}$$

$$N_{had} = N_{\psi(3770)} + N^{ISR}_{\psi(3686)} + N^{ISR}_{J/\psi} + N_{continuum}$$

$$N_{\psi(3770)} = N_{had} - N^{ISR}_{\psi(3686)} - N^{ISR}_{J/\psi} - N^{377\ 3\ MeV}_{continuum}$$

$$N^{ISR}_{\psi(3686)} = L\ \sigma^{ISR}_{\psi(3686)}\ \varepsilon$$

1）计算$\sigma^{ISR}_{\psi(3686)}$ 时， 轻子宽度大了0.23 keV, 导致$\sigma^{ISR}_{\psi(3686)}$ 大0.26 nb

➔ 多估计了ψ(3686)的背景数。

$$N^{377\ 3\ MeV}_{continuum} = N^{3671\ MeV}_{continuum} \times f \times \eta$$

$$f = \frac{3.671^{\ 2}}{3.773^{\ 2}}$$

$$\eta = 1.025 \quad \text{（估计值）}$$

2）CLEO-c 效率乘了1.025 的修正因子！多估计了连续背景。

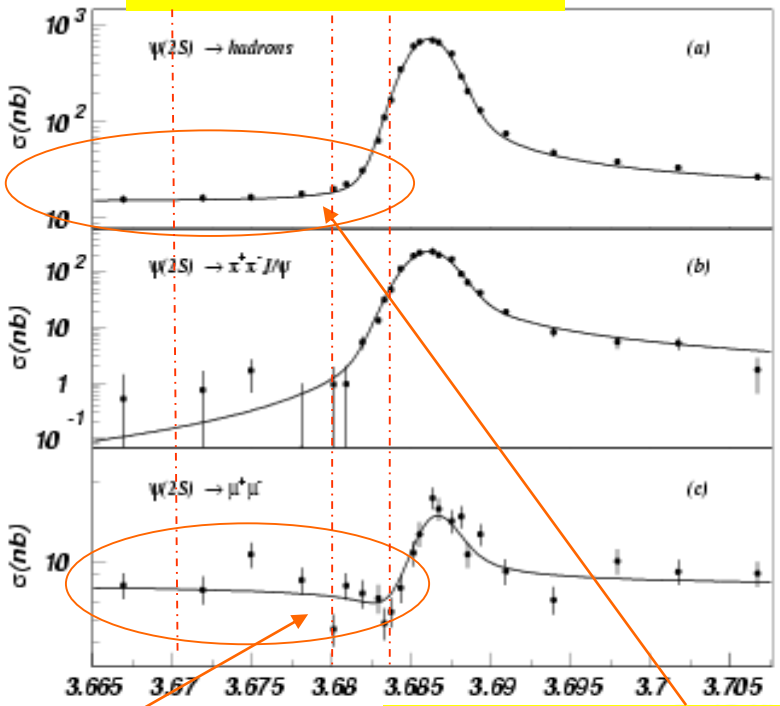
1)和2)两项使ψ(3770)的截面减小了0.66 nb

**[ 0.26+16x0.025=0.26+0.40=0.66 nb ]**

# Effects of Interference

## BES-II Measurements of $e^+e^-$ → hadrons

PLB 550 (2002)24

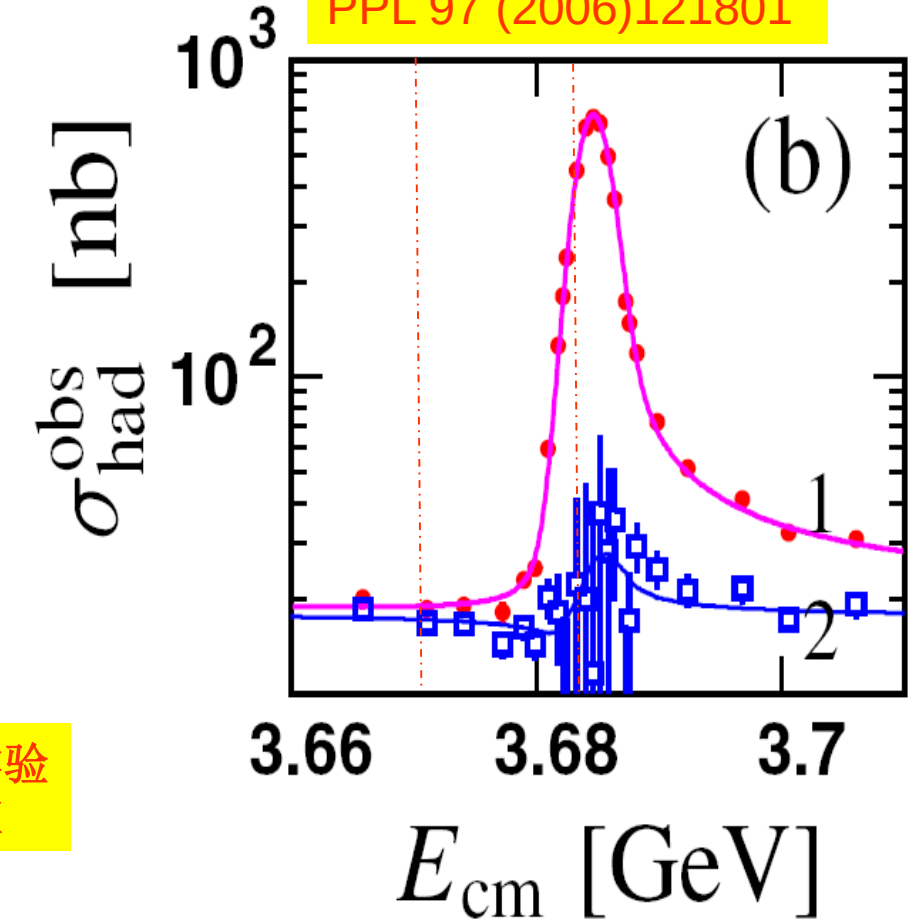



干涉效应

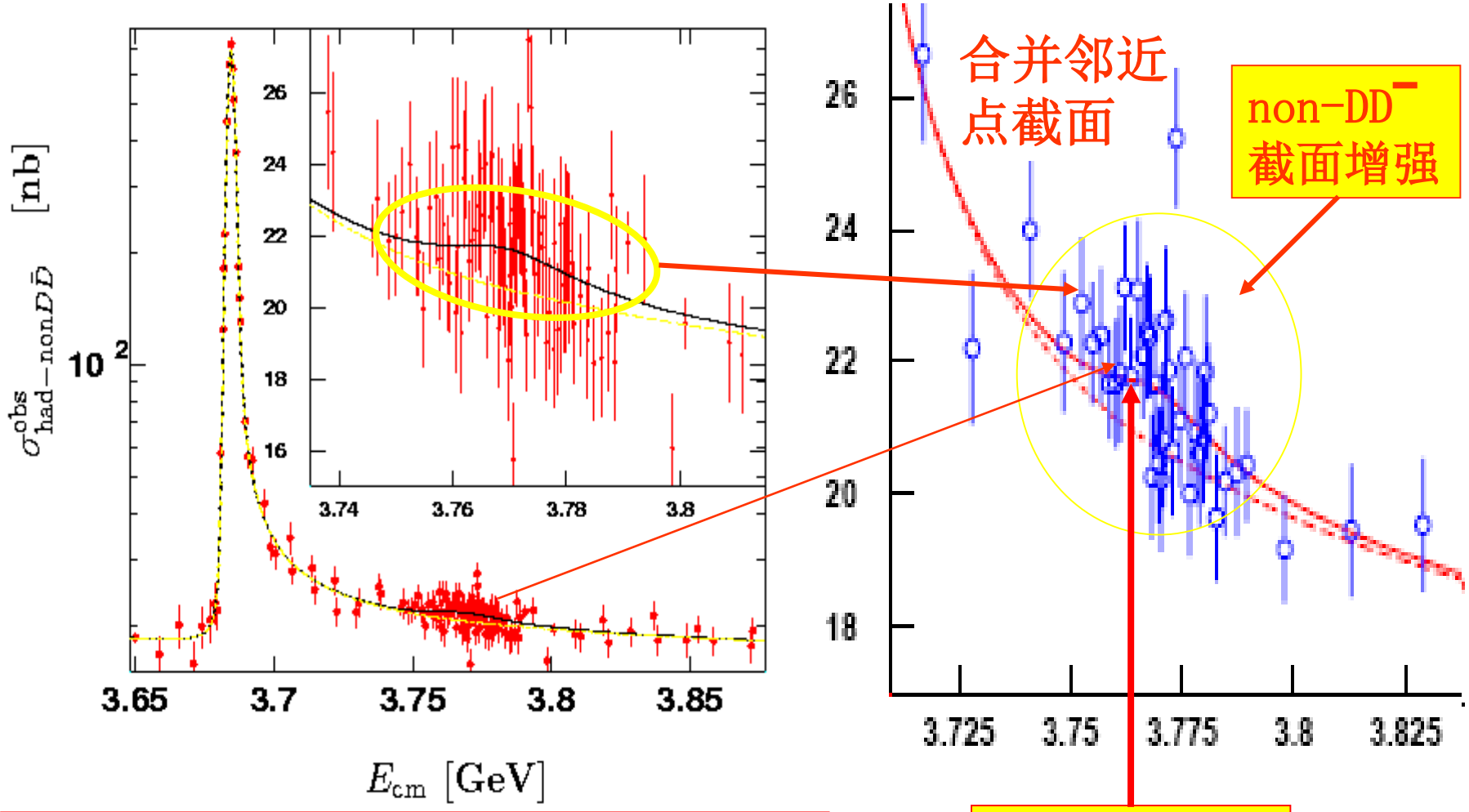
对于单举强子末态，实验并上没观测到干涉效应

Figure 6. The cross section for (a) $e^+e^- \to$ hadrons, (b) $e^+e^- \to \pi^+\pi^- J/\psi$, and (c) $e^+e^- \to \mu^+\mu^-$ versus center-of-mass energy. The solid curves represent the results of the fit to the data.

PPL 97 (2006)121801



# ψ(3770)→non-DD̄ 截面反常增强




首次直接观测到non-DD̄强子截面增强

Issue about B[ψ(3770)→non-DD]

# ψ(3770)非-DD衰变分支比与4-夸克态

M.B. Voloshin 指出，如果ψ(3770)波函数中有4-夸克态成分，实验上就能观测到很大的非-DD衰变分支比。

PHYSICAL REVIEW D 71, 114003 (2005)

## $\bar{c}c$ purity of $\psi(3770)$ and $\psi'$ challenged

M. B. Voloshin

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(Received 6 May 2005; published 6 June 2005)

It is suggested that the resonance $\psi(3770)$ may contain a sizeable ($O(10\%)$ in terms of the probability weight factor) four-quark component with the up- and down-quarks and antiquarks in addition to the $c\bar{c}$ pair, which component in itself has a substantial part with isospin $I = 1$. Furthermore such a four-quark part of the wave function should also affect the properties of the $\psi'$ charmonium resonance through the $\psi(3770) - \psi'$ mixing previously considered in the literature. It is argued that an admixture of extra light quark pairs can explain a possible discrepancy between the theoretical expectations and the recent data on the non-$D\bar{D}$ decay width of the $\psi(3770)$ and the ratio of the yield of charged and neutral $D$ meson pairs in its decays, as well as on the extra rate of the $\psi'$ direct decay into light hadrons and the rate of the decay $\psi' \to \pi^0 J/\psi$. It is further argued that the suggested four-quark component of the wave function of the $\psi(3770)$ should give rise to a measurable rate for the decays $\psi(3770) \to \eta J/\psi$ and $\psi(3770) \to \pi^0 J/\psi$.

It is well known [29] that the $c\bar{c}$ pair inside a four-quark component can annihilate in second order in the QCD coupling $\alpha_s$, i.e. much faster than a colorless $J^{PC} = 1^{--}$ heavy quark pair, which is bound by the conservation laws to annihilate via three gluons. In particular a $^3S_1$ $c\bar{c}$ pair in

4-夸克态分量中的cc湮没的速度比色单态cc的速度快得多，从而能测到很大的非-DD衰变分支比。

# ψ(3686) Resonance Parameters

**PDG08**

**ψ(2S) WIDTH**

| VALUE (keV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **317± 9 OUR FIT** | | | | | |
| **286±16 OUR AVERAGE** | | | | | |
| 358±88± 4 | | ABLIKIM | 08B | BES2 | $e^+e^- \to$ hadrons |
| 290±25± 4 | 2.7k | ANDREOTTI | 07 | E835 | $p\overline{p} \to e^+e^-,\ J/\psi X$ |
| 331±58± 2 | | ABLIKIM | 06L | BES2 | $e^+e^- \to$ hadrons |
| 264±27 | | [6] BAI | 02B | BES2 | $e^+e^-$ |
| 287±37±16 | | [7] ARMSTRONG | 93B | E760 | $\overline{p}p \to e^+e^-$ |

[6] From a simultaneous fit to the hadronic and $\mu^+\mu^-$ cross section, assuming $\Gamma = \Gamma_h + \Gamma_e + \Gamma_\mu + \Gamma_\tau$ and lepton universality. Does not include vacuum polarization correction.

[7] The initial-state radiation correction reevaluated by ANDREOTTI 07 in its Ref. [4].

**ψ(2S) PARTIAL WIDTHS**

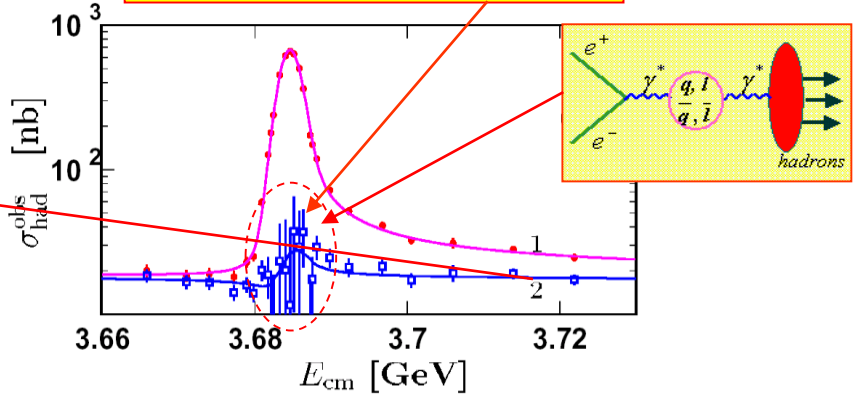
**Γ(hadrons)** **$\Gamma_1$**

| VALUE (keV) | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 258±26 | BAI | 02B | BES2 | $e^+e^-$ |
| 224±56 | LUTH | 75 | MRK1 | $e^+e^-$ |

**Γ($e^+e^-$)** **$\Gamma_4$**

| VALUE (keV) | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **2.38 ±0.04 OUR FIT** | | | | |
| **2.33 ±0.07 OUR AVERAGE** | | | | |
| 2.338±0.037±0.096 | ABLIKIM | 08B | BES2 | $e^+e^- \to$ hadrons |
| 2.330±0.036±0.110 | ABLIKIM | 06L | BES2 | $e^+e^- \to$ hadrons |
| 2.44 ±0.21 | [8] BAI | 02B | BES2 | $e^+e^-$ |
| 2.14 ±0.21 | ALEXANDER | 89 | RVUE | See $\Upsilon$ mini-review |

实验上首次观测到的真空极化效应！




The value of $\Gamma^{ee}_{\psi(3686)}$ =2.54 keV measured by CLEO-c is 0.21 keV larger than the world averaged value of $\Gamma^{ee}_{\psi(3686)}$=2.33 keV

After 2006, the world averaged value of $\Gamma^{ee}_{\psi(3686)}$ dose not include the CLEO-c's measurement of the $\Gamma^{ee}_{\psi(3686)}$

BES-II
ψ(3770) 组
BES 2
RVUE

PRL96，082004（2006）

PRL 96, 082004 (2006) PHYSICAL REVIEW LETTERS week ending 3 MARCH 2006

**Observation of $\psi(3770) \to \pi\pi J/\psi$ and Measurement of $\Gamma_{ee}[\psi(2S)]$**

N. E. Adam,[1] J. P. Alexander,[1] K. Berkelman,[1] D. G. Cassel,[1] V. Crede,[1] J. E. Duboscq,[1] K. M. Ecklund,[1] R. Ehrlich,[1]

$$\Gamma_{ee}[\psi(2S)] = (2.54 \pm 0.03 \pm 0.11)\ \text{keV}.$$

CLEO-c

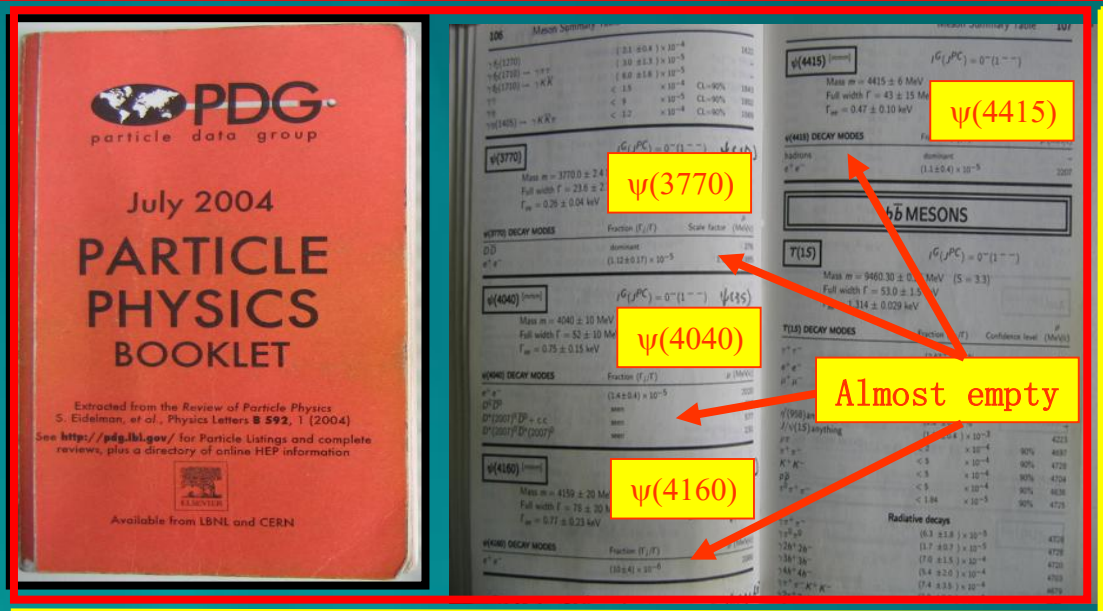
# 发现 $\psi(3770)\rightarrow J/\psi\pi^+\pi^-$ 的重要意义和影响

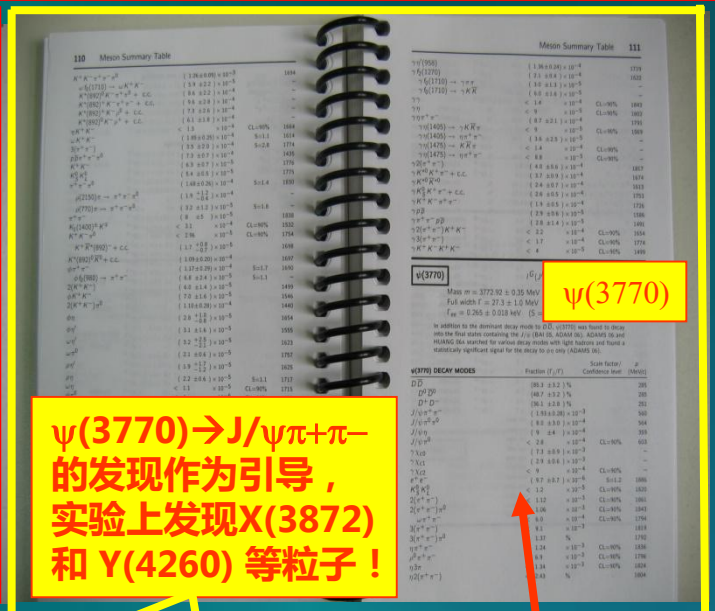
此发现揭示了DD̲ 阈上粒子 $X_{abvD\underline{D}}$可以通过强作用转换到$J/\psi\pi^+\pi^-$末态的物理规律，它彻底地颠覆了统治物理学家二十多年之久的“除了以$10^{-5}$几率衰变到$e^+e^-$末态外，DD̲阈上粒子不能衰变到其它 non-DD̲ 末态的传统认识”。这种传统认识被新发现颠覆所带来的结果，是迅速引导许多实验组物理学家和学者立即转向利用 $J/\psi\pi^+\pi^-$ 末态作为搜寻目标，研究 DD̲ 阈上粒子的 non-DD̲ ($D=D^{0/+}$, $D^{*0/+}$, $Ds^+$, $Ds^{*+}$)衰变，从而在短短几年内发现了多个新粒子，如XYZ 等。

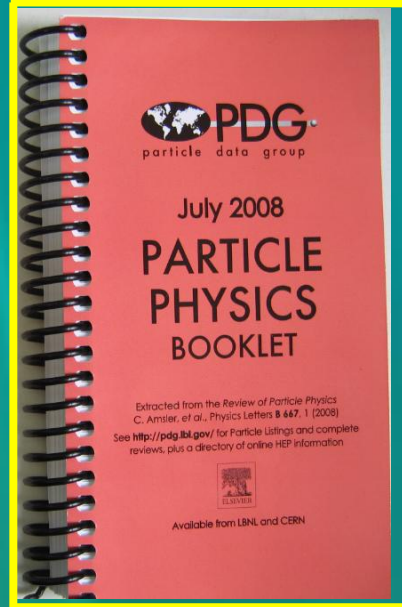
- 2002年6月，在BES合作组成都年会上，我们报道了发现首例DD̲阈上粒子 $X_{abvD\underline{D}}\rightarrow J/\psi\pi^+\pi^-$，我们假定 $X_{abvD\underline{D}}=\psi(3770)$，即$\psi(3770)\rightarrow J/\psi\pi^+\pi^-$衰变。此消息立刻传播到其它高能物理实验组，BELLE实验组物理工作者立即在数据中寻找此过程，并从$J/\psi\pi^+\pi^-$不变质量谱中发现 X(3872)。
- BaBar等实验组也都相继开始在各自数据样本中研究 $J/\psi\pi^+\pi^-$末态，并从$J/\psi\pi^+\pi^-$不变质量谱中，发现了Y(4260)等一系列新的奇特态。
- D0 和CDF 组也都在他们的数据样本中研究 $J/\psi\pi^+\pi^-$末态，寻找对应的转换过程。

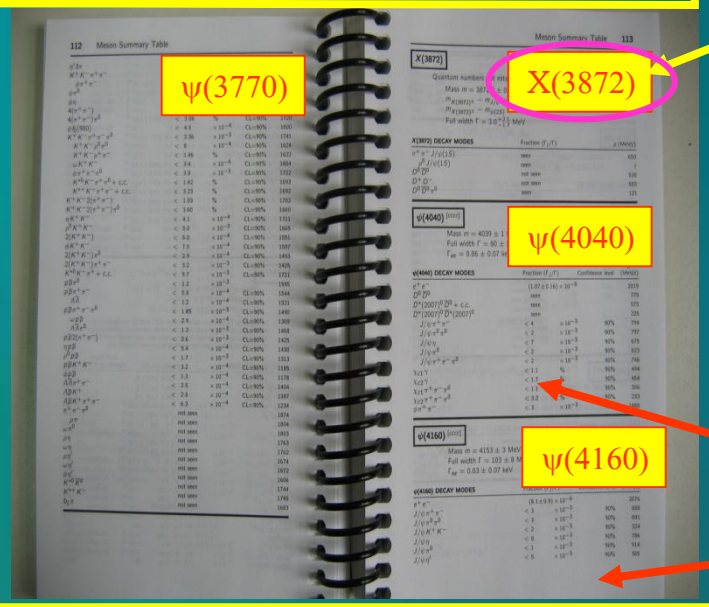
此发现主要的科学历史意义在于，中国的实验物理工作者们以巧妙的分析方法和技术，从在3.773 GeV 处采集的数据样本中，发现了首例 DD̲ 阈上粒子的 non-DD 衰变：$X_{abvD\underline{D}}\rightarrow J/\psi\pi^+\pi^-$，揭示了 DD̲ 阈上粒子 $X_{abvD\underline{D}}$可以通过强作用转换到 $J/\psi\pi^+\pi^-$ 的物理规律，颠覆了“除了以十万分之几的几率衰变到$e^+e^-$ 之外，DD̲ 阈上粒子 $X_{abvD\underline{D}}$ 100% 衰变到 DD̲ 末态”的传统认识”，并由此打开了实验上广泛研究 DD̲ 阈上粒子 $X_{abvD\underline{D}}\rightarrow$ non-DD̲ 衰变的窗口，导致在短短的几年内实验发现了 X(3872)和 Y(4260) 等多个奇特粒子。由于是在3.773 附近采集的数据样本中发现了 $J/\psi\pi^+\pi^-$，所以BES认为该过程为：$\psi(3770)\rightarrow J/\psi\pi^+\pi^-$，并测定该衰变分支比。

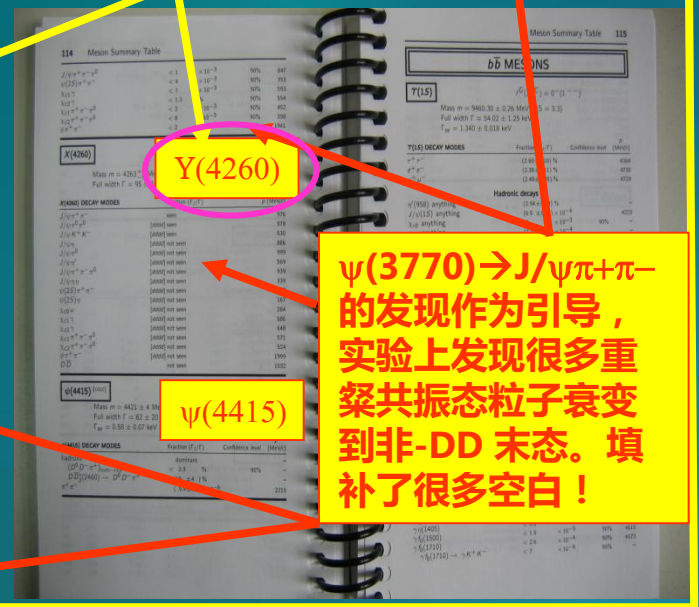
# Effect of discovery of ψ(3770)→J/ψπ⁺π⁻ on physics




- In 2004， there is almost empty block in the ‘Meson Summary Table’ of this BOOKLET, since few experimental physicists studied NOCP decays of $X_{abvD\underline{D}}$ at that time
- In 2008， a lot of measurements are filled the Meson Summary Table. Actually, the BES played a leading role in study of NOCP decays of $X_{abvD\underline{D}}$.

# Response to discovery: 15% of ψ(3770) decay into non-DD̄

**Before 2007, Prof. Voloshin never cited BES-II published results on non-DD̄ decays of ψ(3770), However, in a paper to review Charmonium published in 2008, he discussed the effects of existing measurements on Charmonium physics. He cited 6 BES-II's papers in discussion of progress on Charmonium physics. He put the BES-II results at the first place in his discussion.**

ELSEVIER

Progress in Particle Physics and Nuclear Physics

Progress in Particle and Nuclear Physics 61 (2008) 455–511

Progress in Particle and Nuclear Physics

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Review

## Charmonium

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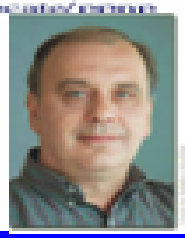


Recently the physics of charmonium regained a great renewed interest due to the massive dedicated investigation by BES and CLEO-c and the studies using decays of *B* mesons and the radiative return technique at the B factories with a higher initial energy of the electron and positron beams. After a 'dry spell' of more than two decades during which no new states of charmonium have been found with any certainty, new observations discover charmonium and charmonium-related resonances at a rate that outpaces the ability of the theory to fit their properties in a consistent scheme. Furthermore, the data very strongly suggest that among the new resonances there are exotic four-quark states, possibly hybrid states with gluonic degrees of freedom in addition to the $c\bar{c}$ pair, and also loosely bound states of heavy hadrons – charmonium molecules. Thus it looks like that charmonium not only has provided us with a 'hadronic atomic physics' but quite possibly also with a 'hadronic chemistry', and in its mature age of 33 charmonium still offers us new intriguing puzzles.

# Compare with CLEO-c

- **$D^0 \to K^- e^+ \nu$ 和 $D^0 \to \pi^- e^+ \nu$ 衰变实验研究与 CLEO-c 精密测量结果的对比：**

在BES-III 实验结果发表前，CLEO-c 实验组一直被国际高能物理界认定为做粲介子物理研究水平最高的团队，其精密测量结果代表着世界上最高的精密程度。BES-III精密测量结果与CLEO-c 对比如下：

| L | $0.818 fb^{-1}$ <=> $2.92 fb^{-1}$ | | $\frac{N_{BES-III}}{N_{CLEO-c}} - 1$ |
|---|---|---|---|
| CLEO-c | | | |
| $N_{\bar{D}^0 tag}$ | 661769 | 2362305 | |
| $N_{D^0 \to K^- e^+ \nu}$ | 14123 | 50419 | |
| $N_{D^0 \to \pi^- e^+ \nu}$ | 1374 | 4905 | |
| BES-III | $0.818 fb^{-1}$ <=> $2.92 fb^{-1}$ | | |
| $N_{\bar{D}^0 tag}$ | 782511 | 2793317 | 18.2% |
| $N_{D^0 \to K^- e^+ \nu}$ | 19804 | 70727 | 40.3% |
| $N_{D^0 \to \pi^- e^+ \nu}$ | 1763 | 6297 | 27.8% |

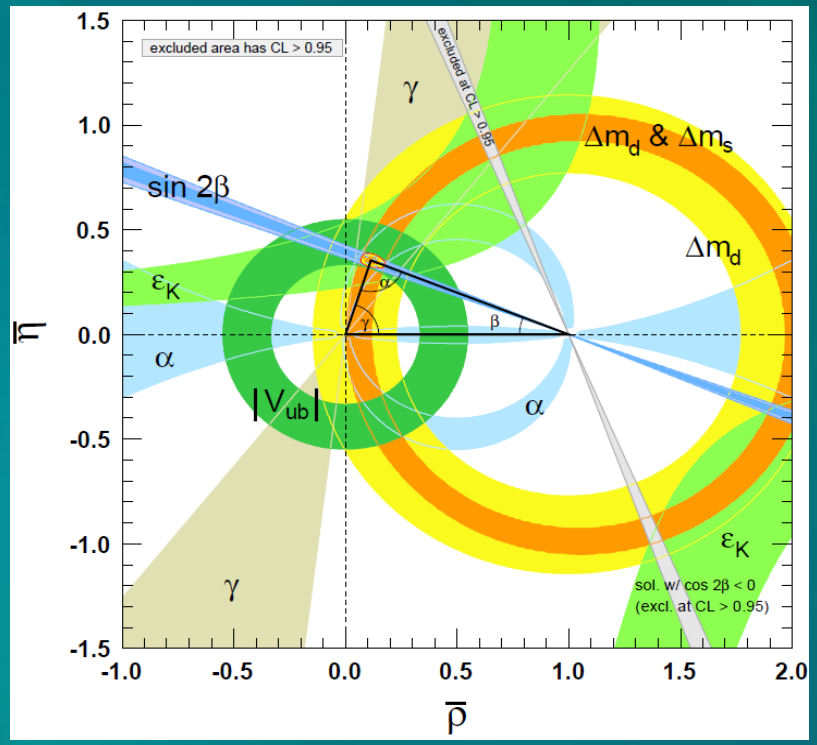
归一化到同样亮度对比，BES-III anti-$D^0$ tag 事例数比CLEO-c 多18.2%；$D^0 \to K(\pi)^- e^+ \nu$ 的重建效率比 CLEO-c 高22%(10%)。

BES-III找到的$D^0 \to K(\pi)^- e^+ \nu$ 事例数比 CLEO-c 的多40% (28.2%), BES-III 测量结果的系统误差比CLEO-c 的 小 20%；这使得 BES-III 测定的物理量结果的统计精度和系统精度都高于 CLEC-c 结果对应的精度。这反映了研究团队的软实力。

To compare with the CLEO-c, we normalize the numbers of events of the anti-$D^0$ tags and $D^0 \to K(\pi)^- e^+ \nu$ by a factor of 3.582[it is the ratio of the Luminosity of BES-III data over the Luminosity of CLEO-c ] to get the numbers of these events from the 0.818 $fb^{-1}$ of data at BES-III, we find that our number of the anti-$D^0$ tag is 18% more than that of CLEO-c, and the numbers of $D^0 \to K(\pi)^- e^+ \nu$ is 40%(28%) more than the CLEO-c. The systematic uncertainties of our measurements are ~20% smaller than the CLEO-c, Both of these result in the more than precision measurements of these decays at the BES-III experiment.

# 成果的科学意义

BES D介子纯轻和半轻衰变研究结果，在相当大的程度上提高了标准模型理论参数中 2个参数的精度，同时可以间接改进另外3个参数的精度。




- 味物理研究

  K介子工厂，B 介子工厂，τ-粲介子工厂，t-夸克产生于衰变

- 味物理研究的一个重要目标

  通过过约束拟合，在 (η, ρ) 平面上展示对比多样化的测量结果，检验SM，寻找新物理。

- 精密检验SM 受限于:

  $\Delta m_d$, $\Delta m_s$, $|V_{ub}|$, …

- BES D介子纯轻和半轻衰变结果的作用

  可以改进 $\Delta m_d$, $\Delta m_s$和 $|V_{ub}|$ 测定精度 ➔ 减小幺正三角形测定的误差 ➔ 更精密地 检验 SM 和 寻找新物理

**粲介子纯轻子和半轻子衰变研究是小专题，大物理！**