

Experimental Studies of $\psi(3770)$ Production and Decays at BES

荣刚

Institute of High Energy Physics, CAS

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1. Introduction to $\psi(3770)$ Physics
2. Experimental Facility
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Introduction

$\psi(3770)$ 物理与 QCD

$\psi(3770)$ 是粲偶素家族(**c quark and anti-c quark** 束缚态)的成员。强作用力把**cc-bar** 束缚在一起。

描述强相互作用的理论 – **QCD**（量子色动力学）还在不断的发展和完善过程中，还需要大量的、各种不同的实验来检验。

基于**QCD**理论发展的各种理论模型（基于**QCD**的势模型理论，格点规范理论，**QCD**求和规则的理论...）对粲偶素态的质量，衰变宽度及衰变的分支比等都有定量的预言。

实验上精密地测定粲偶素态的质量、衰变分宽度、总宽度以及衰变的分支比等对发展和完善**QCD**理论都是非常重要的。

$\Psi(3770)$ 物理与 QCD

历史上，原子光谱的精密实验研究为量子电动力学（**QED**）的建立和发展奠定了实验基础。当代夸克偶素，特别是重夸克偶素(**cc-bar** 和 **bb-bar**)的精密实验研究结果为发展**QCD**的理论体系提供了重要的实验数据。

国际上，有些理论家把重夸克偶素态比作**QCD**的氢原子。由此，可以看出重夸克偶素态的实验研究在发展和完善**QCD**理论体系方面所起到的重要作用。

2003年前，国际高能物理界粲夸克偶素物理的实验研究主要集中在基态和低激发态粲夸克偶素[η_c , J/Ψ , χ_{cJ} , $\Psi(3686)$] 的产生和衰变特性的研究方面。而高激发态粲夸克偶素[如 $\Psi(3770)$, $\Psi(4040)$, $\Psi(4016)$ 和 $\Psi(4415)$]物理的实验研究基本上是空白。实验上研究这些高激发态粲夸克偶素的自身特性对发展和完善**QCD**的理论体系具有特殊的意义。

$\Psi(3770)$ 物理与 QCD

在 $E_{cm}=3.70\text{ GeV}$ 以上能区，理论上预期存在着可以在 e^+e^- -annihilation 中直接产生的非常规的介子，如：分子态，四夸克态，胶子球以及胶子和夸克构成的混杂态等。

实验上寻找分子态，四夸克态，胶子球以及胶子和夸克构成的混杂态对发展和验证 QCD 理论是非常重要的。

实验研究特点

这些态耦合到 e^+e^- 的强度很弱，常常被常规的粲偶素态的产生和衰变信息掩盖。

要想从常规的粲偶素态的产生和衰变的信息为主导的数据样本中分离或分辨出这些非常规的介子的产生和衰变信息，首先必须要研究清楚这些高激发粲偶素态的自身特性，包括精密地测定粲偶素态的质量，总宽度，强子分宽度，轻子分宽度，衰变到非-**DD-bar** 和 **DD-bar** 末态的分支比，及衰变到遍举非-**DD-bar** 末态的分支比等。

$\psi(3770)$ 物理研究状况

实验研究现状

在 **BES-II** $\psi(3770)$ 物理实验结果正式发表前，
国际上没有正式发表的 $\psi(3770) \rightarrow D\bar{D}$ 和
 $\psi(3770) \rightarrow \text{non-}D\bar{D}$ 的实验研究结果。

2003年**BES-II** 发现第一个 $\psi(3770) \rightarrow \text{non-}D\bar{D}$ 衰变过程 -- $\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$ ，从此在国际上打开了广泛研究 $\psi(3770) \rightarrow \text{non-}D\bar{D}$ 衰变过程的窗口。

主要的实验

BES-II/BEPC

CLEO-c/CERS

高能区 e^+e^- 物理实验

Experimental Facility

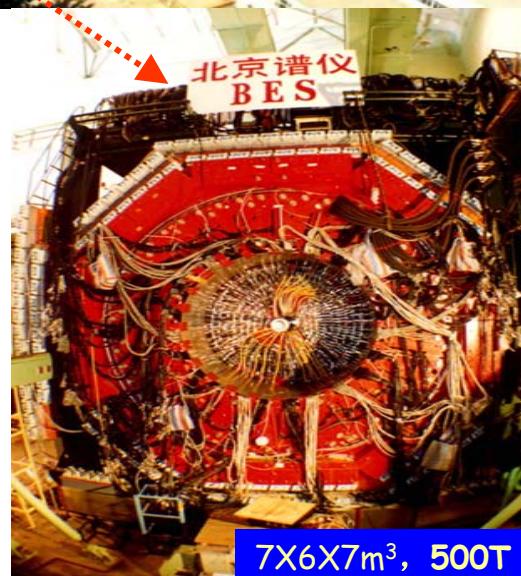
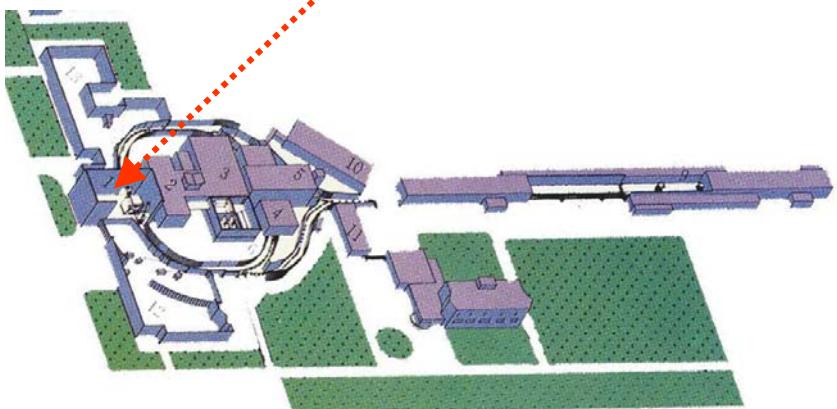
(BES-I & BES-II at BEPC)

The Beijing Electron Positron Collider (BEPC)

BES-II/BEPC

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

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



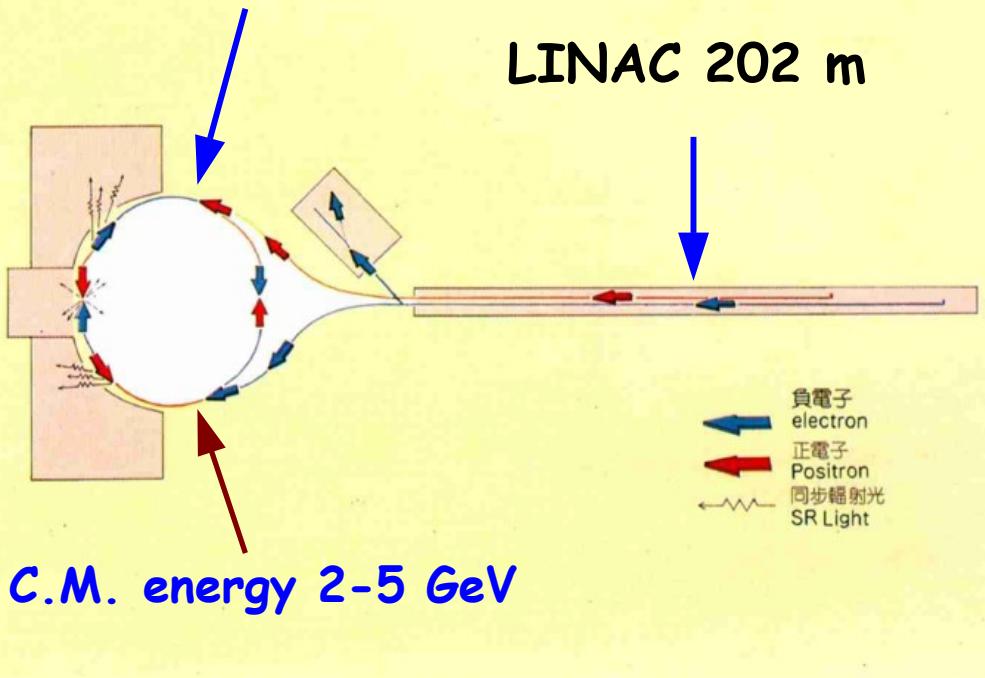
7X6X7m³, 500T

BES-II/BEPC

Beijing Electron Positron Collider

Circumference 240.4 m

LINAC 202 m



BES (Beijing Electron-positron Spectrometer)

A large general purpose electro-magnetic spectrometer. It measure the **energy**, **momentum** of charged particles, photon and does **particle identification** to reconstruct the decay events fully.

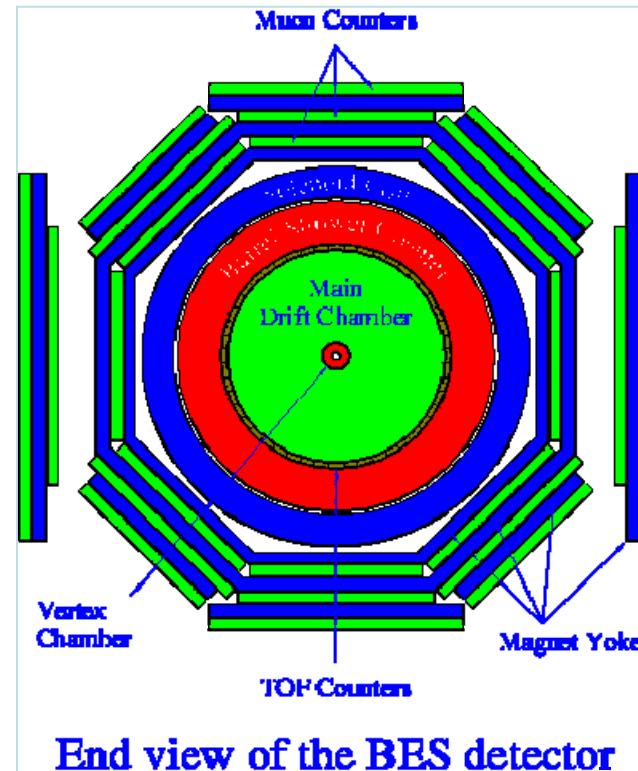
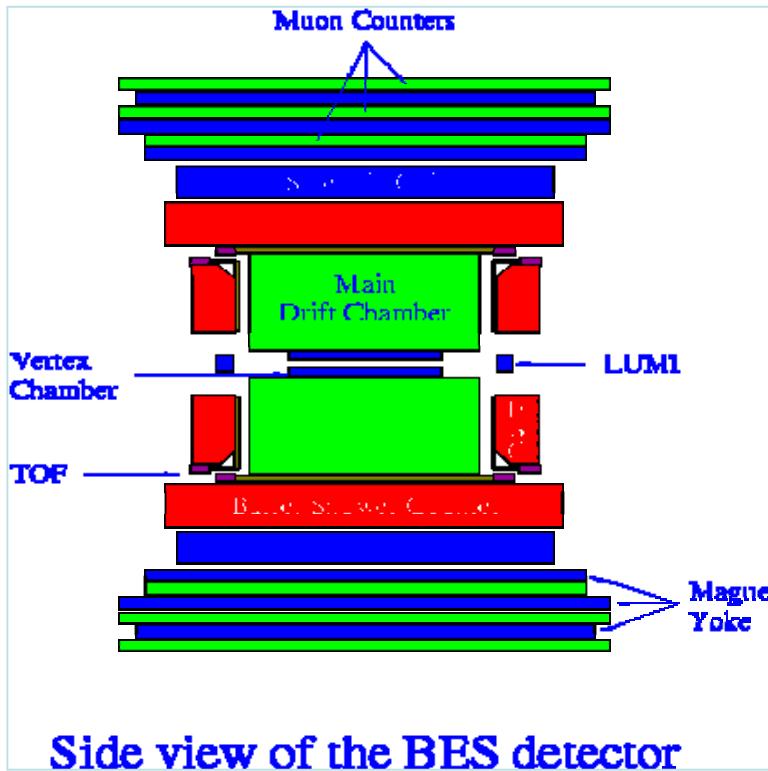
physics goals

Quarks			Leptons		
u	c	t	d	s	b
up	charm	top	down	strange	bottom
ν_e	ν_μ	ν_τ	e^- -neutrino	μ^- -neutrino	τ^- -neutrino
e^-	μ^-	τ^-	electron	muon	tau

Three Generations of Matter

Also studies of light hadron (u, d, s quarks) production in e^+e^- annihilation

BES-II Detector



$$\text{VC: } \sigma_{xy} = 100 \text{ } \mu\text{m}$$

$$\text{MDC: } \sigma_{xy} = 220 \text{ } \mu\text{m}$$

$$\sigma_{dE/dx} = 8.5 \text{ \%}$$

$$\Delta p/p = 1.7\% \sqrt{(1+p^2)}$$

$$\text{TOF: } \sigma_T = 180 \text{ ps}$$

$$\text{BSC: } \Delta E/\sqrt{E} = 22 \text{ \%}$$

$$\sigma_\phi = 7.9 \text{ mrd}$$

$$\sigma_z = 3.1 \text{ cm}$$

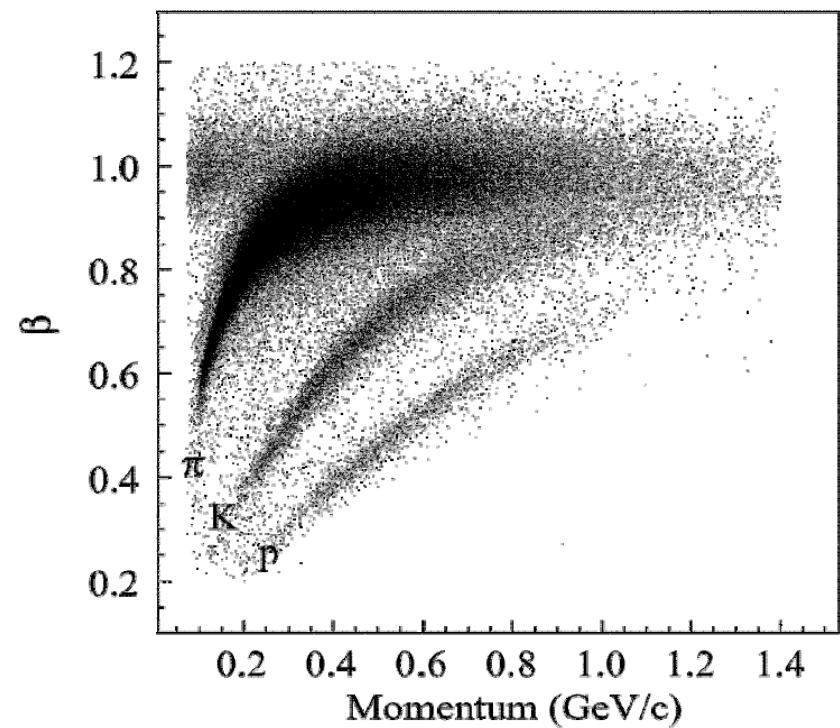
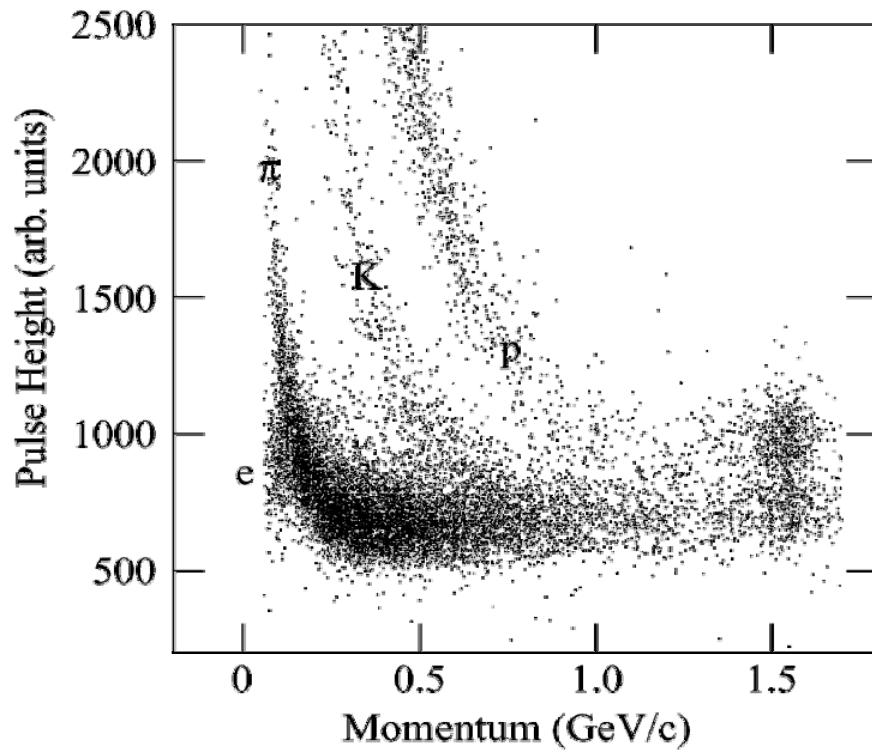
$$\mu \text{ counter: } \sigma_{r\phi} = 3 \text{ cm}$$

$$\sigma_z = 5.5 \text{ cm}$$

$$\text{B field: } 0.4 \text{ T}$$

Particle Identification

Muon identification can be done for the charged track with momentum of great than 0.52 GeV/c



Data Samples

$\psi(4030)$ and $\psi(4140)$ data samples

~ 22 pb⁻¹ data taken at 4.03 GeV with BES-I

~ 2 pb⁻¹ data taken at 4.14 GeV with BES-I

$\psi(3770)$ data sample [at BES-II]

~18 pb⁻¹ data taken at 3.773 GeV

~7 pb⁻¹ data taken at the region from 3.768 GeV
to 3.778 GeV

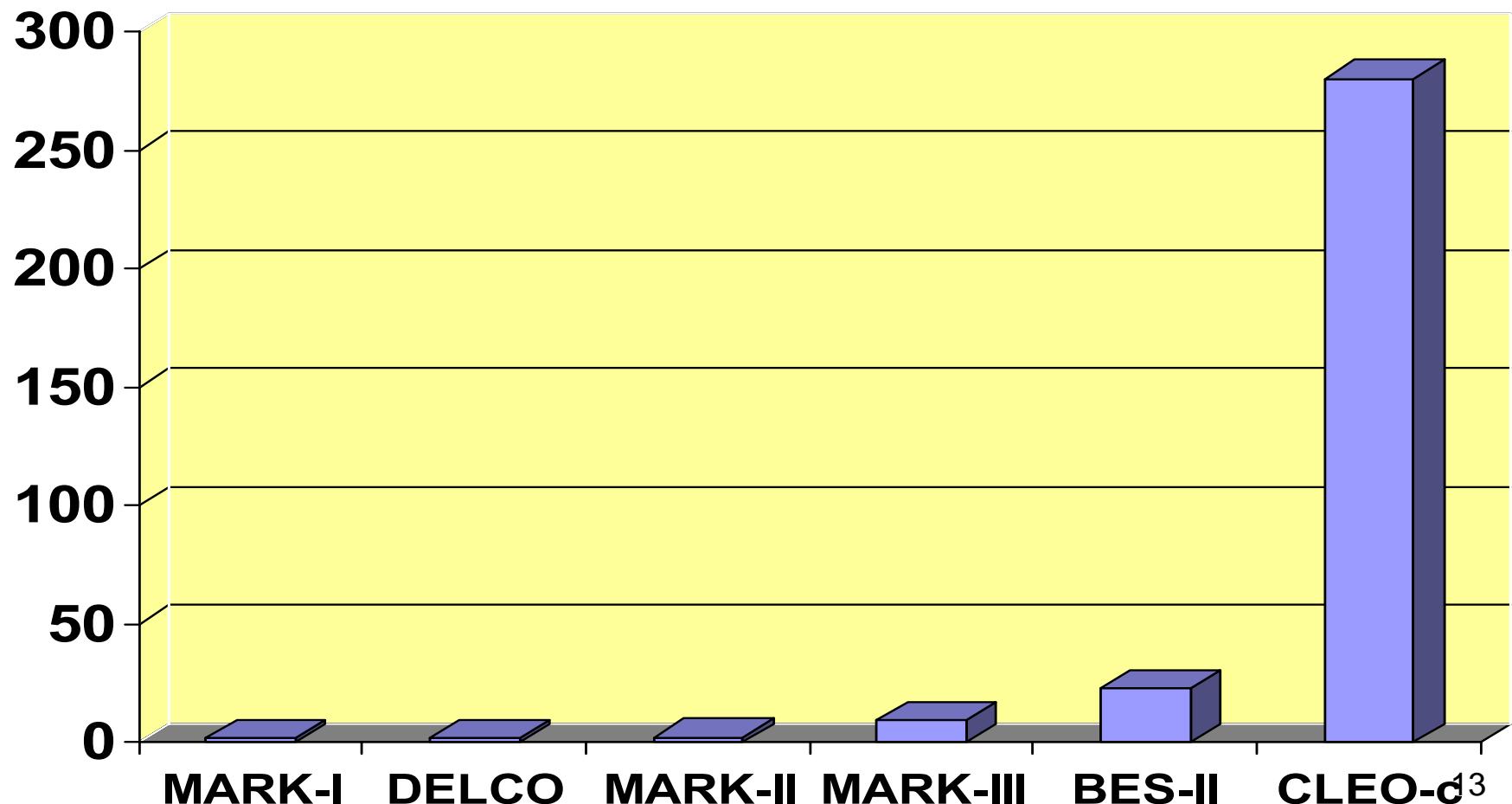
~8 pb⁻¹ data taken in the energy region from 3.665
to 3.878 GeV

The total integrated Luminosity is about 33 pb⁻¹.

Data Samples

World $\psi(3770)$ Samples (pb^{-1})

Largest sample from CLEO-c by Summer, 2005



Studies of $\psi(3770)$ production & Decays at BES-II

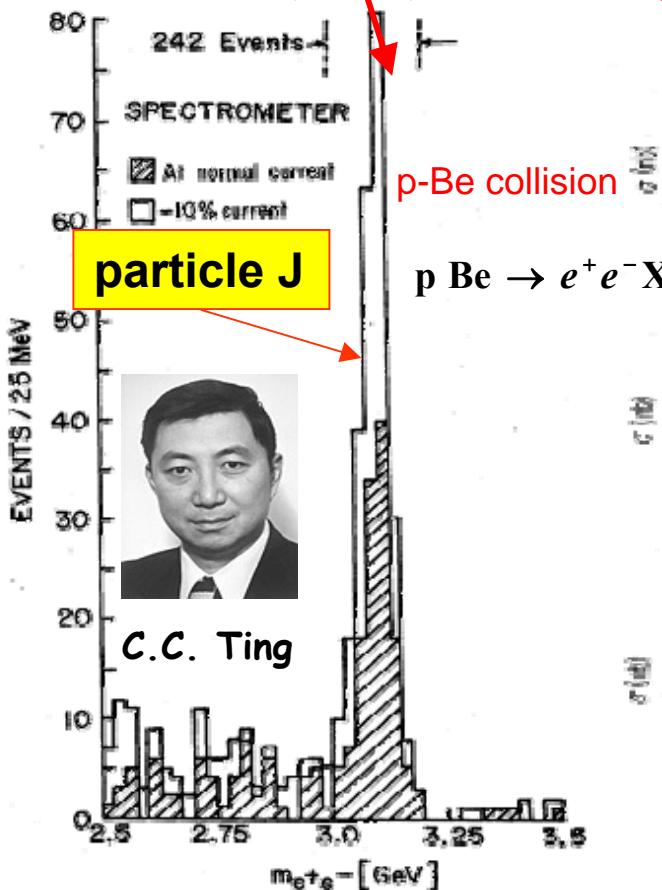
Discovery of c quark

Discovery of J/ ψ

So called “November Revolution of Particle Physics!”

PRL33, 1404 (1974)

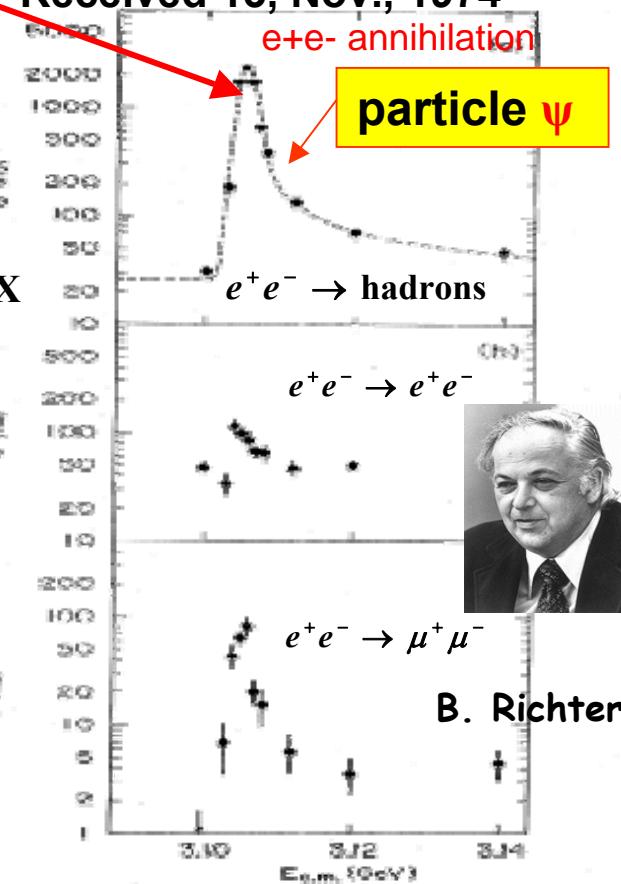
Received 12, Nov., 1974



Charmonium: bound states of $cc\bar{c}\bar{c}$

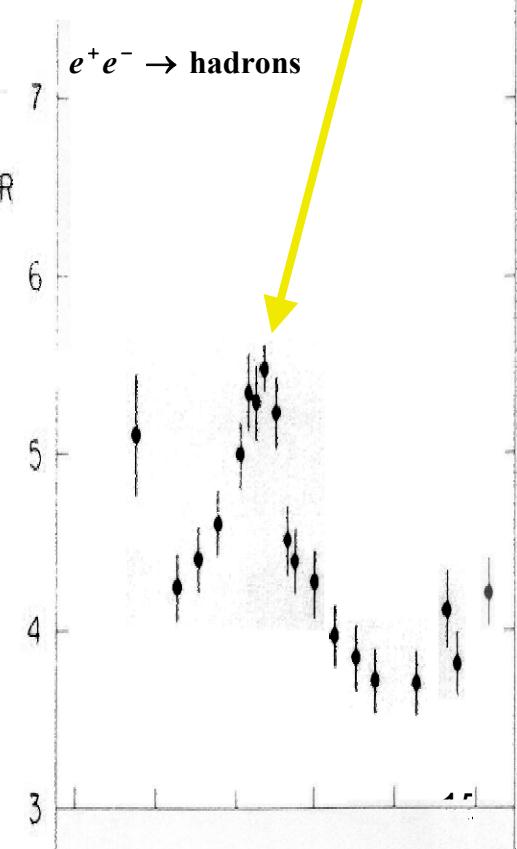
PRL33, 1406 (1974)

Received 13, Nov., 1974



Discovery of $\psi(3770)$

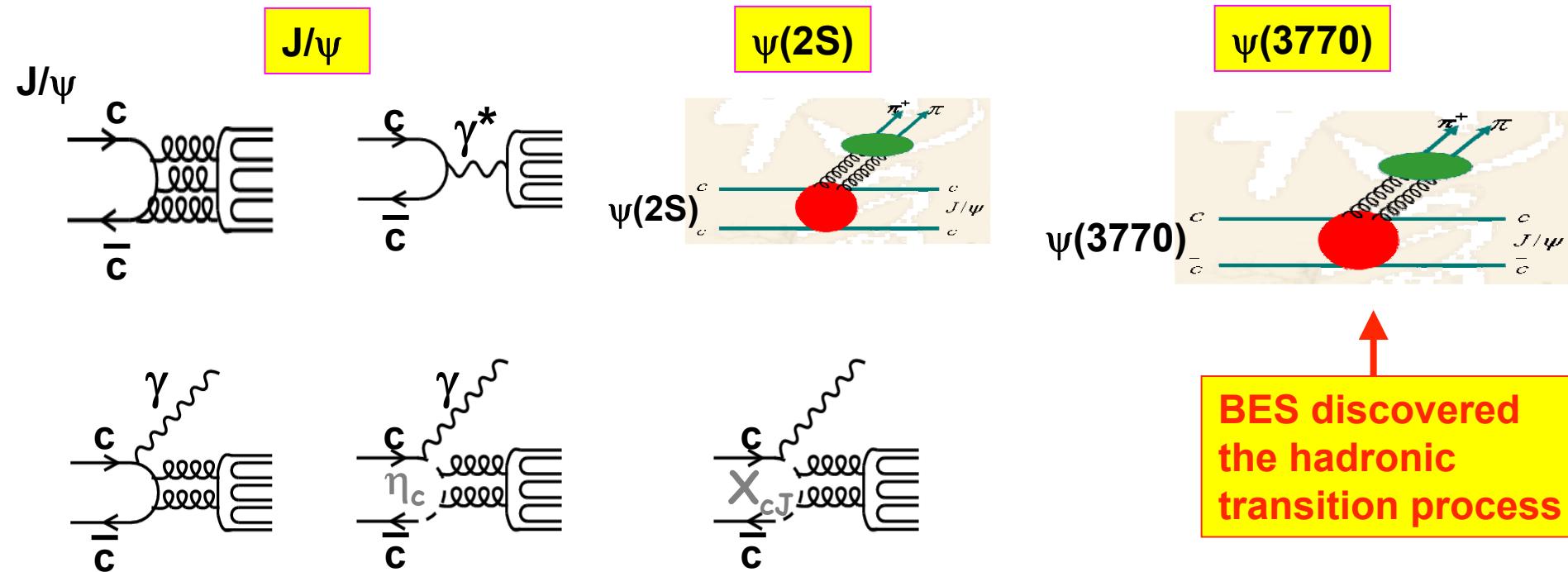
PRL39, 526 (1977)



Charmonium

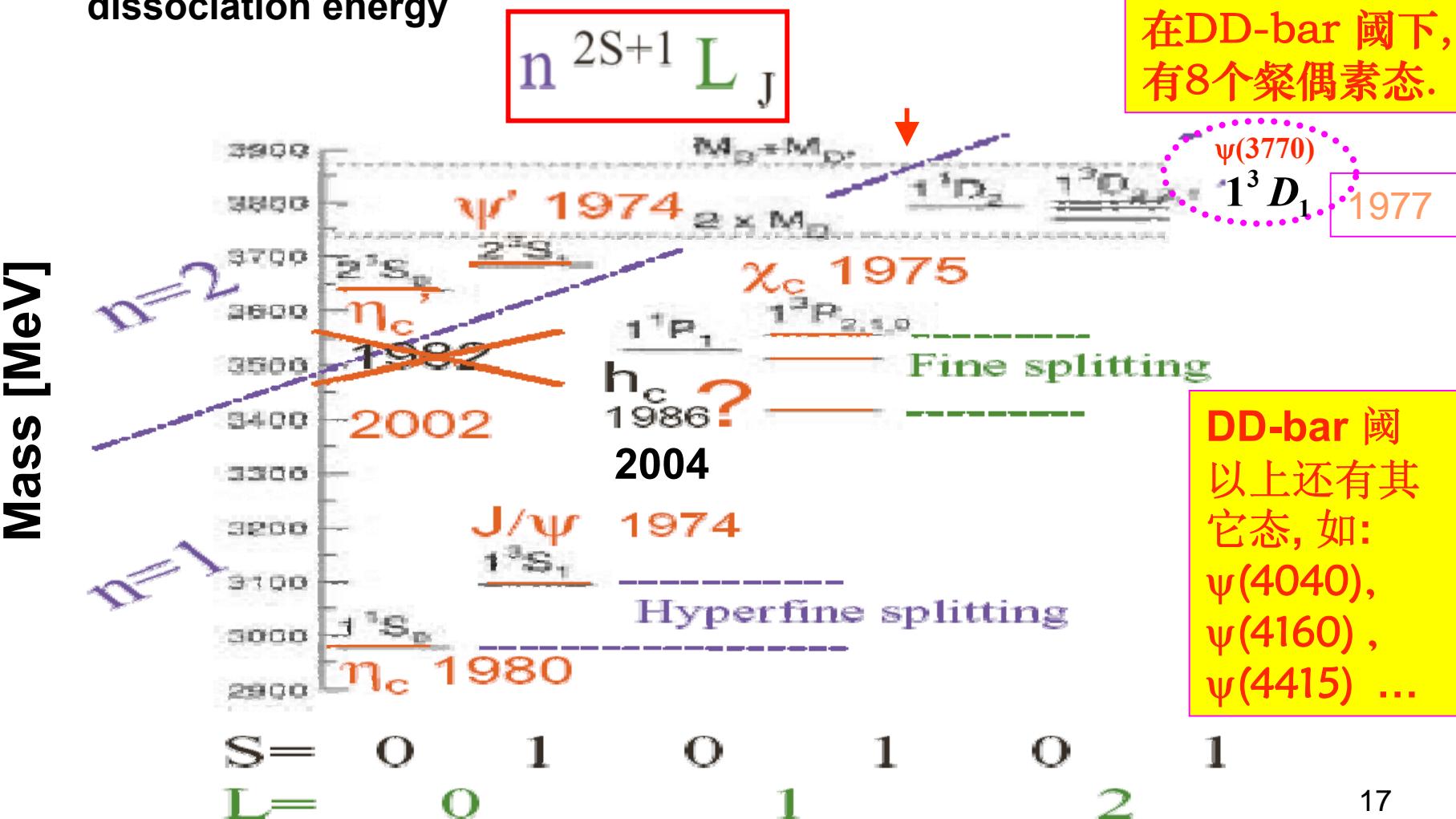
粲夸克偶素 (Charmonium)

由 $c\bar{c}$ 组成的系统称为粲夸克偶素或粲偶素



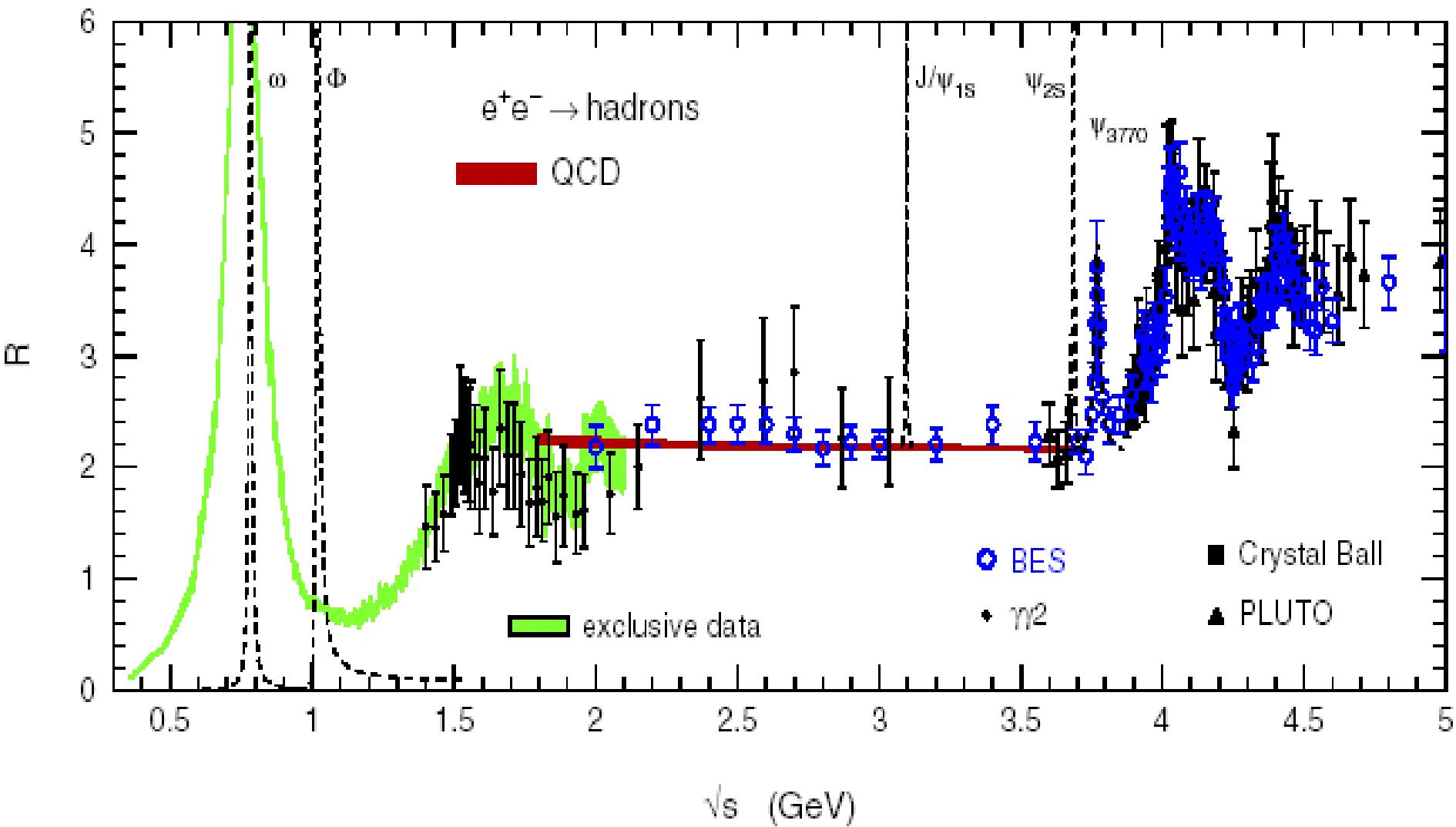
Charmonium

Charmonium is the $c\bar{c}$ bound state. There are 8 states below dissociation energy



$e^+e^- \rightarrow \text{Hadrons}$

$$R = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$



$e^+e^- \rightarrow \text{Hadrons}$

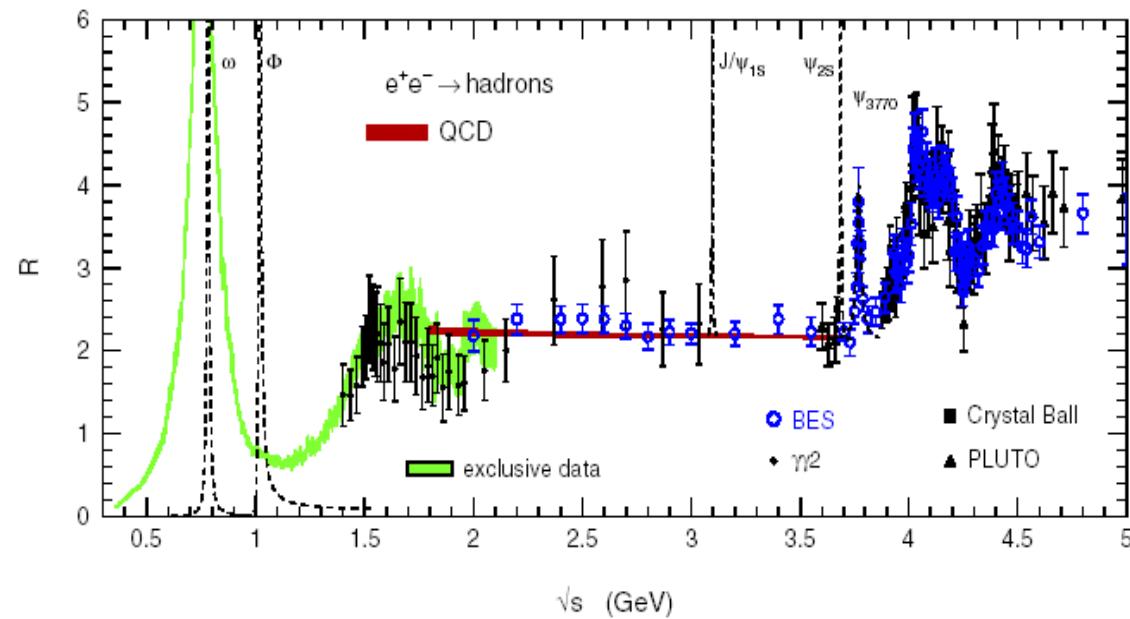
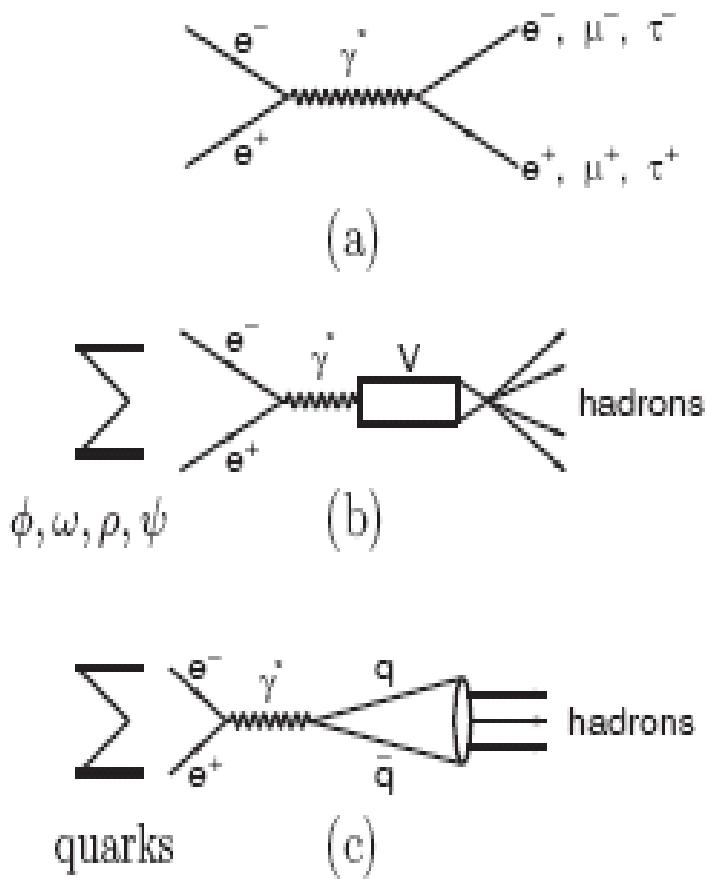
粲介子可以在 e^+e^- 湮灭中直接产生或经过矢量介子衰变而产生。

$E_{\text{cm}} < 2.0 \text{ GeV}$: QED过程 + 矢量介子产生

$2.0 < E_{\text{cm}} < 3.0 \text{ GeV}$: QED过程 + 连续强子产生

$3 < E_{\text{cm}} < 5.0 \text{ GeV}$: QED过程 + 矢量介子产生
+ 连续强子产生

$\psi(3770)$, $\psi(4040)$, $\psi(4016)$ 等衰变可以产生粲介子对。



What is $\psi(3770)$?

cc-bar pure 1^3D_1 wave: $\left\{ \begin{array}{l} M = 3755 \text{ MeV} \\ \Gamma_{\text{tot}} \approx 30 \text{ MeV} \\ \Gamma_{ee} \approx 70 \text{ eV} \end{array} \right.$

SLAC 219

MARK-I observed the $\psi(3770)$ resonance $\left\{ \begin{array}{l} M = 3772 \pm 6 \text{ MeV} \\ \Gamma_{\text{tot}} \approx 28 \pm 5 \text{ MeV} \\ \Gamma_{ee} \approx 370 \pm 90 \text{ eV} \end{array} \right.$

1977年
MARK-I实验组发现
 $\psi(3770)$

To describe the large leptonic width, the mixing with 2^3S_1 is introduced. The mixing increase the leptonic width of the resonance.

$\psi(3770)$ resonance is believed to be a mixture of 1^3D_1 and 2^3S_1 states of the $c\bar{c}$ system.

$$\left\{ \begin{array}{l} |\psi(3686)\rangle = -\sin \theta_{mix} |1^3D_1\rangle + \cos \theta_{mix} |2^3S_1\rangle \\ |\psi(3770)\rangle = \cos \theta_{mix} |1^3D_1\rangle + \sin \theta_{mix} |2^3S_1\rangle \end{array} \right.$$

Where θ_{mix} is mixing angle.

S-D Mixing

Old
model

$$\left\{ \begin{array}{l} \tan 2\theta_{mix} = \frac{2\Delta}{M_2 - M_1} \\ M_1 = M_{\psi(3686)} \cos^2 \theta_{mix} + M_{\psi(3770)} \sin^2 \theta_{mix} \\ M_2 = M_{\psi(3686)} \sin^2 \theta_{mix} + M_{\psi(3770)} \cos^2 \theta_{mix} \end{array} \right.$$
$$\tan^2 \theta_{mix} = \frac{\Gamma_{ee}^{\psi(3770)}}{\Gamma_{ee}^{\psi(3686)}} \left[\frac{M_{\psi(3770)}}{M_{\psi(3686)}} \right]^2$$

The mixing angle is an important parameter in the mixing model.

The physical states $|\psi(3686)\rangle$ and $|\psi(3770)\rangle$ with masses $M_{\psi(3686)}$ and $M_{\psi(3770)}$ are the eigenvalues of the mass matrix.

S-D Mixing

New mixing model

PRD 41 (1990) 41, PRD 44 (1991) 44
arXiv:hep-ph/0105327 v2 5 June 2001

$$\Gamma(\psi(3770) \rightarrow e^+ e^-) = \frac{4\alpha e_c^2}{M_{\psi(3770)}^2} \left| \sin \theta_{mix} R_{2S}(0) + \frac{5}{2\sqrt{2}m_c^2} \cos \theta_{mix} R_{1D}''(0) \right|^2$$

$$\Gamma(\psi(3686) \rightarrow e^+ e^-) = \frac{4\alpha e_c^2}{M_{\psi(3686)}^2} \left| \cos \theta_{mix} R_{2S}(0) - \frac{5}{2\sqrt{2}m_c^2} \sin \theta_{mix} R_{1D}''(0) \right|^2$$

$$e_c = 2/3$$

R is the radial wave function

$$\frac{M_{\psi(3770)}^2 \Gamma(\psi(3770) \rightarrow e^+ e^-)}{M_{\psi(3686)}^2 \Gamma(\psi(3686) \rightarrow e^+ e^-)} = \left| \frac{0.734 \sin \theta_{mix} + 0.095 \cos \theta_{mix}}{0.734 \cos \theta_{mix} - 0.095 \sin \theta_{mix}} \right|^2$$

$\psi(3770)$ Decays

- $\psi(3770) \rightarrow e^+e^-, \mu^+\mu^-, \tau^+\tau^-$
- $\psi(3770) \rightarrow J/\psi\pi^+\pi^-, J/\psi\pi^0\pi^0, J/\psi\pi^0, J/\psi\eta$
- $\psi(3770) \rightarrow \gamma\chi_{cJ} (J = 0, 1, 2)$
- $\psi(3770) \rightarrow$ 轻强子末态

早期理论上认为~99%的
ψ(3770)都衰变到**D̄D**。

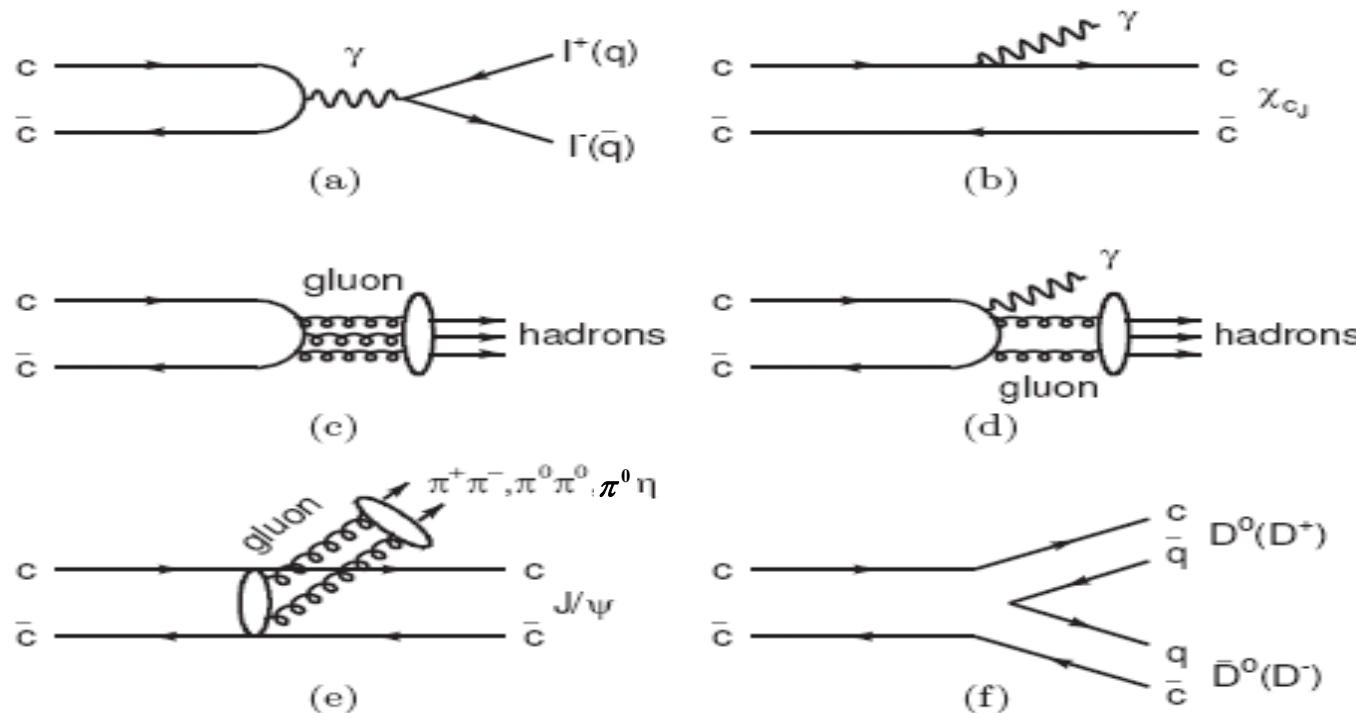


图 1-2 (a) 淹没到虚光子，虚光子再耦合到轻子对($l = e, \mu, \tau$)或夸克对 $q\bar{q}$ ，(b) 通过辐射光子跃迁到能量较低的聚偶素态，(c) 淹没到三个胶子，(d) 淹没到两个胶子和一个光子，(e) 通过辐射胶子跃迁到能量较低的聚偶素态，(f) 衰变到聚介子对。

Puzzle of $\Psi(3770)$ production and decays

Theoretical prediction

$\Gamma(\psi'' \rightarrow \gamma \chi_{cJ}) \leq 500 \text{ keV}$ ($\psi'' \& \psi'$, K.T.CHAO, 16 Oct., 2002)

$\Gamma(\psi'' \rightarrow J/\psi \pi\pi) < 200 \text{ keV}$, Y.P.Kuang, PRD41(1990)155

$\Gamma(^3 D_1 \rightarrow ggg) = 160 \text{ keV}$ PLB267(1991)11

$\Gamma(\psi'' \rightarrow non - D\bar{D}) \leq 860 \text{ keV}$

$BF(\psi'' \rightarrow non - D\bar{D}) \leq 3.6\%$

Theoretical prediction !

$BF(\psi'' \rightarrow non - D\bar{D}) \leq 5\%$

Recent theoretical prediction

arXiv:0802.1849v1 [hep-ph], Zhi-Gui He, Ying Fang, Kuang-Ta Chao

Experiment

$\Psi(3770)$ production cross section at peak

$$\sigma_{\psi''}^{prd} = \frac{12\pi}{M_{\psi''}^2} \times BF(\psi'' \rightarrow e^+e^-) = 12.4 \pm 1.9 \text{ nb}$$

$\Psi(3770)$ resonance parameters

Puzzle of $\psi(3770)$ production and decays

DD-bar cross section

MARK-III measured the observed DD-bar cross section (at $E_{cm} = 3.768 \text{ GeV}$)

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

→ production cross section

$$f_{ISR} = 0.688$$

$$\boxed{\sigma^{prdct}(e^+e^- \rightarrow D\bar{D}) = 7.3 \pm 0.7 \text{ nb}}$$

(Added all errors in quadratically)

→ About 38% of $\psi(3770)$ does not decay to DD-bar ! ??

与理论预期矛盾！

是否因为不同的实验组测定的截面有偏离？

To clarify this situation, it is important to more precisely measure both DD-bar cross section and $\psi(3770)$ resonance parameters at the same experiment !

$\psi(3770)$ Production

Observed & expected cross sections

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

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

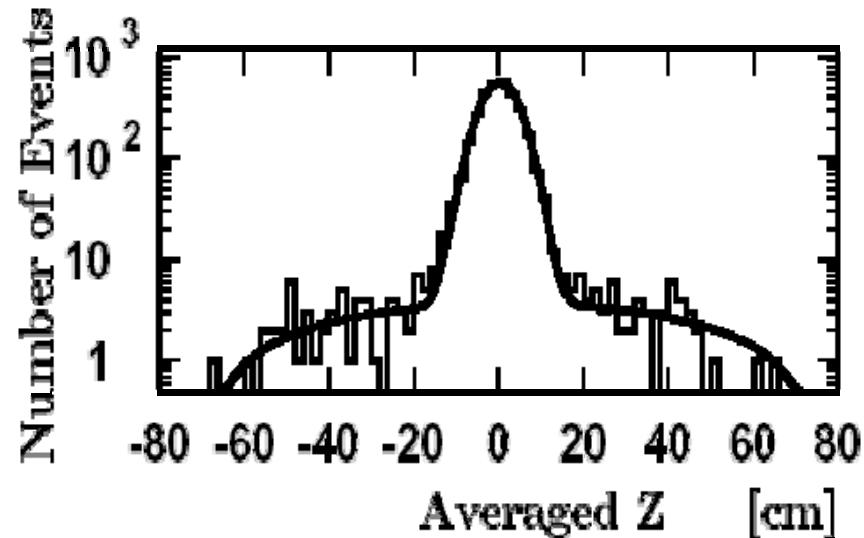
$$\sigma_{had}^{expect}(s) = \int_0^1 dx F(x, s) \sigma^B(s(1-x))$$

$F(x, s)$ is sampling function

(Kuraev and Fadin)

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

For $\psi(3770)$, we use energy-dependent total width $\Gamma_{tot}(s)$

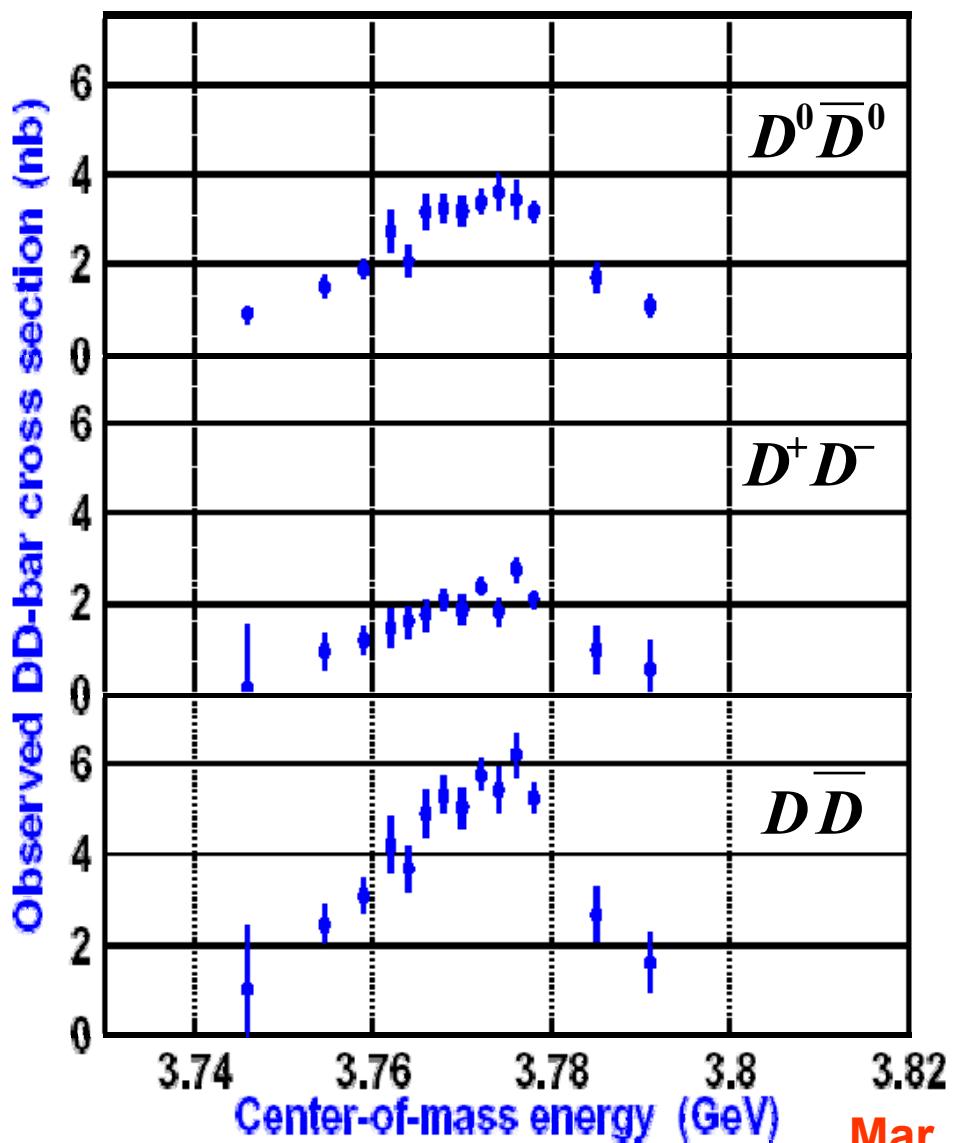


The distribution of event vertex in Z

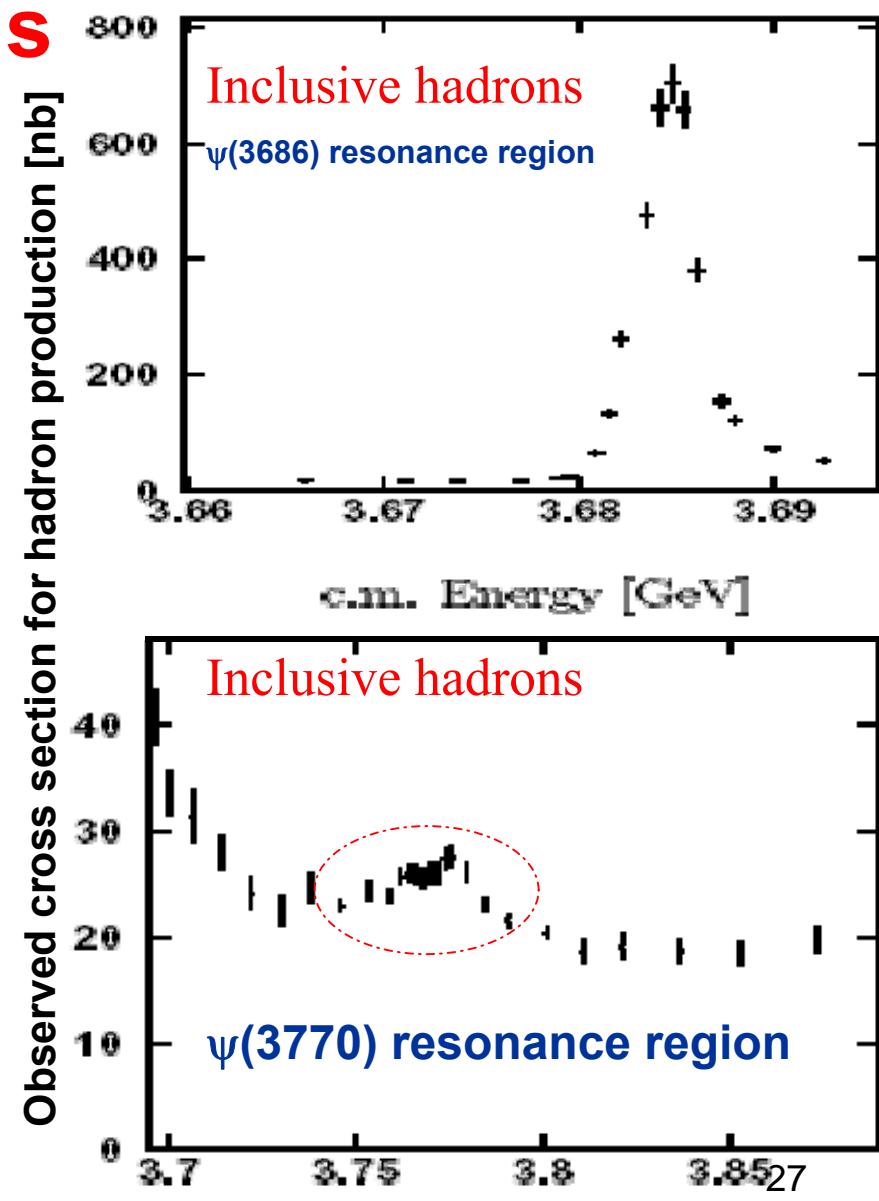
Fitting the distribution of the event vertex gives the number of hadronic events n_{had} .

$\Psi(3770)$ Production

Observed cross sections



Mar. 2003 data set



$\psi(3770)$ and DD Production

Fit to the observed cross sections

Fitting the observed inclusive hadron and DD-bar cross sections to the theoretical cross sections, we obtain the branching fractions

$$\sigma_{\psi(3770)}^B = \frac{12\pi\Gamma_{ee}^0\Gamma_{tot}(s)}{(s - M^2) + M^2\Gamma_{tot}^2(s)} \quad \sigma_{D\bar{D}}^B = \frac{12\pi\Gamma_{ee}^0\Gamma_{D\bar{D}}(s)}{(s - M^2) + M^2\Gamma_{tot}^2(s)}$$

The total energy dependent width has three components:

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

momentum of D at peak

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

$\psi(3770)$ total width

threshold function

momentum of D

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

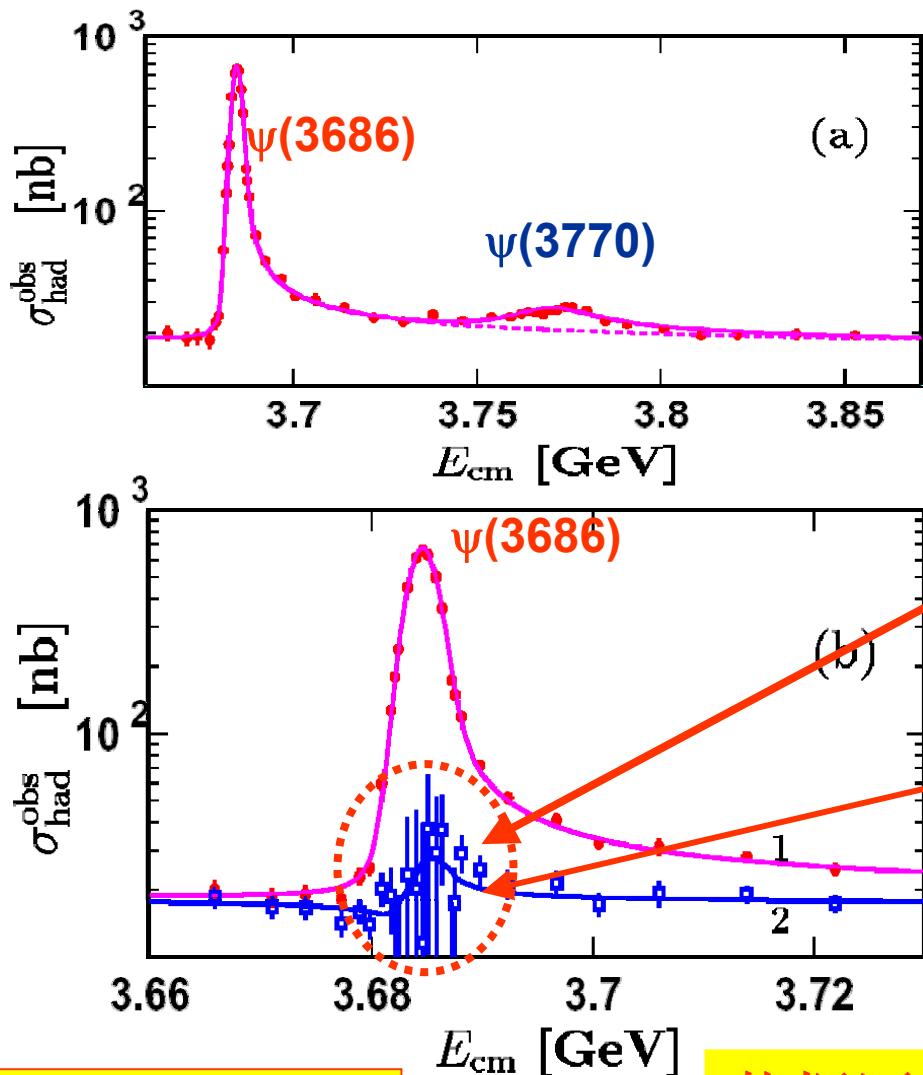
Blatt-Weisskopf penetration factor

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

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

$\psi(3770)$ Production

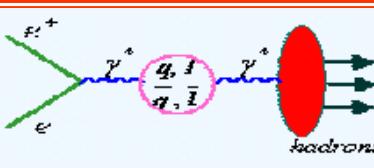
Line-Shape and Resonance Parameters of $\psi(3770)$ and $\psi(3686)$



首次测定分支比

$B[\psi(3770) \rightarrow \text{non-}D\bar{D}] = (16.4 \pm 7.3 \pm 4.2)\%$

If one do not consider the effects of vacuum polarization corrections on the observed cross sections in the data reduction, the total width of $\psi(3686)$ would decrease by about 40 keV!



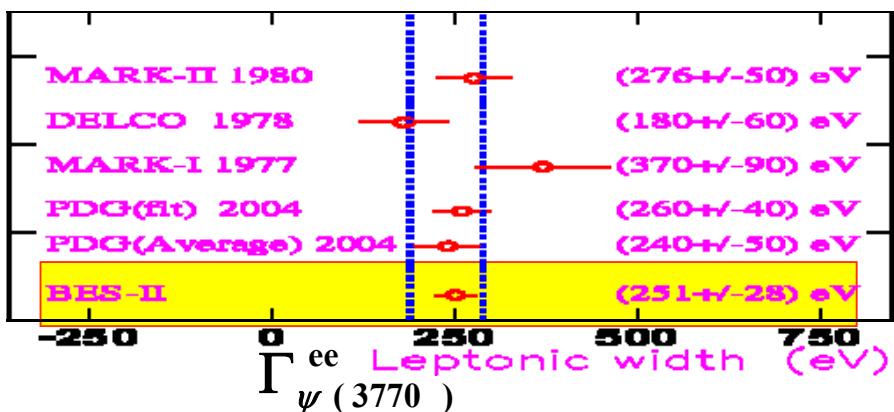
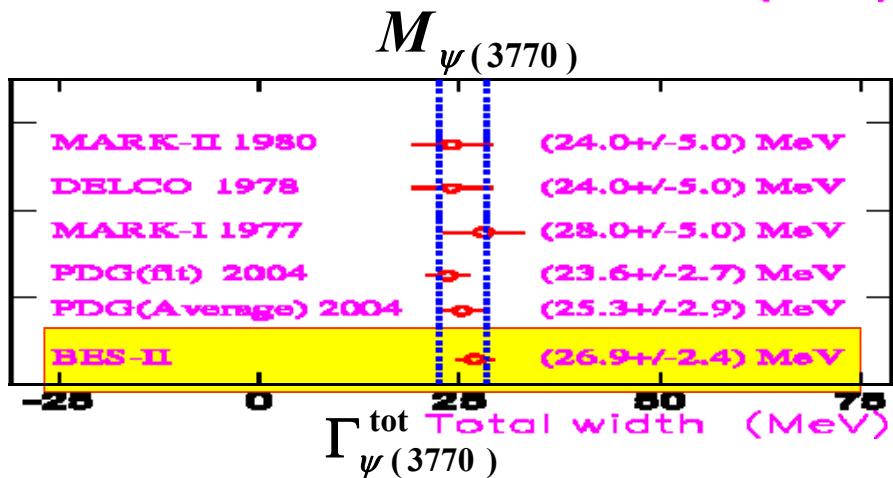
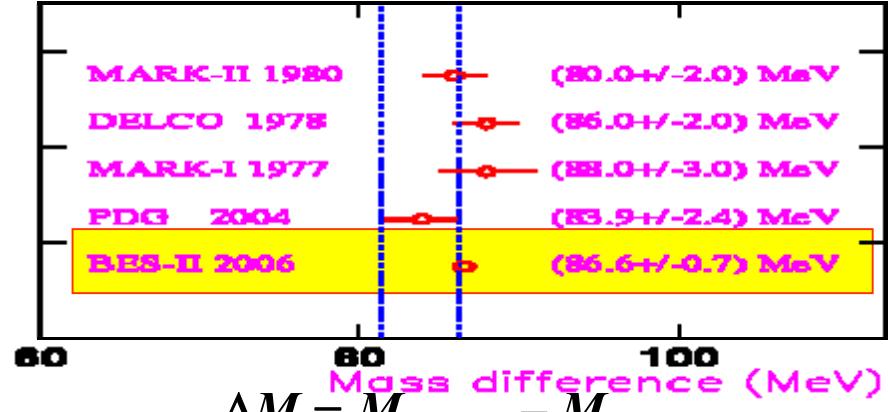
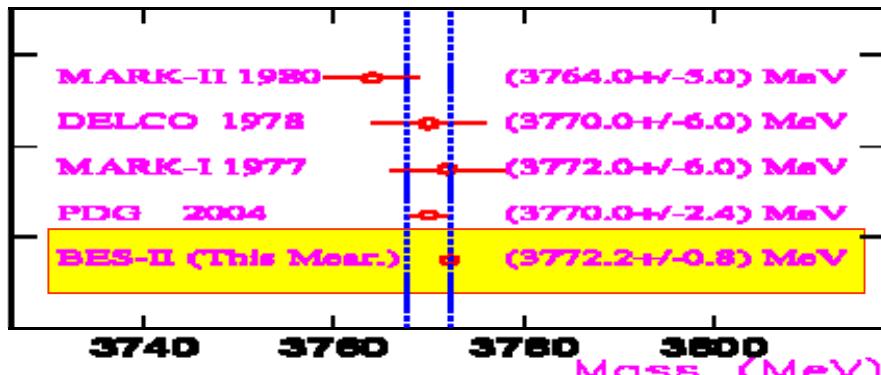
Mar. 2003 data set

Mainly due to vacuum polarization corrections

After subtraction of $\psi(3686)$, $\psi(3770)$ and J/ψ from the observed cross sections, one obtains the expected cross sections of the continuum hadron production.

$\psi(3770)$ Resonance Parameters

Comparison of $\psi(3770)$ Resonance Parameters



$$\sigma_{\psi(3770)}^{prd} \Big|_{\sqrt{s}=3772.3 \text{ MeV}} = 9.63 \pm 0.66 \pm 0.35 \text{ nb}$$

$$R_{uds} = 2.262 \pm 0.054 \pm 0.109$$

PRL 97 (2006) 121801

Mar. 2003 data set

$$\sigma_{\psi(3770)}^{obs} \Big|_{\sqrt{s}=3772.3 \text{ MeV}} = 6.94 \pm 0.48 \pm 0.28 \text{ nb}$$

which is consistent within error with

$$\sigma_{\psi(3770)}^{obs} \Big|_{\sqrt{s}=3772.3 \text{ MeV}} = 8.12 \pm 1.56 \text{ nb}$$

obtained based on PDG04 parameters

$\psi(3686)$ Resonance Parameters

Comparison of $\psi(3686)$ Resonance Parameters

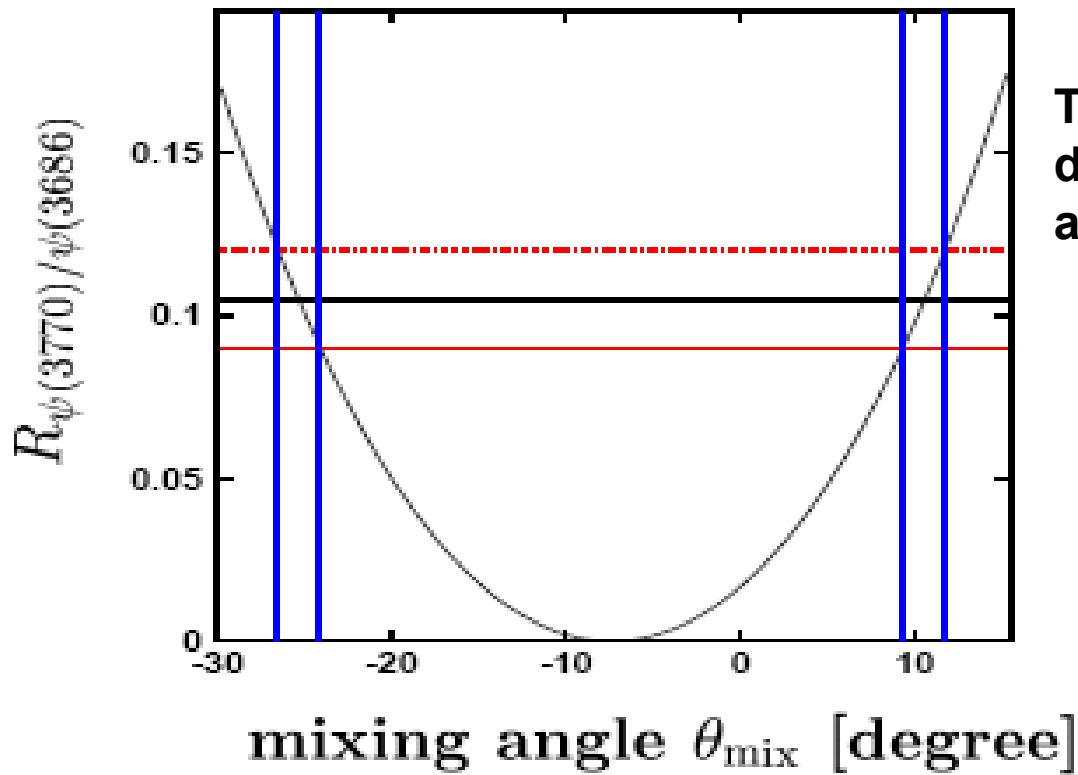
Obtained based on cross section scan

experiment	M_{ψ} (MeV)	$\Gamma_{\psi}^{\text{tot}}$ (keV)	Γ_{ψ}^{ee} (keV)
E760	$3686.0 \pm 0.1 \pm 0.3$	$306 \pm 36 \pm 16$	
BES-II	<i>N / A</i>	264 ± 27	2.44 ± 0.21
PDG04	3686.09 ± 0.03	281 ± 17	2.12 ± 0.12
This work	$3685.5 \pm 0.0 \pm 0.3$	$331 \pm 58 \pm 2$	$2.33 \pm 0.04 \pm 0.11$

Mixing Angle of the S-D Mixing

The ratio of the scaled leptonic widths of $\psi(3770)$ to $\psi(3686)$

$$R_{\psi(3770)/\psi(3686)} = \frac{M_{\psi(3773)}^2 \Gamma(\psi(3773) \rightarrow e^+e^-)}{M_{\psi(3686)}^2 \Gamma(\psi(3686) \rightarrow e^+e^-)} \quad R_{\psi(3770)/\psi(3686)}^{BES} = 0.105 \pm 0.015.$$



This solution is favored by relative decay rates for $\psi(3770) \rightarrow J/\psi \pi^+\pi^-$ and $\psi(3686) \rightarrow J/\psi \pi^+\pi^-$

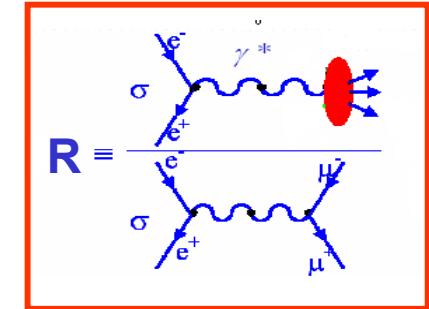
$$\theta_{mix} = (10.6 \pm 1.3)^\circ$$

Figure 19.1: The ratio $R_{\psi(3770)/\psi(3686)}$ of the scaled leptonic widths as a function of mixing angle θ_{mix} , where the dashed lines show the $\pm 1\sigma$ intervals of the measured quantities.

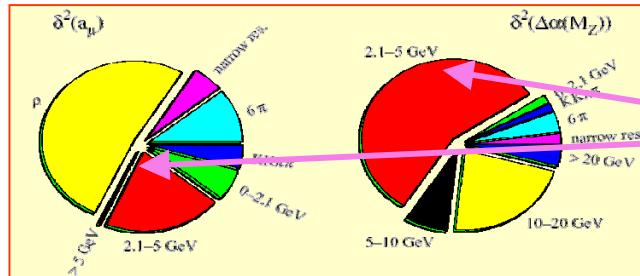
The quantity R

◆ Why are we interested in R(s) ?

- Vacuum polarization correction needs the R(s) values, which plays an important role in the precision test of the Standard Model.
- For evaluation of the electromagnetic coupling at the Z mass scale, $\alpha_{QED}(M_Z)$
- For determination of $a_\mu = (g_\mu - 2)/2$ of the muon.



$$a_\mu^{\text{had, LO}} = \frac{\alpha^2(0)}{3\pi^2} \int_{4m_\pi^2}^\infty ds \frac{K(s)}{s} R(s)$$



$\alpha_{QED}(M_Z)$ affects the determination of the mass of Higgs boson from the measurement of $\sin^2 \theta_W$.

- Evaluate $\alpha_s(s)$
- Non- $\bar{D}\bar{D}$ decays of $\psi(3770)$

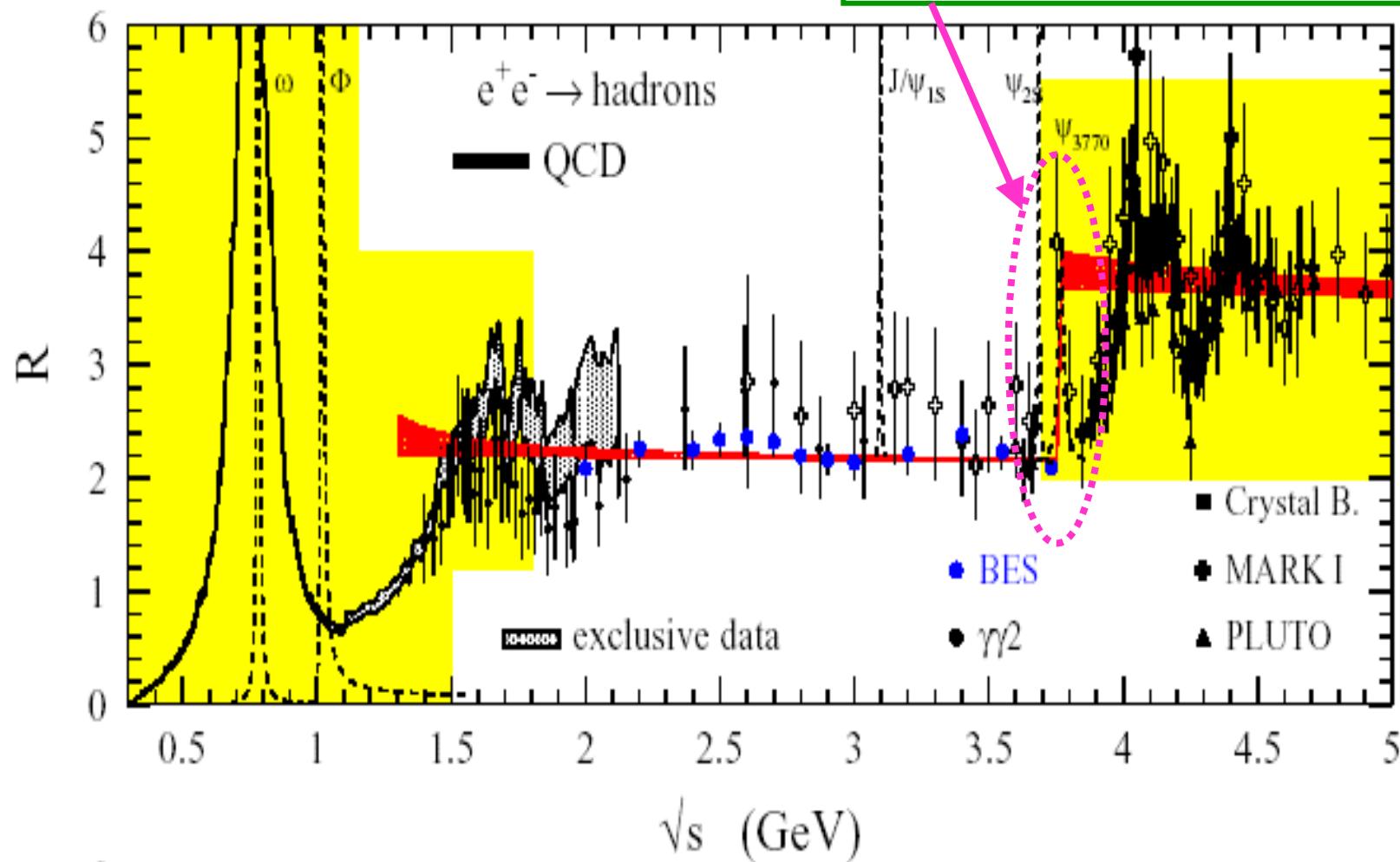
The R values at all energies is needed to calculate the effects of vacuum polarization on the parameters of Standard Model. [for example, $\alpha_{QED}(M_Z)$ and a_μ]. A large uncertainty in this calculation arises from the uncertainties in the measured R values in the open charm threshold region (3.7 GeV to 5.0 GeV).

The quantity R

The Previously Measured quantity R

Including all hadrons

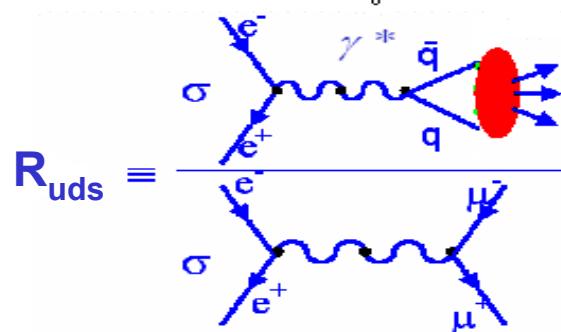
Precision measurement of the cross sections in this region



The quantity R

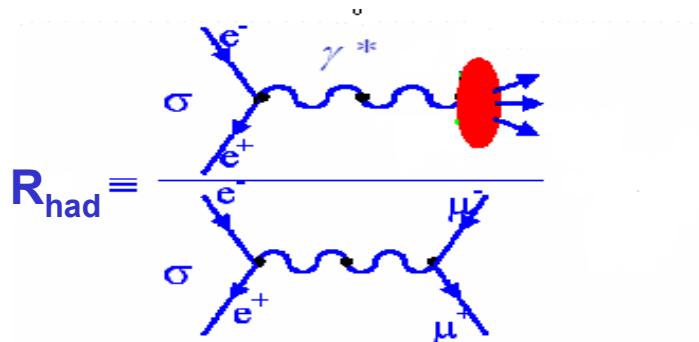
Definition & measurements of different R

$$R_{uds(c)+\psi(3770)}(s) = \left\{ \begin{array}{l} R_{uds(c)}(s) + R_{\psi(3770)}(s) \text{ (above DD-bar threshold)} \\ R_{uds} \text{ (below cc-bar threshold)} \end{array} \right.$$



$$R_{uds} = \frac{R_{uds(c)}(s) + \sum R_{res,i}(s)}{R_{had}(s)}$$

$R_{res,i}(s)$ are R values due to all 1^{--} resonances decay to hadrons.



calculate

$$\alpha_{QED}(M_Z)$$

$$a_\mu = (g_\mu - 2)/2$$

Results

$$R_{uds} = 2.141 \pm 0.025 \pm 0.085$$

Below DD-bar threshold

$$R^{pQCD}_{uds} = 2.15 \pm 0.03$$

PRL 97, 262001 (2006)

The quantity R

R_{had} , $R_{\text{uds}(c)}$ and $R_{\text{uds}(c)+\psi(3770)}$

Results

PRL 97, 262001 (2006)

Table 1. Systematic uncertainties in the determination of R values

Sources	$\Delta_{\text{SYS}} (\%)$
Luminosity	1.8
Hadron selection	2.5
M. C. modeling	2.0
ISR	1.5
$\Psi(3770)$ resonance parameters	2.7
Total (off $\Psi(3770)$ region)	3.9
Total (within $\Psi(3770)$ region)	4.9

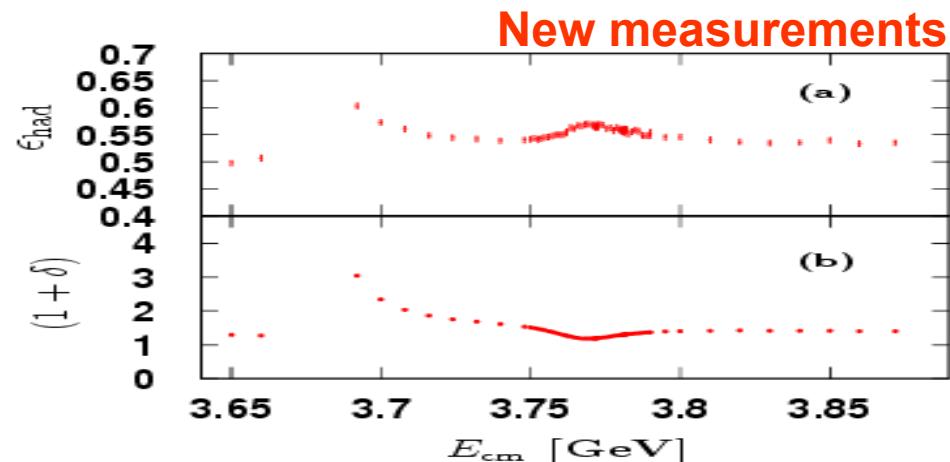
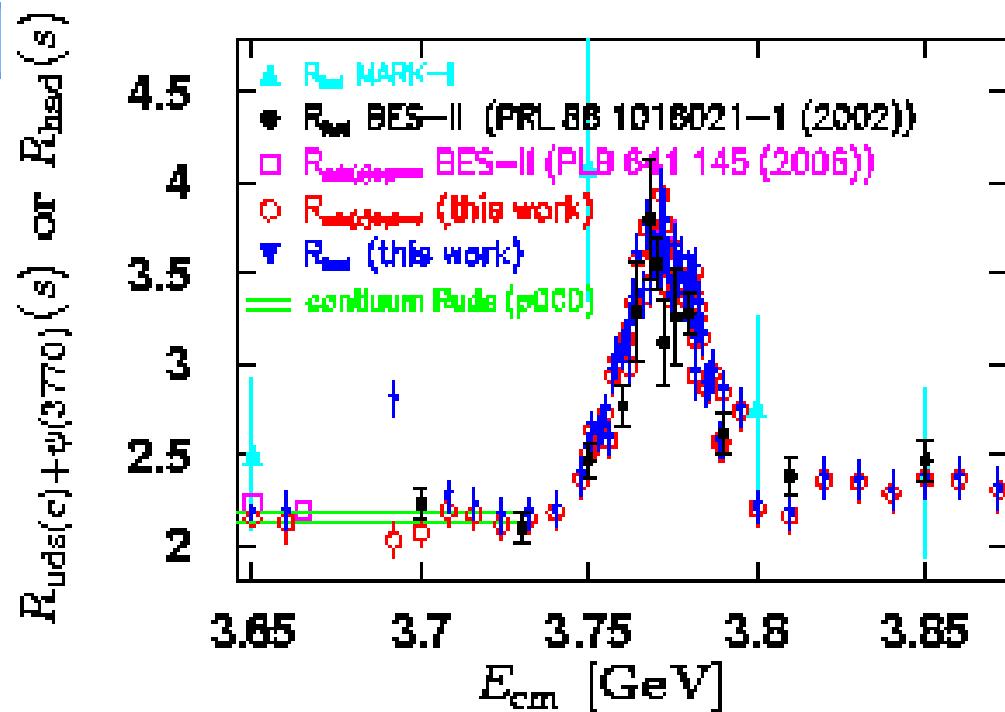
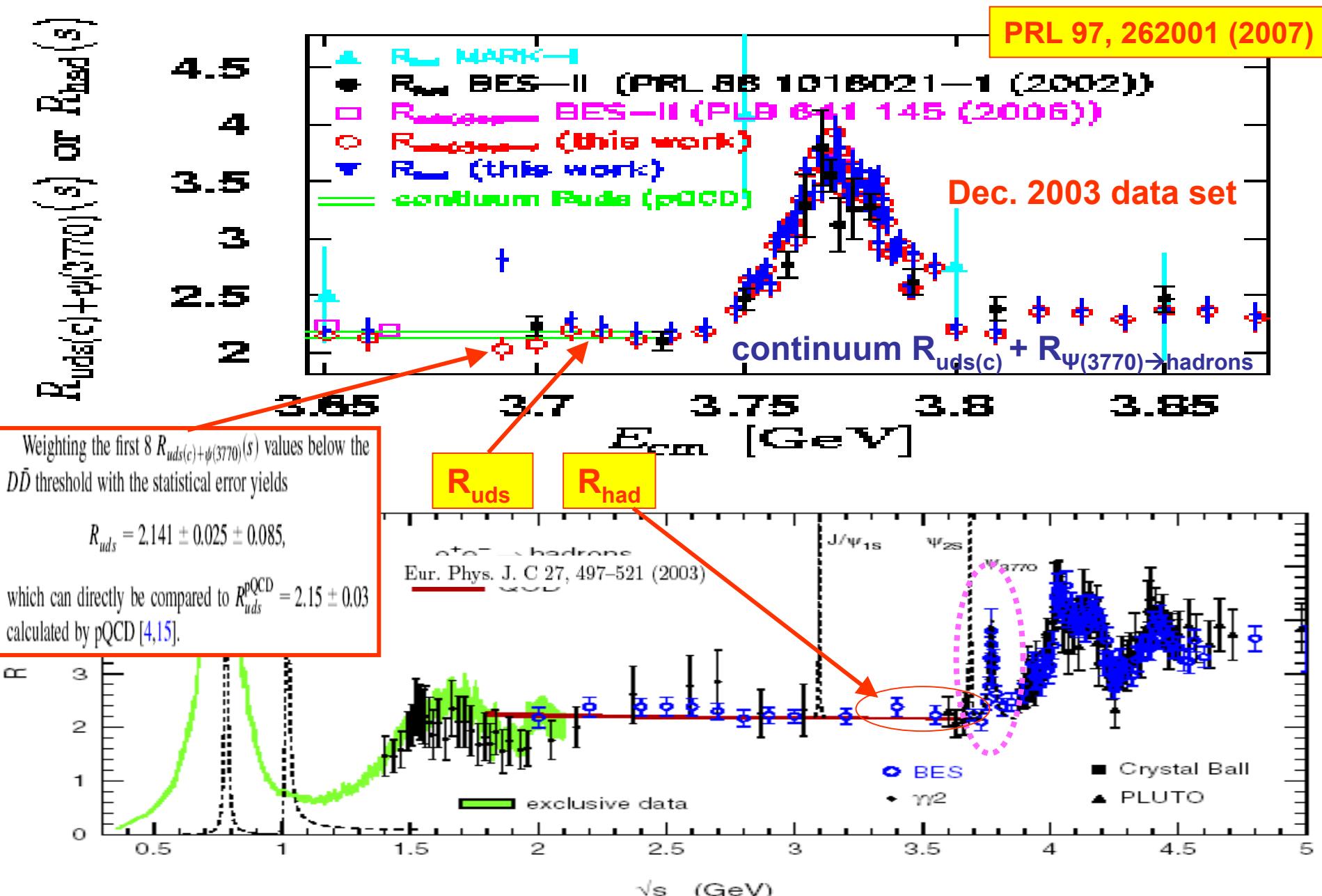


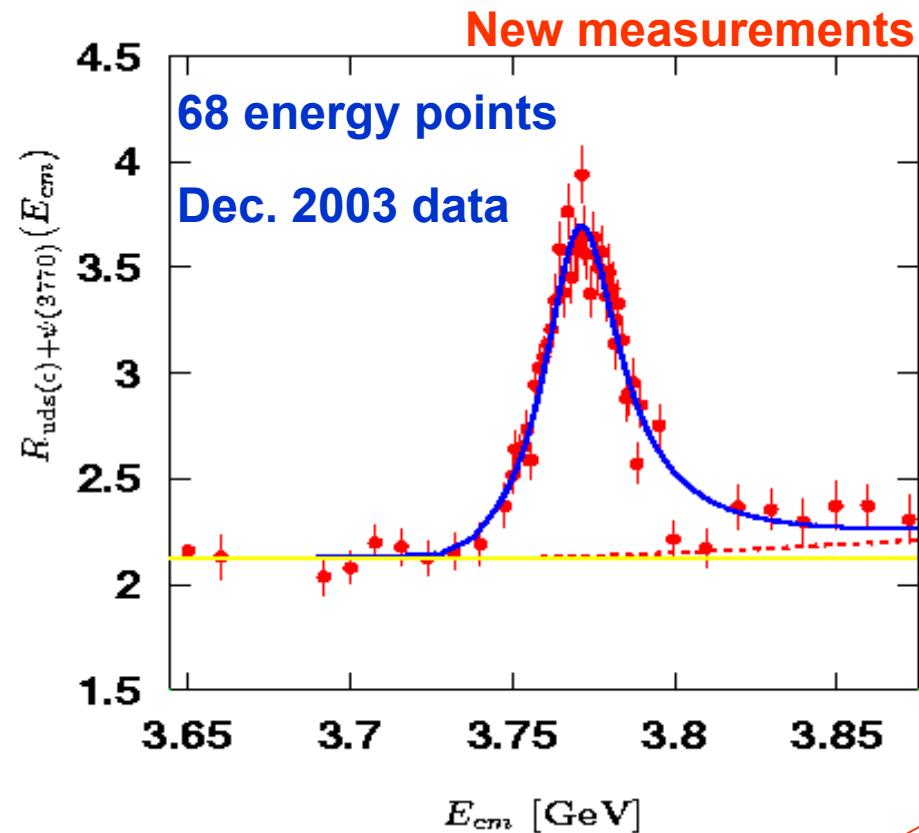
FIG. 2: (a) The efficiency versus the nominal c.m. energy; (b) The ISR factor versus the nominal c.m. energy (see text).



The quantity R

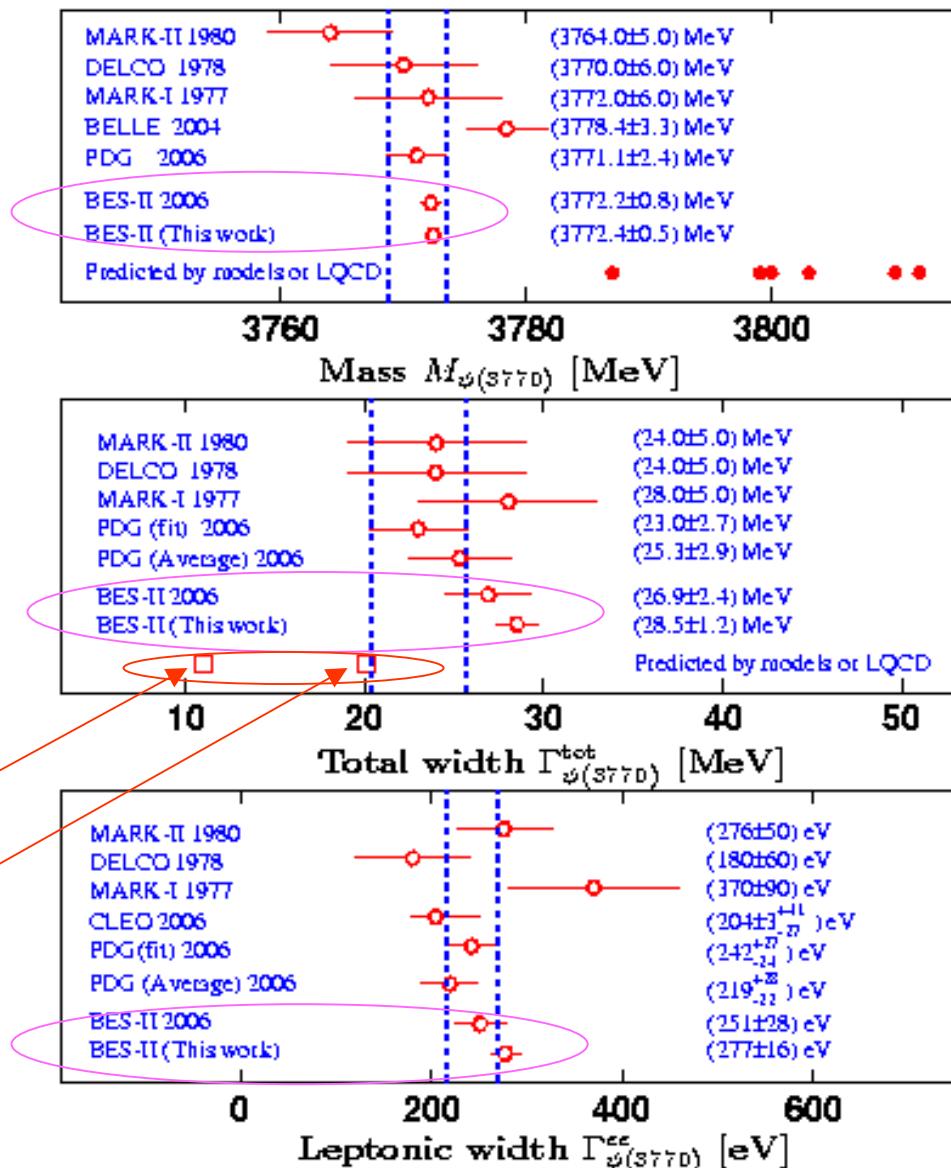


Resonance Parameters of $\psi(3770)$



$\Gamma(\psi(3770) \rightarrow D\bar{D}) = 11$ MeV (Heikkila ...)

$\Gamma(\psi(3770) \rightarrow D\bar{D}) = 20.1$ MeV (Eichten ...)



Resonance Parameters of $\psi(3770)$

Comparison with those measured by other experiments (energy scan)

Experiment	$\sigma^{\text{prd}}[e^+e^- \rightarrow \psi(3770)][\text{nb}]$	$\sigma^{\text{obs}}[e^+e^- \rightarrow \psi(3770)][\text{nb}]$	
BES (PLB 652 (2007) 238)	$10.0 \pm 0.3 \pm 0.5$	$7.2 \pm 0.2 \pm 0.4$	Dec. 2003 data
BES [PRL 97(2006)121801]	$9.6 \pm 0.7 \pm 0.4$	$6.9 \pm 0.5 \pm 0.3$	Mar. 2003 data
MARKII		9.3 ± 1.4	

$M_{\psi(3770)}(\text{MeV})$	$\Gamma^{\text{tot}}_{\psi(3770)}(\text{MeV})$	$\Gamma^{\text{ee}}_{\psi(3770)}(\text{eV})$	Note
$3772.4 \pm 0.4 \pm 0.3$	$28.5 \pm 1.2 \pm 0.2$	$277 \pm 11 \pm 13$	PLB 652 (2007) 238
$3772.2 \pm 0.7 \pm 0.3$	$26.9 \pm 2.4 \pm 0.3$	$251 \pm 26 \pm 11$	PRL 97(2006)121801

Experiment	BES [PLB 652(2007) 238]	BES [PRL 97(2006)121801]	PDG
$B[\psi(3770) \rightarrow e^+e^-][\times 10^{-5}]$	$0.97 \pm 0.03 \pm 0.05$	$0.93 \pm 0.06 \pm 0.03$	1.05 ± 0.14

Dec. 2003 data

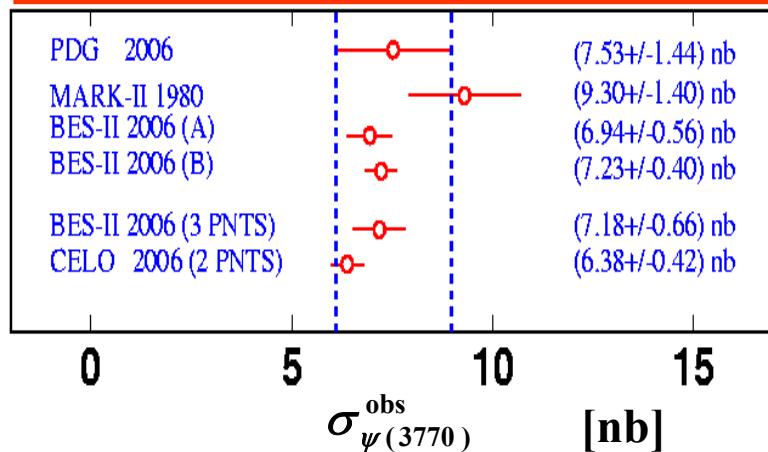
Mar. 2003 data

$R_{uds} = 2.121 \pm 0.023 \pm 0.084$ (fit to cross sections at 68 energy points) 39

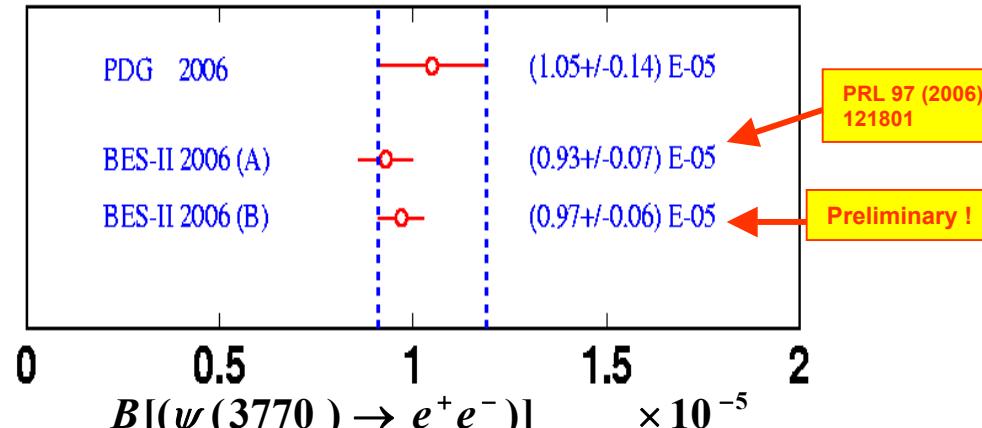
Cross Section & Br of $\psi(3770)$

What about World Average

Comparison of measurements of the cross section for $\psi(3770)$ production



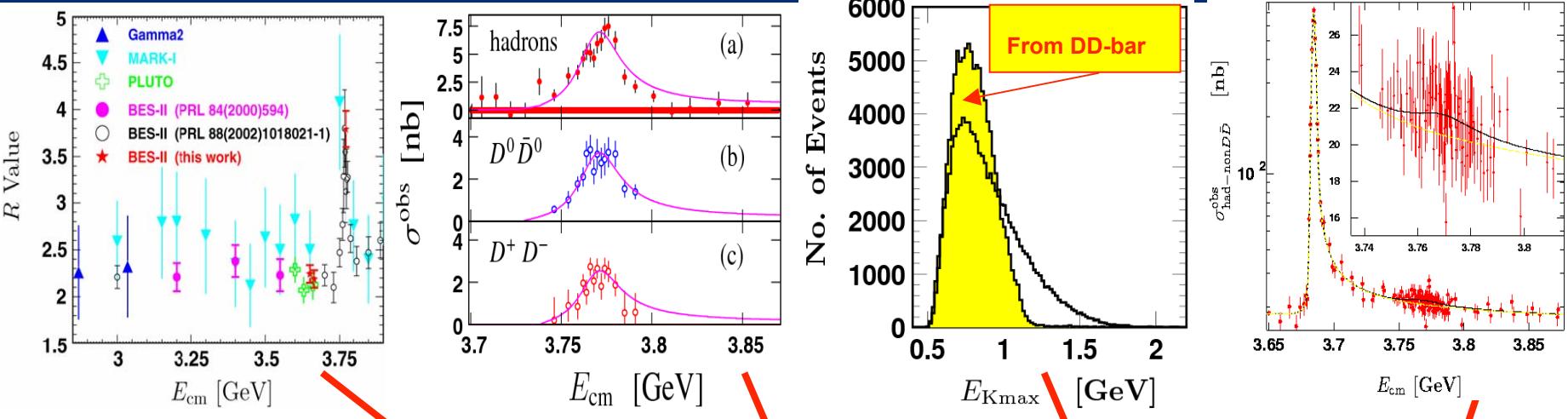
Leptonic branching fraction



$$B[\psi(3686) \rightarrow e^+ e^-] = (0.704 \pm 0.122 \pm 0.033)\% \quad \text{PRL 97 (2006) 121801}$$

$$B[\psi(3686) \rightarrow e^+ e^-] = (0.735 \pm 0.018)\% \quad \text{PDG04}$$

Measurements of $B[\psi(3770) \rightarrow \text{nonDD}]$



	PLB641, 145	PRL97,121801	PRD76,122002	PLB 659,74
$B(\psi'' \rightarrow D^0 \bar{D}^0)[\%]$	$49.9 \pm 1.3 \pm 3.8$	$46.7 \pm 4.7 \pm 2.3$	--	--
$B(\psi'' \rightarrow D^+ D^-)[\%]$	$35.7 \pm 1.1 \pm 3.4$	$36.9 \pm 3.7 \pm 2.8$	--	--
$B(\psi'' \rightarrow D\bar{D})[\%]$	$85.5 \pm 1.7 \pm 5.8$	$83.6 \pm 7.3 \pm 4.2$	$86.6 \pm 5.0 \pm 3.6$	$84.9 \pm 5.6 \pm 1.8$
$B(\psi'' \rightarrow \text{non-}D\bar{D})[\%]$	$14.5 \pm 1.7 \pm 5.8$	$16.4 \pm 7.3 \pm 4.2$	$13.4 \pm 5.0 \pm 3.6$	$15.1 \pm 5.6 \pm 1.8$
Ruds	$2.218 \pm 0.019 \pm 0.089$	$2.262 \pm 0.054 \pm 0.109$	$2.214 \pm 0.031 \pm 0.094$	$2.199 \pm 0.047 \pm 0.119$
$\sigma^{\text{obs}}_{\psi(3770)} [\text{nb}]$	$7.18 \pm 0.20 \pm 0.63$	$6.94 \pm 0.48 \pm 0.28$	$7.07 \pm 0.36 \pm 0.45$	--
$\sigma_{\text{non}D\bar{D}} [\text{nb}]$	--	--	$0.95 \pm 0.35 \pm 0.29$	$1.08 \pm 0.40 \pm 0.15$
$\sigma_{D\bar{D}} [\text{nb}]$	--	--	$6.12 \pm 0.37 \pm 0.23$	--

Branching Fractions for $\psi(3770) \rightarrow \text{non-}D\bar{D}$

Branching fraction for $\psi(3770) \rightarrow \text{non-}D\bar{D}$ -bar

Citation: W.-M. Yao et al. (Particle Data Group), J. Phys. G 33, 1 (2006) and 2007 partial update for edition 2007



$$I^G(J^{PC}) = 0^-(1^{--})$$

PDG07

$\psi(3770)$ MASS

From $m_{\psi(2S)}$ and mass difference below.

VALUE (MeV)	DOCUMENT ID
3772.4±1.1 OUR FIT Error includes scale factor of 1.8.	

$$m_{\psi(3770)} - m_{\psi(2S)}$$

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
86.3±1.1 OUR FIT Error includes scale factor of 1.8.				
86.3±1.1 OUR AVERAGE Error includes scale factor of 1.9. See the ideogram below.				
86.7±0.7		ABLIKIM 06L	BES2 $e^+e^- \rightarrow \text{hadrons}$	
92.3±3.0±1.3	34	CHISTOV 04	BELL $B^+ \rightarrow \psi(3770)K^+$	
80 ± 2		SCHINDLER 80	MRK2 e^+e^-	
86 ± 2		¹ BACINO 78	DLCO e^+e^-	
88 ± 3		RAPIDIS 77	MRK1 e^+e^-	

$\psi(3770)$ WIDTH				
VALUE (MeV)	DOCUMENT ID	TECN	COMMENT	
25.2±1.8 OUR FIT				
26.3±1.9 OUR AVERAGE				
26.9±2.4±0.3	ABLIKIM 06L	BES2 $e^+e^- \rightarrow \text{hadrons}$		
24 ± 5	SCHINDLER 80	MRK2 e^+e^-		
24 ± 5	BACINO 78	DLCO e^+e^-		
28 ± 5	RAPIDIS 77	MRK1 e^+e^-		

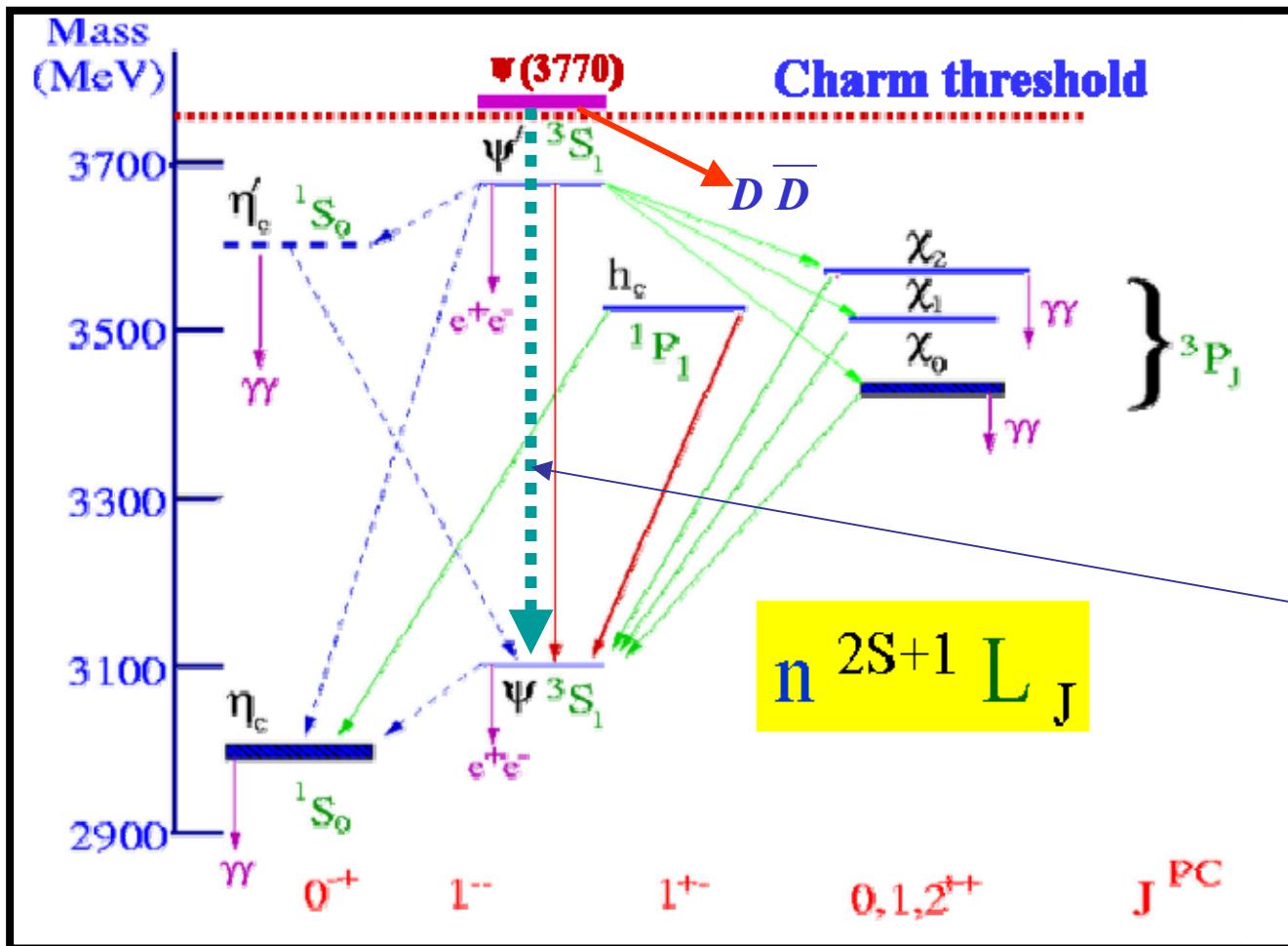
$\psi(3770)$ DECAY MODES

In addition to the dominant decay mode to $D\bar{D}$, $\psi(3770)$ was found to decay into the final states containing the J/ψ (BAI 05, ADAM 06). ADAMS 06 and HUANG 06A searched for various decay modes with light hadrons and found a statistically significant signal for the decay to $\phi\eta$ only (ADAMS 06).

Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
$\Gamma_1 D\bar{D}$	(85 ± 5) %	
$\Gamma_2 D^0\bar{D}^0$	(48.7 ± 3.2) %	
$\Gamma_3 D^+\bar{D}^-$	(36.1 ± 2.8) %	

$$\Psi(3770) \rightarrow J/\psi \pi^+ \pi^-$$

是否存在non- $D\bar{D}$ 衰变过程 $\Psi(3770) \rightarrow \pi^+ \pi^- J/\psi$?



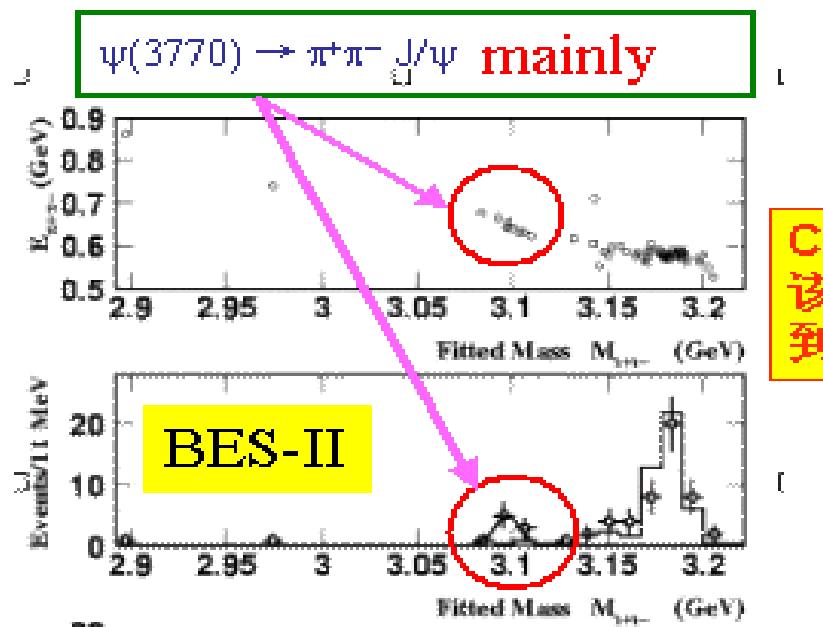
It is an interesting question if transitions inside the $\Psi(3770)$ exist.

??

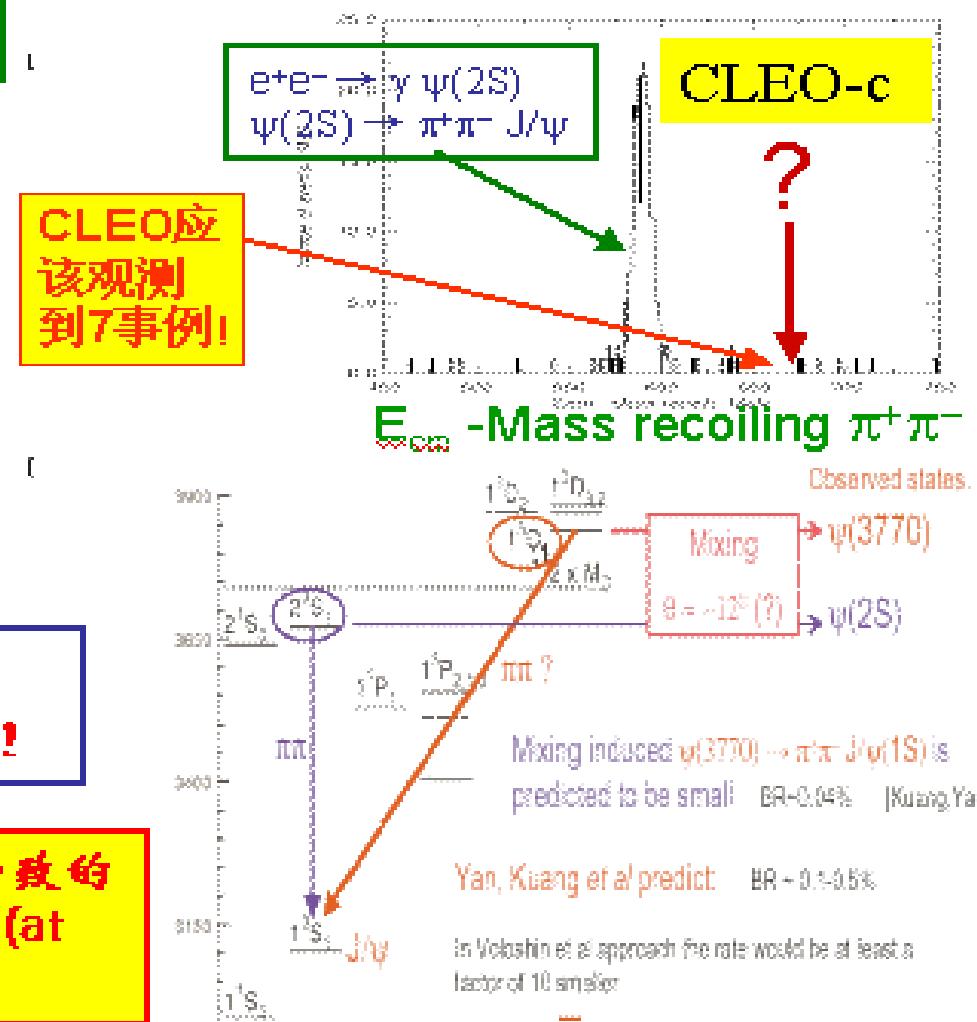
这是粲偶素物理研究领域内的一个基本问题!

$\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$

在2003年Lepton-Photon会议上
关于 $\psi(3770) \rightarrow \pi^+ \pi^- J/\psi$ 的争论



BES-II 结果成为热门话题，
被广泛关注，讨论和引用！

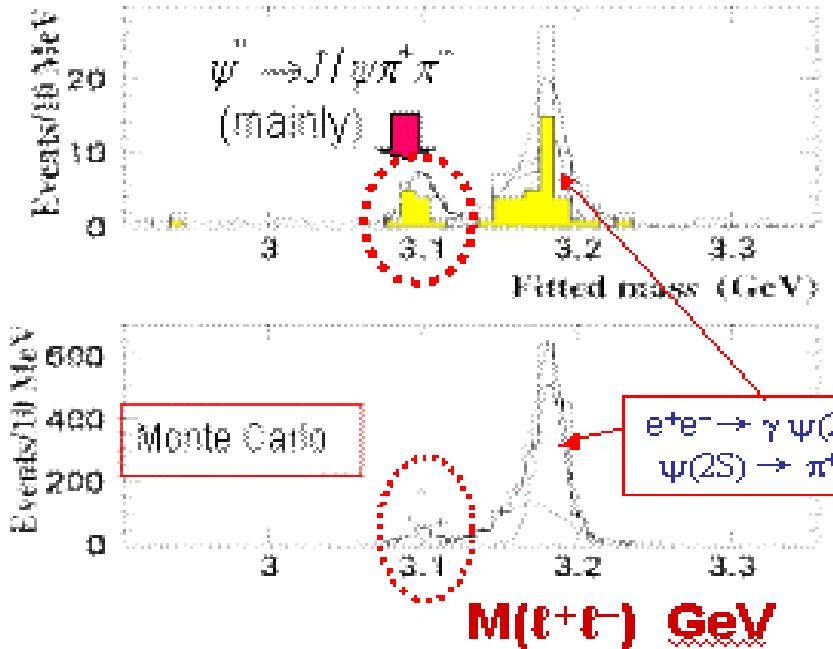


这是BES-II与CLEO-c 的物理结果不一致的
冲突被CLEO 成员第一次在国际会议(at
LPO3)上做的评论！

$\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$

BESII

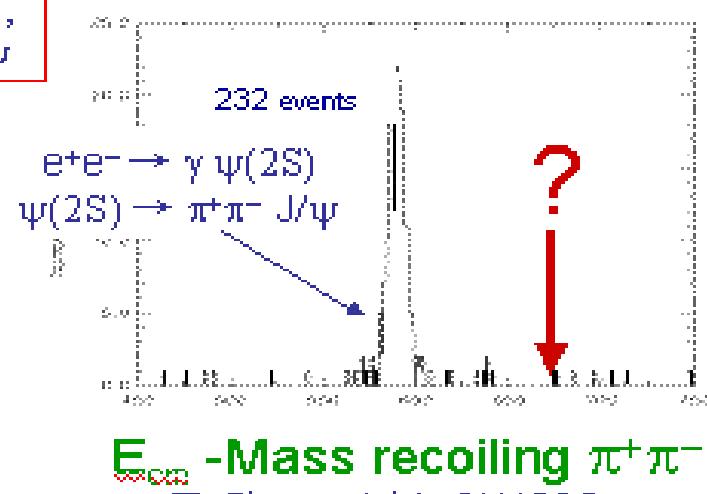
hep-ex/0307028



17.8 ± 4.8 events incl 6.0 ± 0.8 bkgd (0 from cont)
 $\text{BR}(\psi(3770) \rightarrow \pi^+ \pi^- J/\psi) = (0.34 \pm 0.14 \pm 0.08)\%$
 $\Gamma = (80 \pm 32 \pm 21) \text{ keV}$

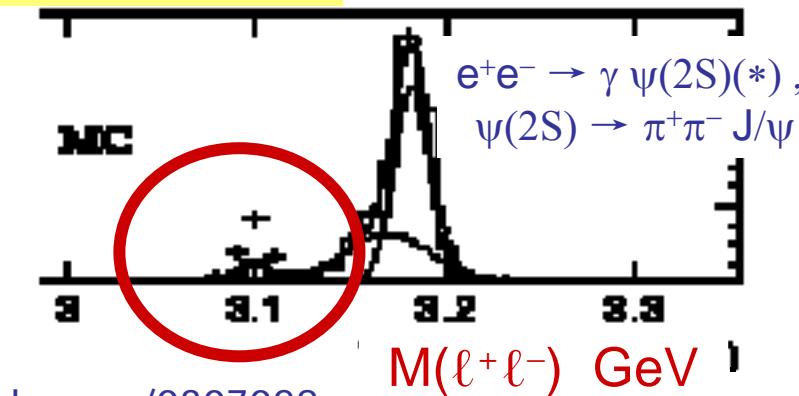
CLEO-c

- $5.2 \pm 0.2 \text{ pb}^{-1}$,
 $(4.5 \pm 0.4) 10^4 \psi''$ decays
- efficiency: 37%
- > < 4.75 events @ 90% CL
 $\text{BR}(\psi(3770) \rightarrow \pi^+ \pi^- J/\psi(1S)) < 0.26\% @ 90\% \text{ CL}$



$\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$

BES-II

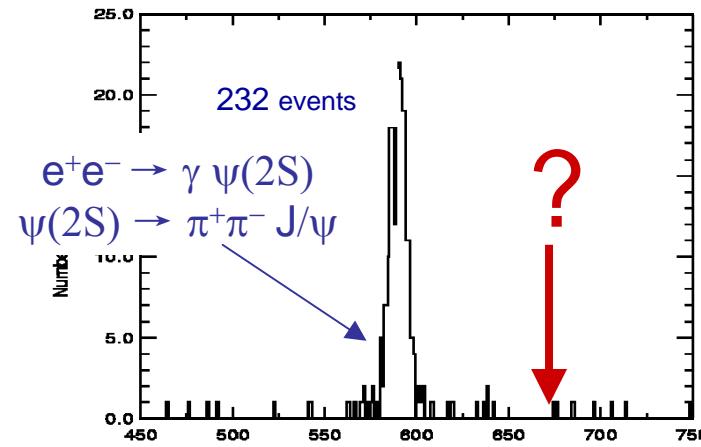


hep-ex/0307028

- 28 pb^{-1} (3.783-3.885GeV),
 $1.85 \times 10^5 \psi''$ decays
- efficiency: 16%
- 17.8 ± 4.8 events incl
 6.0 ± 0.8 bgd (0 from cont)
 $\text{BR}(\psi(3770) \rightarrow \pi^+\pi^- J/\psi)$
 $= (0.34 \pm 0.14 \pm 0.08) \%$
 $\Gamma = (80 \pm 32 \pm 21) \text{ keV}$

CLEO-c

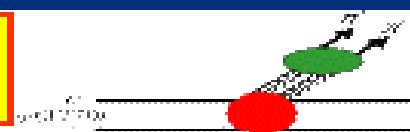
- $5.2 \pm 0.2 \text{ pb}^{-1}$,
 $(4.5 \pm 0.4) 10^4 \psi''$ decays
- efficiency: 37%
- < 4.75 events @ 90%CL
 $\text{BR}(\psi(3770) \rightarrow \pi^+\pi^- J/\psi(1S))$
 $< 0.26\% @ 90\% \text{ CL}$



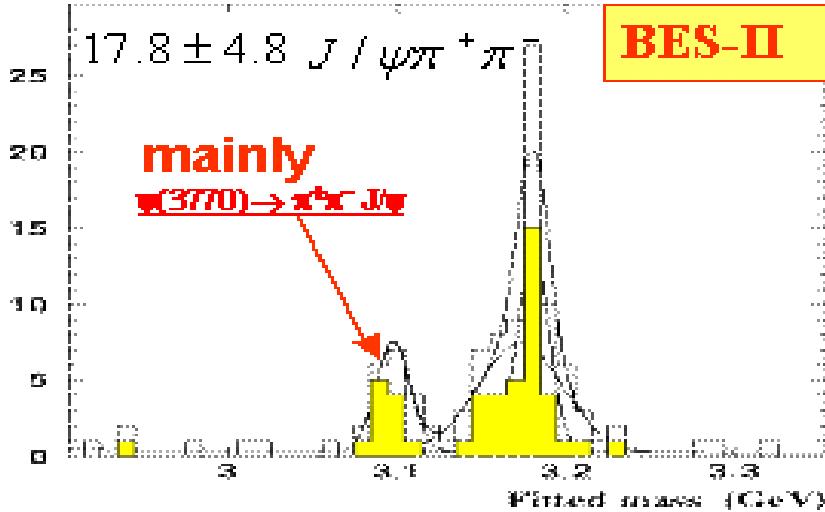
E_{cm} -Mass recoiling $\pi^+\pi^-$
T. Skwarnicki, QWG03

$\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$

$\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$



CLEO-c在LP03上否定了BES-II结果之后,又经过两年的努力,终于也找到的此衰变过程.



BES-II observed the first non- $D\bar{D}$ events of $\psi(3770)$ decays. CLEO-c conformed the BES observation of the non- $D\bar{D}$ decay.

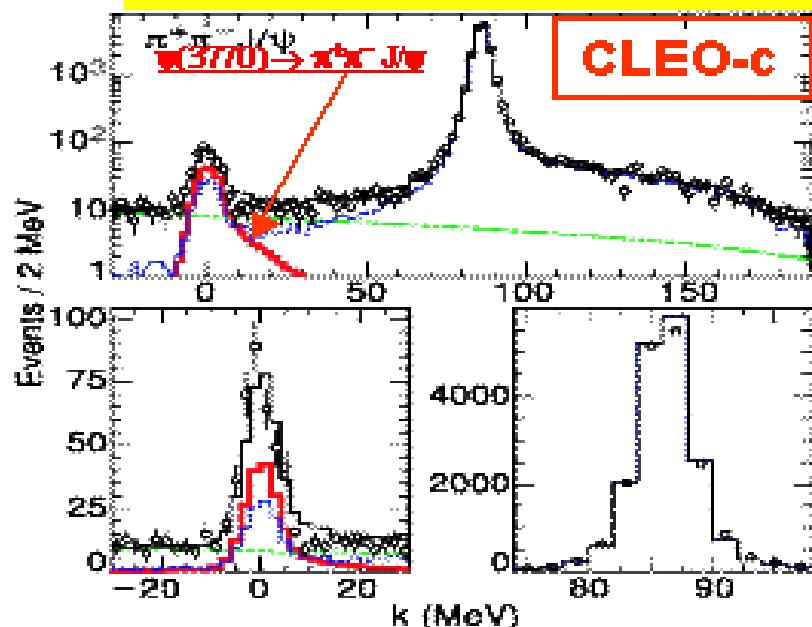


FIG. 2: Fit of the distribution in k for the final state $\psi(3770) \rightarrow \pi^+ \pi^- J/\psi$, showing the data (open circles), overall fit (thin solid line), direct $\psi(3770)$ decay peak (thick solid line), reflected return to the $\psi(3770)$ reflected back, and the background noise (dashed line); see caption for the scale (top), and see figure 1(c) for the relative scale between the direct decay peak (bottom left) and reflected return peak (bottom right).

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

BES-II

PLB 605 (2005)63

$BF(\psi(3770) \rightarrow J/\psi \pi^+ \pi^-) = (0.189 \pm 0.022^{+0.007}_{-0.004})\%$

CLEO-c

PRL96,082004(2006)

The two measurements are consistent within the errors.

$\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$



Available online at www.sciencedirect.com



Physics Letters B www.sciencedirect.com

PLB 605(2005)63

Evidence of $\psi(3770)$ non- $D\bar{D}$ decay to $J/\psi \pi^+ \pi^-$

BES Collaboration

J.Z. Bai^a, Y. Bai^b, J.C. Bian^c, X. Cai^a, J.P. Cheng^a, H.B. Chen^a, H.S. Chen^a,
 J. Chen^a, J.C. Chen^a, Y.B. Chen^a, S.P. Chi^a, Y.P. Chu^a, X.Z. Cui^a, Y.M. Dai^a,

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

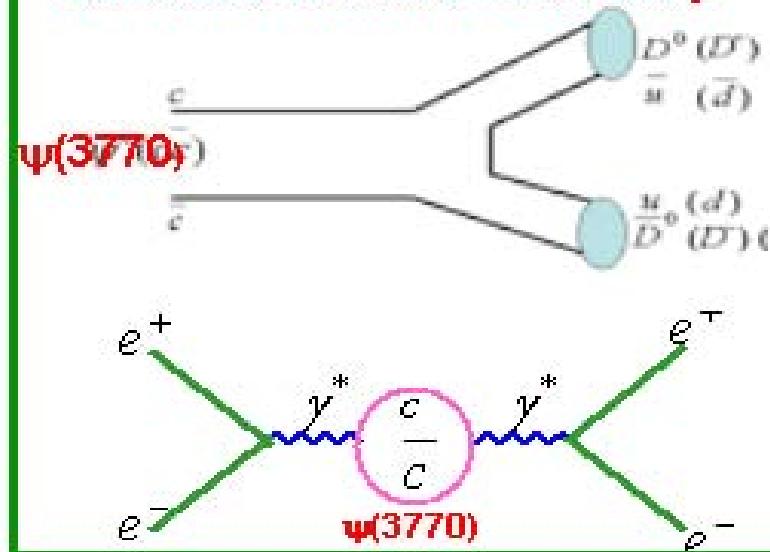
$$\Gamma(\psi(3770) \rightarrow J/\psi \pi^+ \pi^-) = (80 \pm 33 \pm 23) \text{ keV}$$

it is an interesting question if transitions inside the charmonium system exist.

It is very important in elucidating the exact nature of the $\psi(3770)$ and help us understand why the $\psi(3770)$ does not seem to be saturated by $D\bar{D}$ -bar decays.

Test of various theoretical models.

Before BES-II one knows the decays



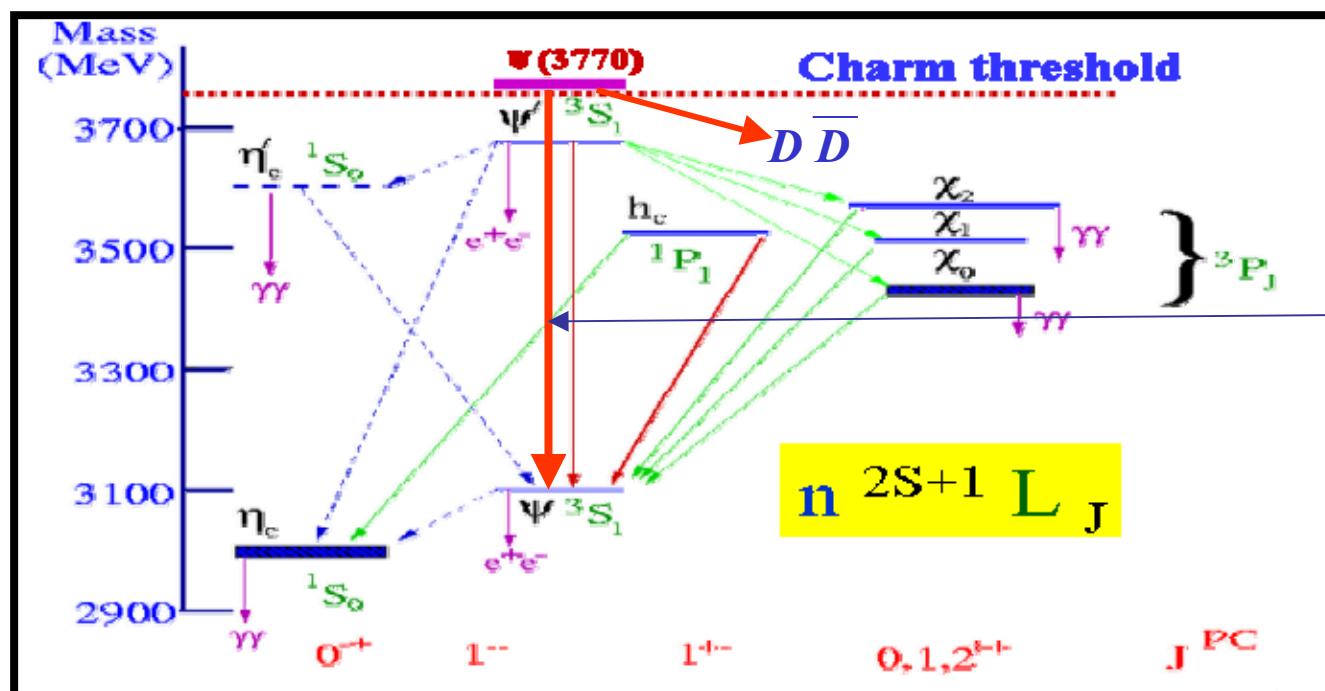
BES “建立”了强跃迁过程



从此在国际高能物理界打开了广泛研究
 $\psi(3770)$ 非- $D\bar{D}\text{bar}$ 衰变的窗口。

$\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$

After about two year argument, CLEO-c finally found the non- $D\bar{D}$ decay of $\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$ and conformed BES result on measurement of the partial width of the decay.



It is an interesting question if transitions inside the $\psi(3770)$ exist.

Yes

The first non- $D\bar{D}$ -bar decay mode of $\psi(3770)$ observed by BES

发现 $\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$ 的意义

科学意义

实验发现的第一个 $\psi(3770)$ 非-**D** \bar{D} 衰变模式.

其它的**D**波态衰变到 $J/\psi \pi^+ \pi^-$ 的宽度可以由此宽度预测, 是一个基本的衰变模式.

其实验宽度可用于检验**QCD**多极展开的理论计算, 从而可以验证和发展**QCD**的理论.

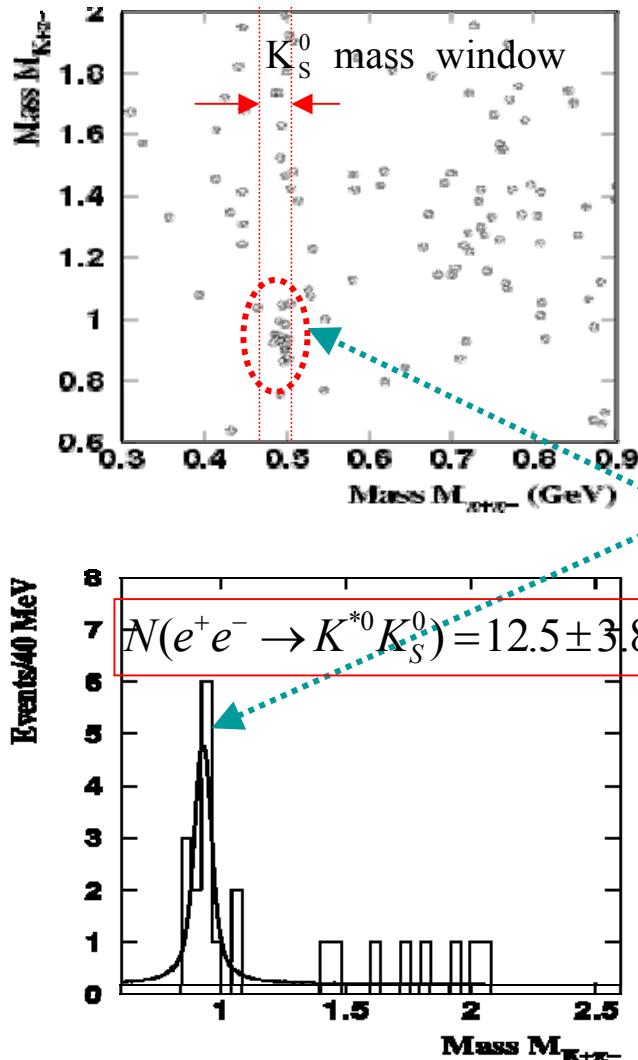
发展相对论的势模型理论.

各实验组广泛的寻找 $\psi(3770) \rightarrow J/\psi \pi^+ \pi^+$ 衰变, 导致在短时间内实验上发现了一系列的新态(粒子).

其它意义

Search for Charmless Decays of $\psi(3770)$

Search for $\psi(3770) \rightarrow K^{*0} \bar{K}^0$

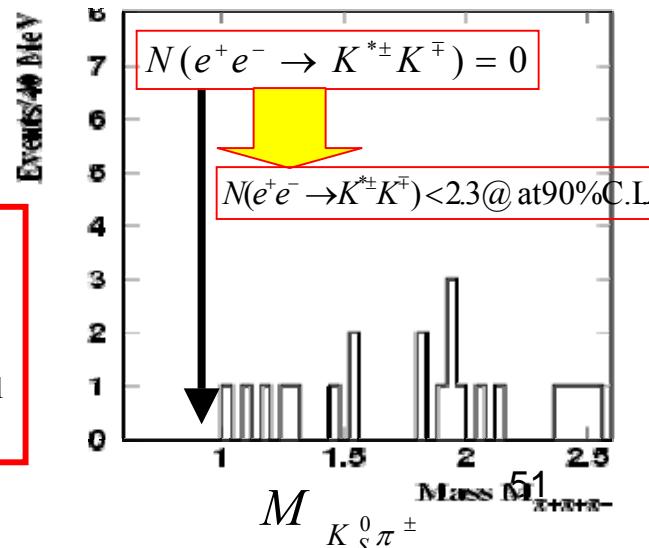


Selection criteria

$K^{*0} K_S^0 + c.c.$

Data taken around $\psi(3770)$ peak $\int L dt = 27.7 \text{ pb}^{-1}$

4-prong with net charge zero
 $|\cos \theta| < 0.85$
 $\text{CL}_{\pi(K)} > 0.001 \Rightarrow \pi(K)$
 $P(\chi^2, 4)_{\pi^+\pi^-\pi^+K^\mp} > 0.01$
 $P(\chi^2, 4)_{\pi^+\pi^-\pi^\pm K^\mp} > P(\chi^2, 4)_{\pi^+\pi^-\pi^+\pi^-}$
satisfy K_S^0 selection

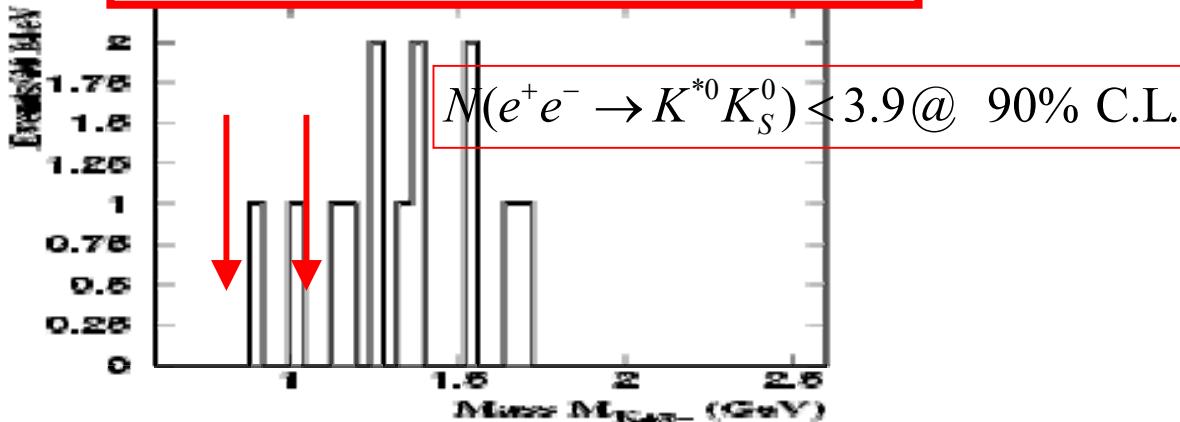


Search for Charmless Decays of $\psi(3770)$

Data taken off-resonance
(@ 3.65 GeV) $\int L dt = 6.4 \text{ pb}^{-1}$

Normalized to the luminosity
and phase space of $\psi(3770)$
production

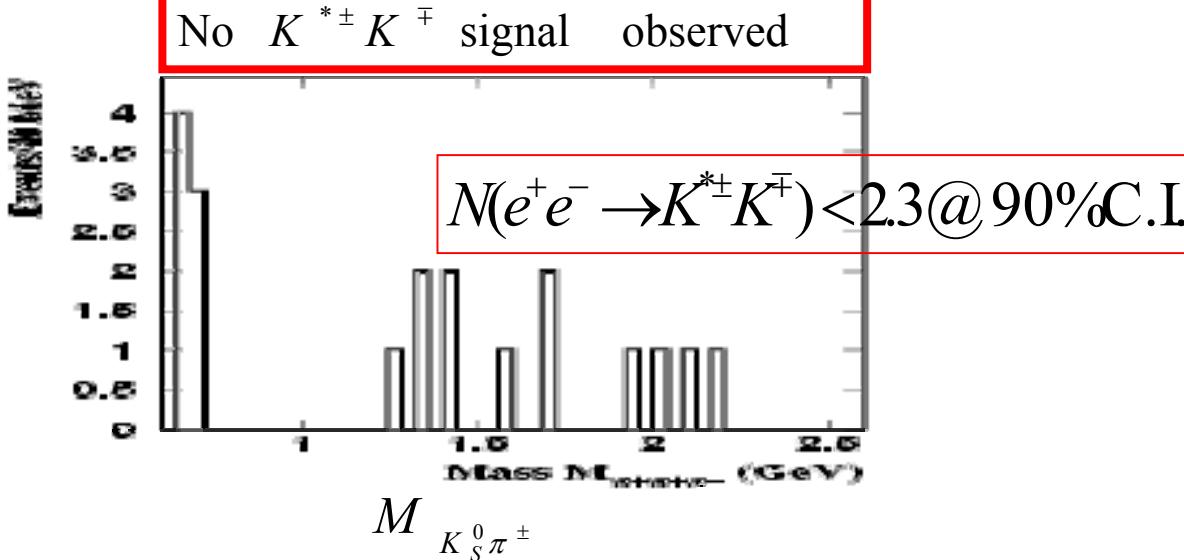
No significant $K^{*0}K_S^0 + c.c.$ signal observed



$$N_{QED}^{K^{*0}K_S^0} < 7.1$$

$$N_{QED}^{K^{*\pm}K^\mp} < 4.2$$

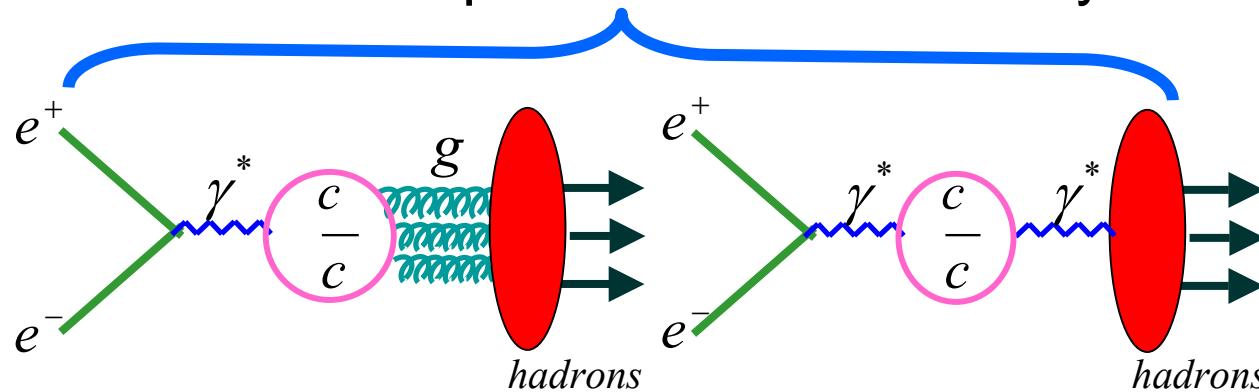
No $K^{*\pm}K^\mp$ signal observed



Search for Charmless Decays of $\psi(3770)$

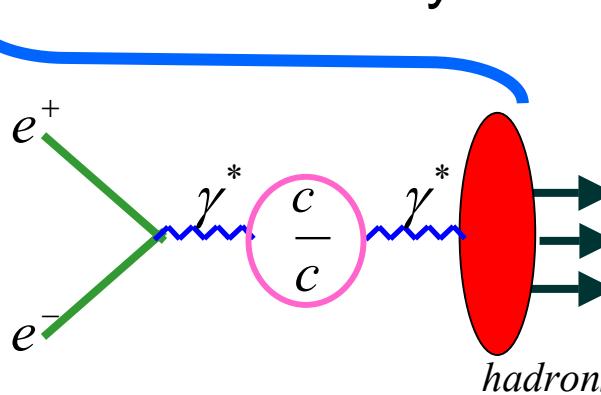
Charmless final states observed

Resonance productions and decays



three gluon annihilation process

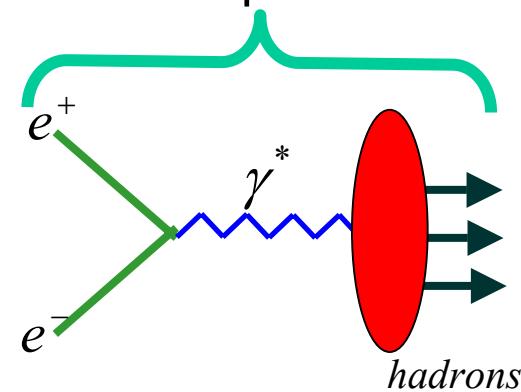
amplitude a_g



one photon *annihilation* process

amplitude a_γ

QED process



one photon continuum process

amplitude a_{QED}

Observed in experiment

$$N(e^+e^- \rightarrow \text{charmless hadrons})_{\text{observed}} \propto |a_g + a_\gamma + a_{QED}|^2$$

Search for Charmless Decays of $\psi(3770)$

A detailed maximum likelihood analysis gives

$$N(\psi(3770) \rightarrow K^{*0} K_S^0) = a^2 = 1.86_{-1.46}^{+2.30}$$

$$N(e^+ e^- \rightarrow K^{*0} K_S^0)_{QED} = b^2 = 0.39_{-0.30}^{+0.49}$$

$$\cos \varphi = -0.999 \Rightarrow \varphi = 180^\circ$$

$$\chi^2 = 9.695$$

$$\text{set } a \equiv 0 \quad \Rightarrow \quad \chi^2 = 16.16$$

giving a significance of 2.4σ

Search for Charmless Decays of $\psi(3770)$

Those yield the branching fraction and upper limit to be

$$BF(\psi(3770) \rightarrow K^{*0} \bar{K}^0) = (4.3_{-3.4}^{+5.4} \pm 1.3) \times 10^{-4}$$

$$BF(\psi(3770) \rightarrow K^{*0} \bar{K}^0) < 1.2 \times 10^{-3} \text{ at 90\% C. L.}$$

and partial width to be

$$\Gamma_{\psi(3770) \rightarrow K^{*0} \bar{K}^0} = (10.1_{-8.0}^{+12.7} \pm 3.3) \text{ keV}$$

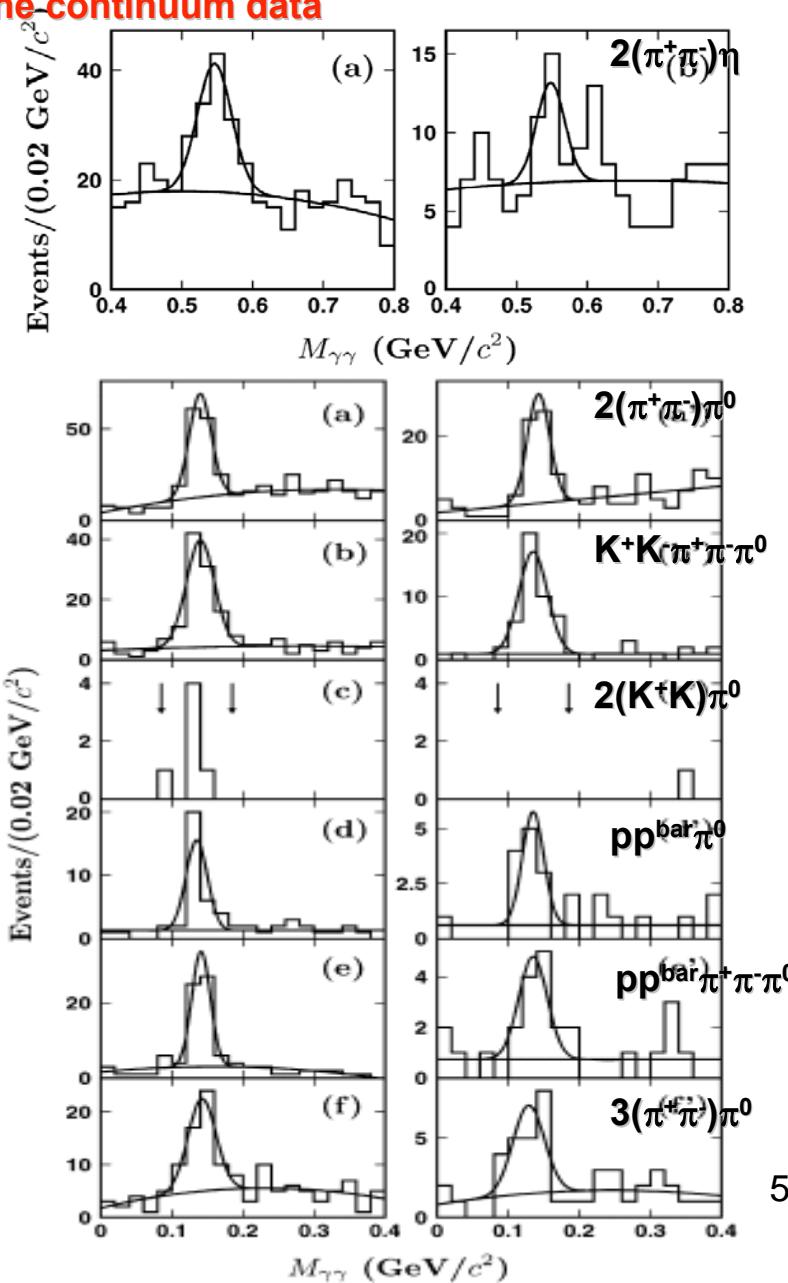
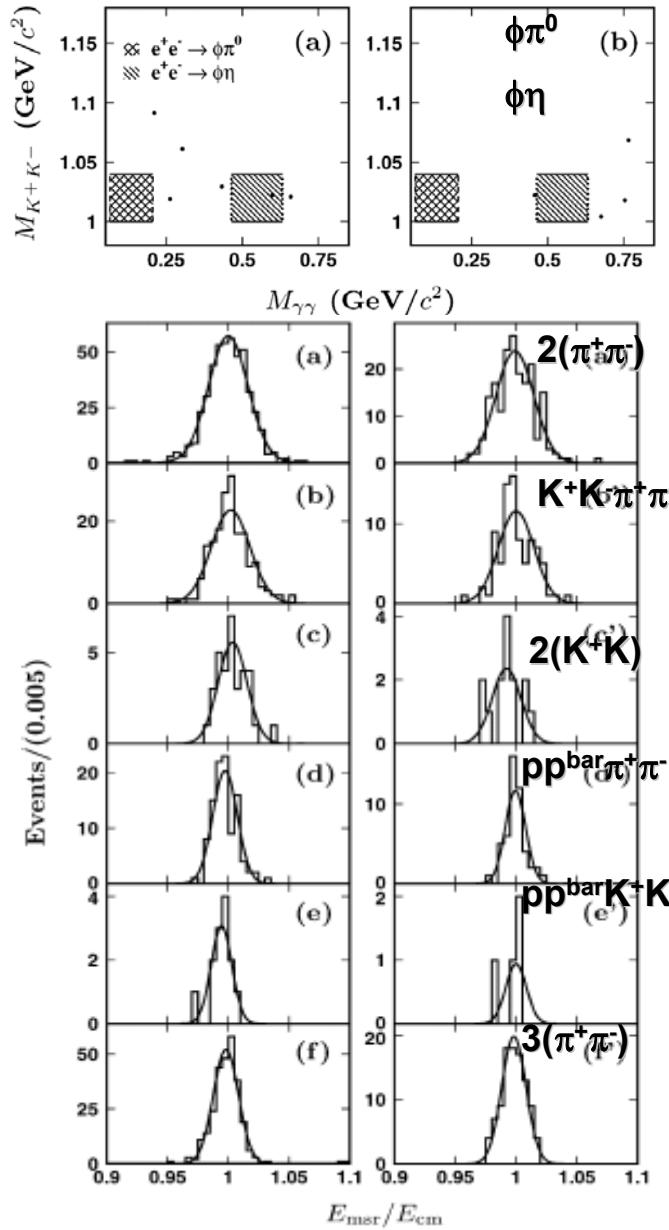
(preliminary !)

$$\Gamma_{\psi(3770) \rightarrow K^{*0} \bar{K}^0} < 29 \text{ keV @ 90\% C.L.}$$

$$\sigma^{obs}(e^+ e^- \rightarrow K^{*0} \bar{K}^0)_{3.773 \text{ GeV}} = (18.4 \pm 6.0 \pm 4.0) \text{ pb}$$

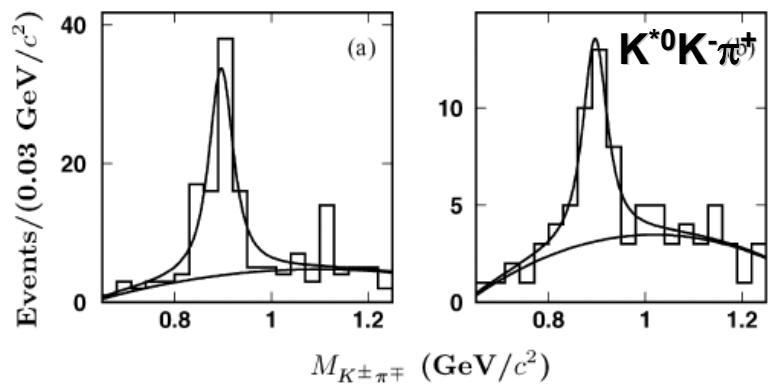
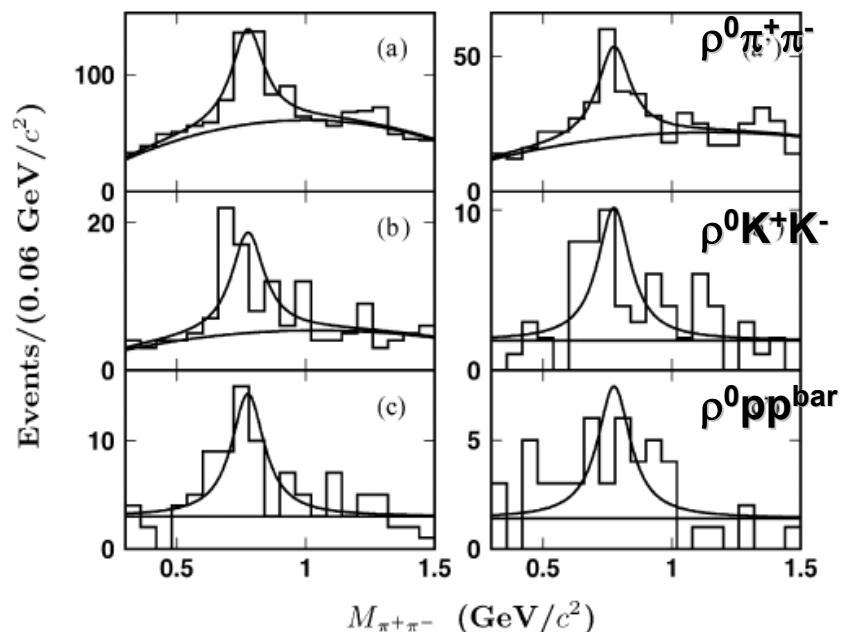
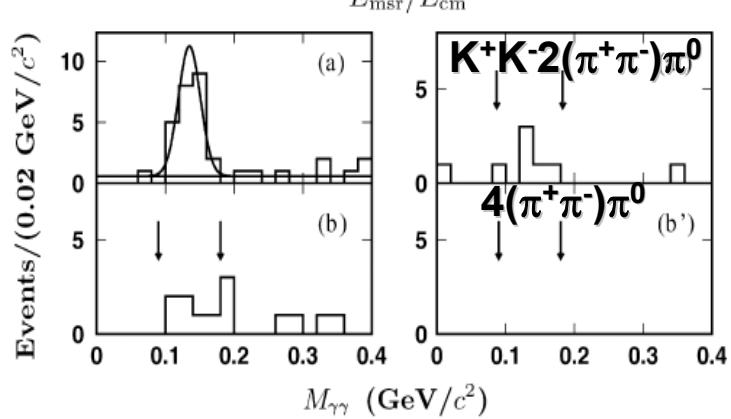
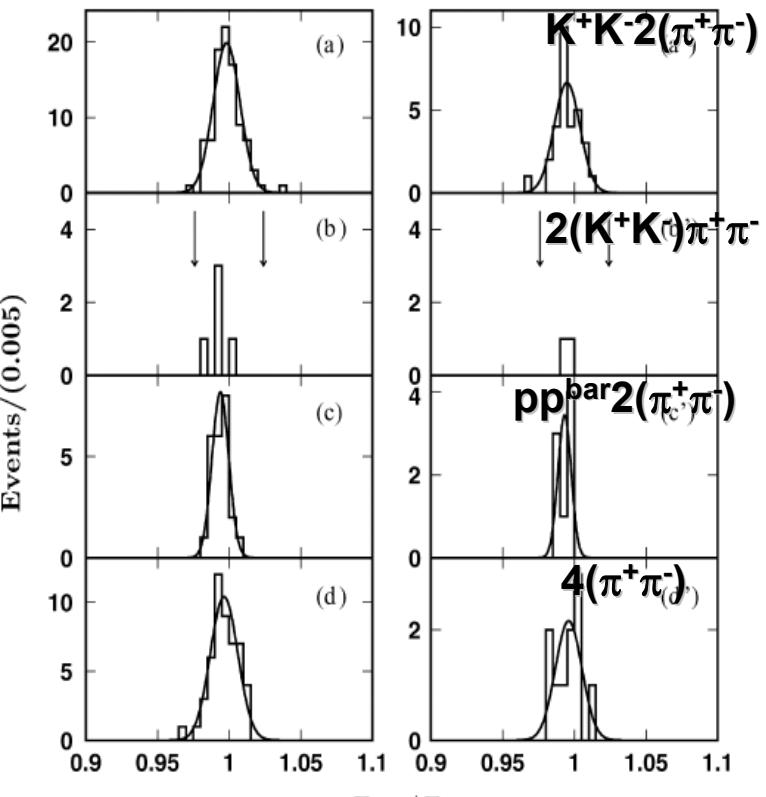
Search for Charmless Decays of $\psi(3770)$

(*)s are for the $\psi(3770)$ resonance data, (*)' is for the continuum data



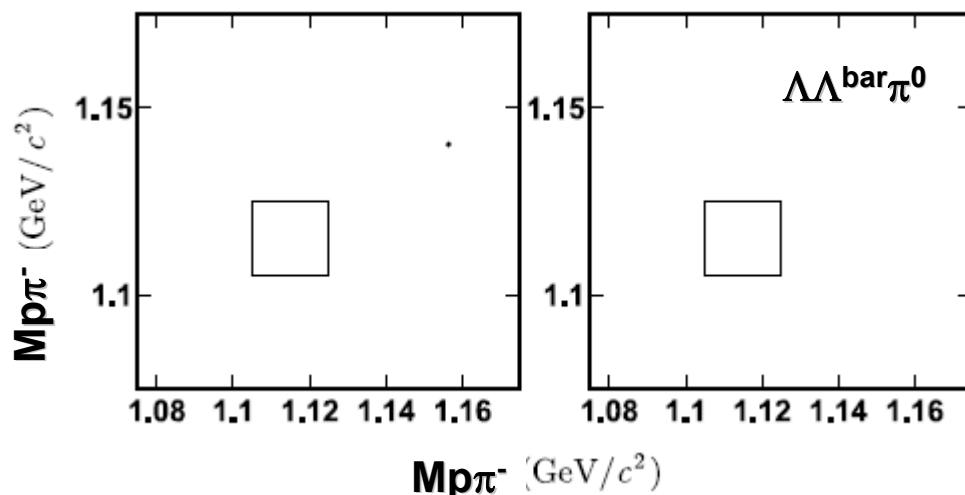
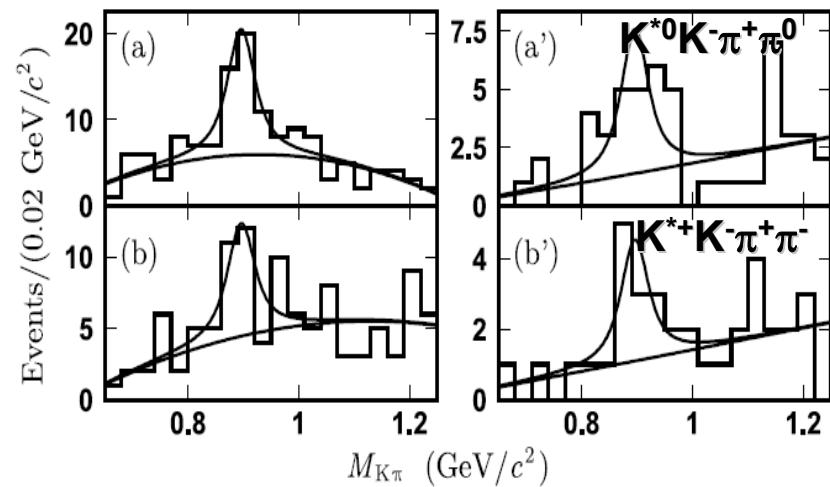
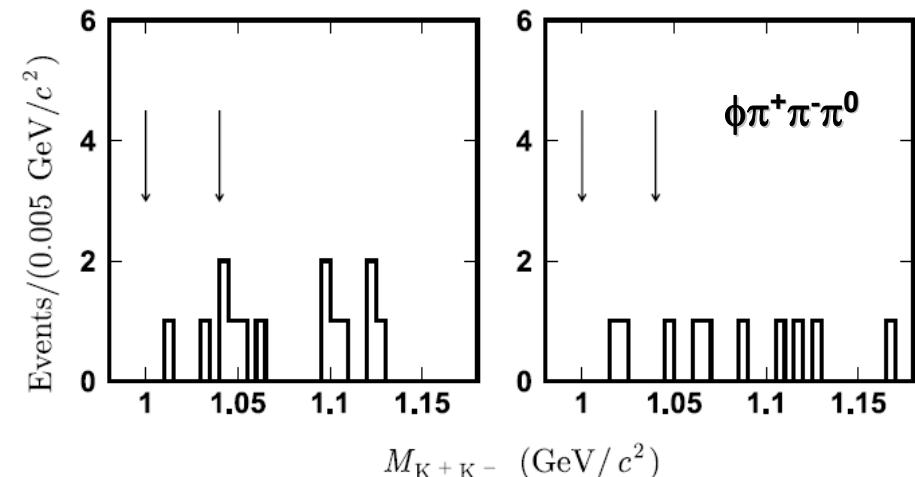
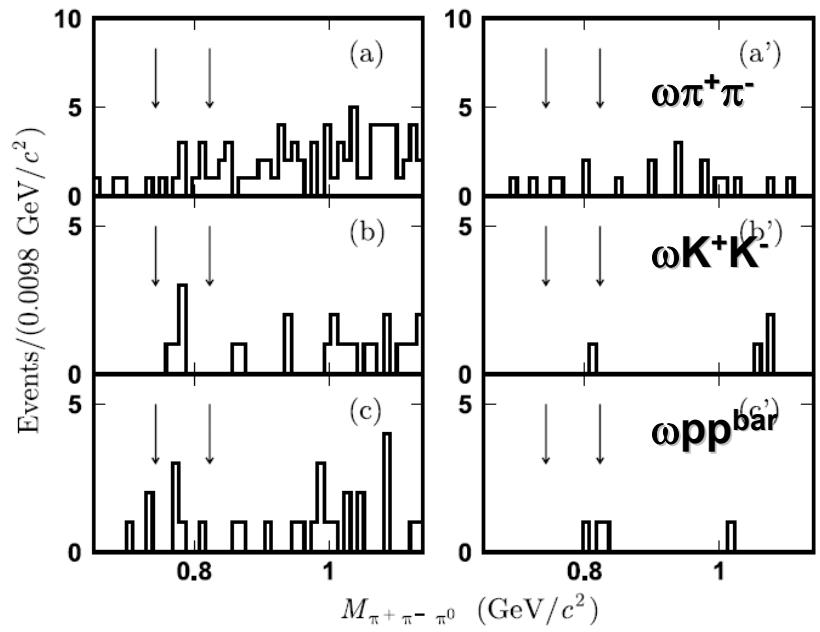
Search for Charmless Decays of $\psi(3770)$

(s) are for the $\psi(3770)$ resonance data, (') is for the continuum data



Search for Charmless Decays of $\psi(3770)$

(s) are for the $\psi(3770)$ resonance data, (') is for the continuum data



Search for Charmless Decays of $\psi(3770)$

Mode	$\sigma^{3.773} [\text{pb}]$	$\sigma^{3.650} [\text{pb}]$	$B^{\text{up}} [\times 10^{-3}]$
$\phi\pi^0$	<3.5	<8.9	<0.5
$\phi\eta$	<12.6	<18.0	1.9
$2(\pi^+\pi^-)$	$173.7 \pm 8.4 \pm 18.4$	$177.7 \pm 13.3 \pm 18.8$	4.8
$K^+K^-\pi^+\pi^-$	$131.7 \pm 10.1 \pm 14.1$	$161.7 \pm 17.9 \pm 17.1$	4.8
$\phi\pi^+\pi^-$	<11.1	<22.9	1.6
$2(K^+K^-)$	$19.9 \pm 3.6 \pm 2.1$	$24.1 \pm 6.5 \pm 2.6$	1.7
ϕK^+K^-	$15.8 \pm 5.1 \pm 1.8$	$17.4 \pm 9.2 \pm 2.0$	2.4
$p\bar{p}^{\text{bar}}\pi^+\pi^-$	$33.2 \pm 3.4 \pm 3.8$	$42.1 \pm 6.1 \pm 4.8$	1.6
$p\bar{p}^{\text{bar}}K^+K^-$	$7.1 \pm 2.0 \pm 0.8$	$6.1 \pm 3.1 \pm 0.7$	1.1
$\phi p\bar{p}^{\text{bar}}$	<5.8	<9.1	0.9
$3(\pi^+\pi^-)$	$236.7 \pm 14.7 \pm 33.4$	$234.9 \pm 23.8 \pm 33.1$	9.1
$2(\pi^+\pi^-)\eta$	$153.7 \pm 40.1 \pm 18.4$	$86.6 \pm 40.3 \pm 10.4$	24.3
$2(\pi^+\pi^-)\pi^0$	$80.9 \pm 13.9 \pm 10.0$	$124.3 \pm 21.7 \pm 14.9$	6.2
$K^+K^-\pi^+\pi^-\pi^0$	$171.6 \pm 26.0 \pm 20.9$	$222.8 \pm 37.7 \pm 27.2$	11.1
$2(K^+K^-)\pi^0$	$18.1 \pm 7.7 \pm 2.1$	<23.0	4.6
$p\bar{p}^{\text{bar}}\pi^0$	$10.1 \pm 2.2 \pm 1.0$	$9.2 \pm 3.4 \pm 1.0$	1.2
$p\bar{p}^{\text{bar}}\pi^+\pi^-\pi^0$	$53.1 \pm 9.2 \pm 6.8$	$29.0 \pm 11.1 \pm 3.7$	7.3
$3(\pi^+\pi^-)\pi^0$	$105.8 \pm 34.4 \pm 16.9$	$126.6 \pm 47.1 \pm 19.2$	13.7

Search for
Charmless
decays of
 $\psi(3770)$

We have searched for
more than 40 modes
for the light hadron
decays.

PLB650(2007)111

Search for Charmless Decays of $\psi(3770)$

Mode	$\sigma^{3.773}[\text{pb}]$	$\sigma^{3.650}[\text{pb}]$	$B^{\text{up}}[\times 10^{-3}]$
$K^+K^-2(\pi^+\pi^-)$	$168.0 \pm 18.2 \pm 23.7$	$164.9 \pm 30.3 \pm 23.2$	< 10.3
$2(K^+K^-)\pi^+\pi^-$	$11.9 \pm 5.8 \pm 1.7$	< 49.1	< 3.2
$p\bar{p}$ 2($\pi^+\pi^-$)	$23.5 \pm 5.0 \pm 3.5$	$22.8 \pm 8.4 \pm 3.4$	< 2.6
$4(\pi^+\pi^-)$	$131.8 \pm 19.5 \pm 23.6$	$76.2 \pm 24.4 \pm 13.9$	< 16.7
$K^+K^-2(\pi^+\pi^-)\pi^0$	$231.5 \pm 63.6 \pm 37.5$	< 375.2	< 52.0
$4(\pi^+\pi^-)\pi^0$	< 206.9	< 119.4	< 30.6
$\rho^0\pi^+\pi^-$	$111.9 \pm 13.1 \pm 13.1$	$113.6 \pm 21.3 \pm 13.1$	< 6.9
$\rho^0K^+K^-$	$34.2 \pm 11.5 \pm 4.4$	$57.6 \pm 17.9 \pm 6.3$	< 5.0
$\rho^0p\bar{p}$	$13.1 \pm 3.2 \pm 1.8$	$17.7 \pm 6.2 \pm 2.8$	< 1.7
$K^{*0}K^-\pi^+$	$94.7 \pm 15.5 \pm 10.4$	$85.5 \pm 26.3 \pm 14.4$	< 9.7
$\Lambda\Lambda^{\bar{b}ar}$	< 2.5	< 6.1	< 0.4
$\Lambda\Lambda^{\bar{b}ar}\pi^+\pi^-$	< 26.7	< 42.9	< 4.4

Search for light-hadron decays of $\psi(3770)$

PLB656(2007)30

Search for Charmless Decays of $\psi(3770)$

Search for light-hadron decays of $\psi(3770)$

Mode	$\sigma^{3.773} [\text{pb}]$	$\sigma^{3.650} [\text{pb}]$	$B^{\text{up}} [\times 10^{-3}]$
$\omega\pi^+\pi^-$	<37.1	<50.8	5.5
ωK^+K^-	<44.4	<53.2	6.6
$\omega p\bar{p}$	<20.3	<30.9	3.0
$\phi\pi^+\pi^-\pi^0$	<25.5	<66.7	3.8
$K^{*0}K^-\pi^+\pi^0$	$116.3 \pm 32.7 \pm 20.0$	$128.1 \pm 59.5 \pm 17.9$	16.3
$K^{*+}K^-\pi^+\pi^-$	$173.9 \pm 73.3 \pm 26.1$	$189.0 \pm 116.3 \pm 28.2$	32.4
$K^+K^-\rho^0\pi^0$	<5.6	$47.6 \pm 33.4 \pm 10.7$	0.8
$K^+K^-\rho^+\pi^-$	$94.2 \pm 31.6 \pm 11.7$	$141.9 \pm 53.3 \pm 19.7$	14.6
$\Lambda\Lambda^{\bar{p}}\pi^0$	<7.9	<21.4	1.2

EPJC52(2007)805

Upper limits are set at 90% CL

We searched for $\psi(3770) \rightarrow$ light hadrons over 40 channels, but no significant signals were found. This does not mean that $\psi(3770)$ does not decay into light hadrons. To extract the branching fractions for $\psi(3770) \rightarrow$ light hadrons from the observed cross sections, one need to make finer cross section scan covering both $\psi(3686)$ and $\psi(3770)$ with larger data samples (BES-III can do this well).⁶¹

Hot Topics on $\psi(3770)$ Physics

Heavy Quarkonia

QQ-bar 的热点问题和不解之谜?

non-DDbar 研究已成为国际HQ物理研究的热点问题!

Puzzle Pieces:
Results on b and c
Spectroscopy and
Decay

Hanna Mahlke-Krueger

Cornell University

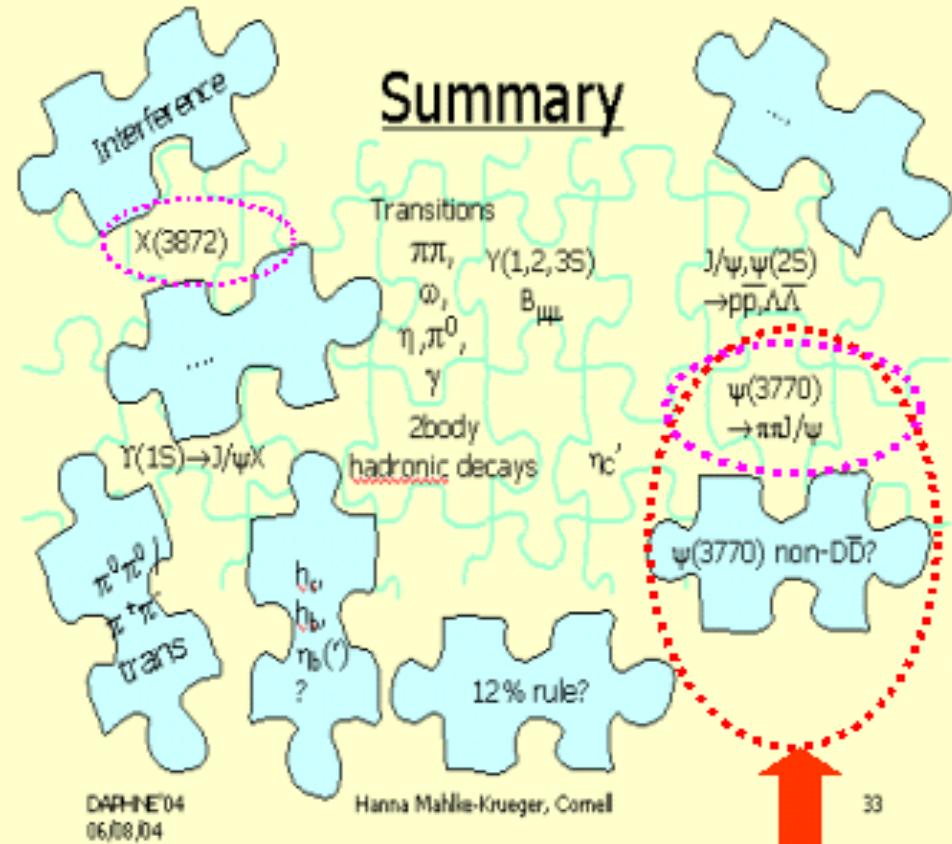


DAPHNE 2004



8类典型的热点问题

3大不解之谜?



主要起源于BES-II
 $\psi(3770)$ 物理研究

$\psi(3770)$ Physics at BES-III

(The Near Future)

What should we do for $\psi(3770)$ at BES-III ?

We should precisely measure the line-shape for $e^+e^- \rightarrow$ hadrons total cross sections in the energy region between 3.700 and 3.90 GeV (or even more wider energy range).

To measure the decay branching fraction for $\psi(3770) \rightarrow$ non- $D\bar{D}$ bar precisely.

To find more exclusive non- $D\bar{D}$ bar decay modes of $\psi(3770)$ and more precisely measure their decay widths.

In the measurements of the branching fractions for $\psi(3770) \rightarrow LH$, we have to consider the possible interference between amplitudes ... We need to make finer cross section scan to extract the branching fractions.

BES-III/BEPC-II

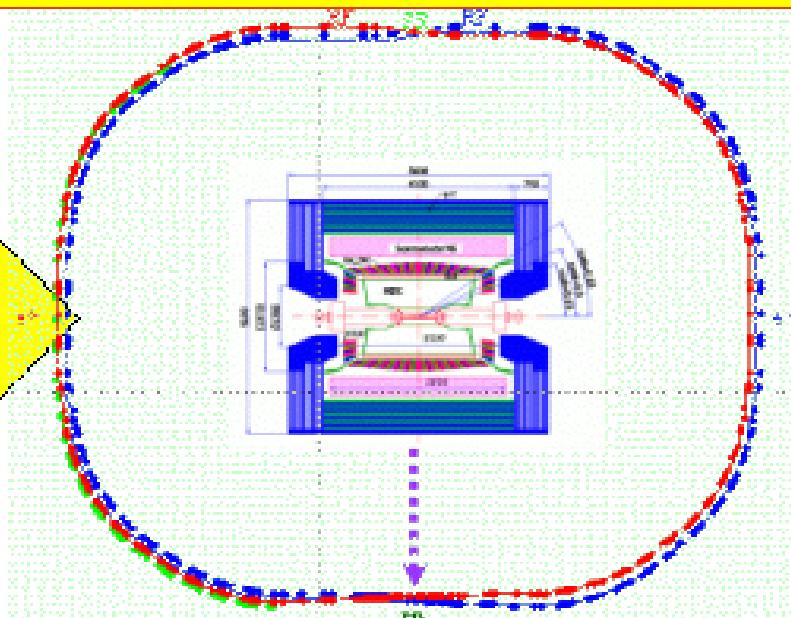
Charm Physics at BES-III



With the BES-II at BEPC we measured many physics quantities about charm and $\psi(3770)$ resonance.

BES-III will be the successor of the previous successful BES-I and BES-II

With the BES-III at the BEPC-II we will more precisely measure these physics quantities and will do some measurements for probes for NEW Physics ! ...

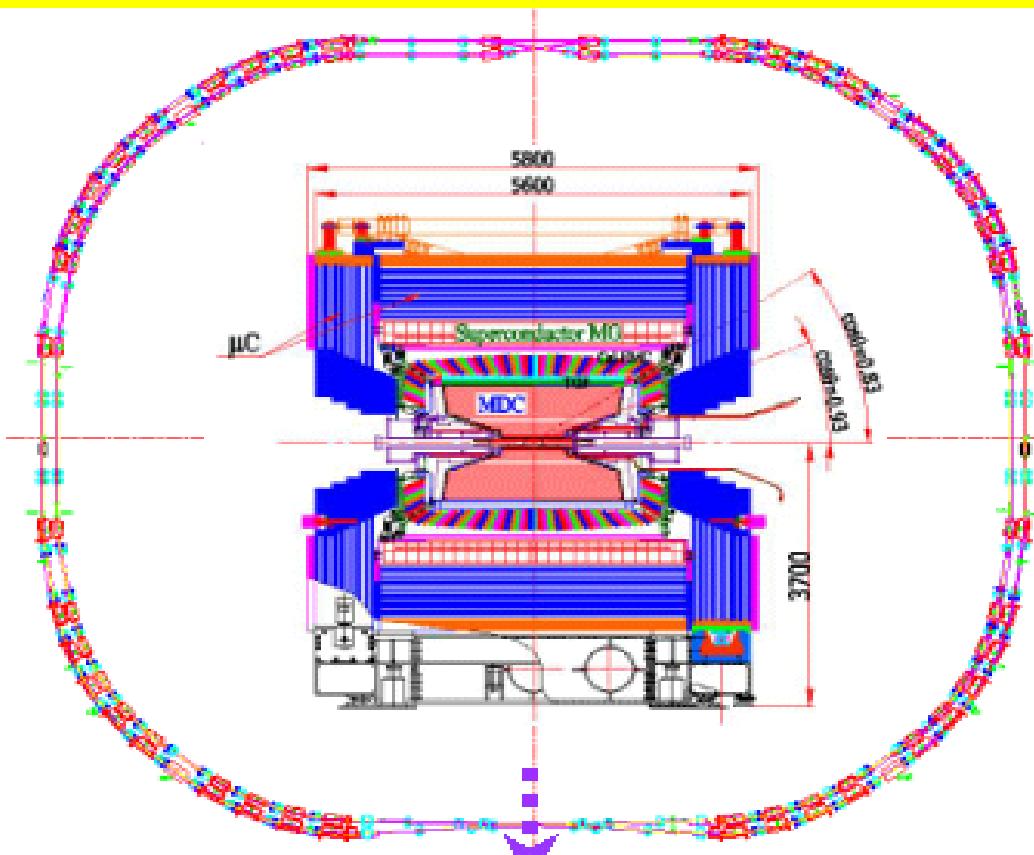


Luminosity reach to 10^{33} at $E_{beam} = 3.78$ GeV (compare to 10^{31} for BEPC).

Large angle coverage, good charged PID & momentum resolution, good photon energy resolution.

BES-III/BEPC-II

BEPCII/BESIII Project



run plan not decided: example 5/fb/yr 15/fb/3yrs
3 yrs @ 3770 30M D \bar{D} /yr = 90M D \bar{D} ~ $\times 20$ full CLEO-c
3 yrs @ 4170 2M Ds $\bar{D}s$ /yr = 6MDs $\bar{D}s$ ~ $\times 20$ full CLEO-c

Design

- Two ring machine
- 93 bunches each
- Luminosity
 - X 5 CESR-c design
 - $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ @ 1.89 GeV
 - $6 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ @ 1.55 GeV
 - $6 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ @ 2.1 GeV
- New BESIII

Status and Schedule

- Most contracts signed
- Linac installed 2005
- Ring to be installed 2006
- BESIII in place and Commissioning 2007

BEPCII/BESIII
data taking summer of 2008

Charm yields at BES-III/BEPC-II

Precision Measurements at BES-III

Charm Production at BES-III

Average L_{um}: $L = 0.5 \times \text{Peak L}_{\text{um}}$:

One year data taking time: T = 10⁷s

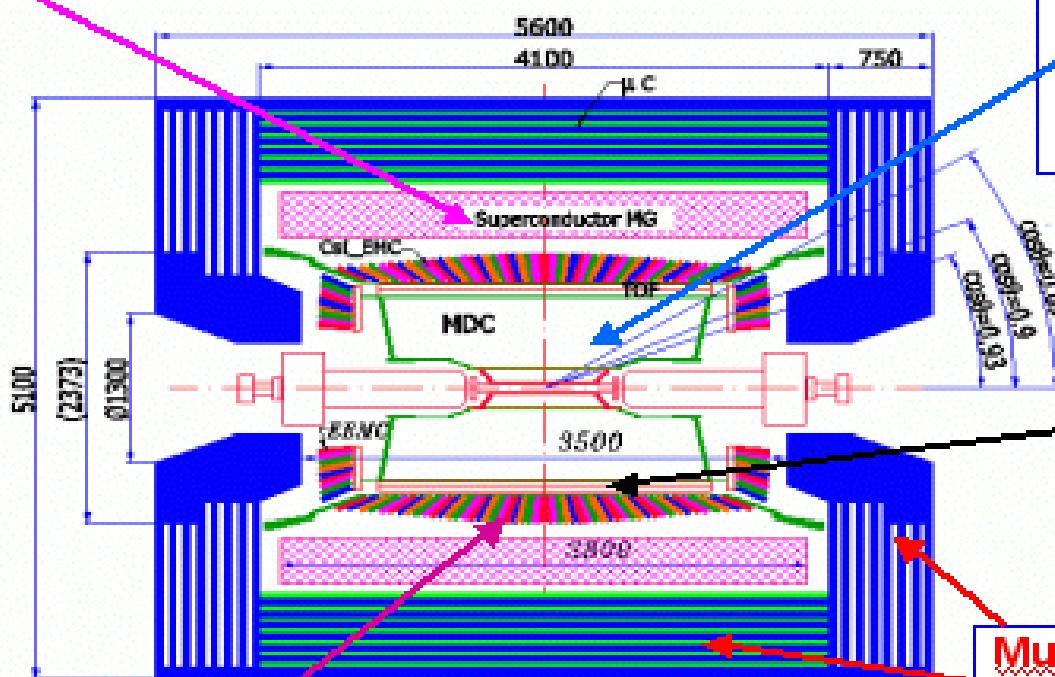
Assuming 6 month running for Physics/year & average efficiency of collecting data is 70%.

$$N_{\text{event}}/\text{year} = \sigma_{\text{exp}} \times L \times T \times \epsilon_{\text{data taking}}$$

Resonance	Mass(GeV) CMS	Peak L _{um} (10 ³³ cm ⁻² s ⁻¹)	Physics Cross Section (nb)	N _{events} /yr
J/ ψ	3.097	0.6	3400	6×10^9
τ	3.670	1.0	2.4	7.3×10^6
$\psi(2S)$	3.686	1.0	640	2.0×10^9
D ⁰ D ⁰ $\bar{\text{bar}}$	3.770	1.0	3.6	11×10^6
D ⁺ D ⁻	3.770	1.0	2.6	7.9×10^6
D _s D _s	4.030	0.6	0.32	0.6×10^6
D _s D _s	4.140	0.6	0.67	1.2×10^6

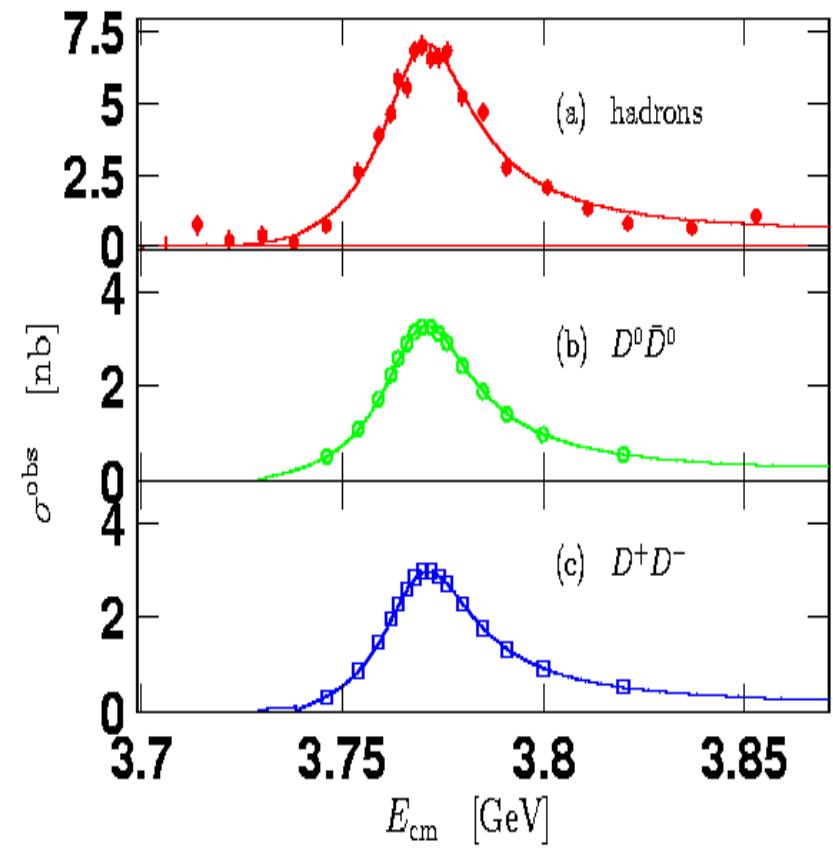
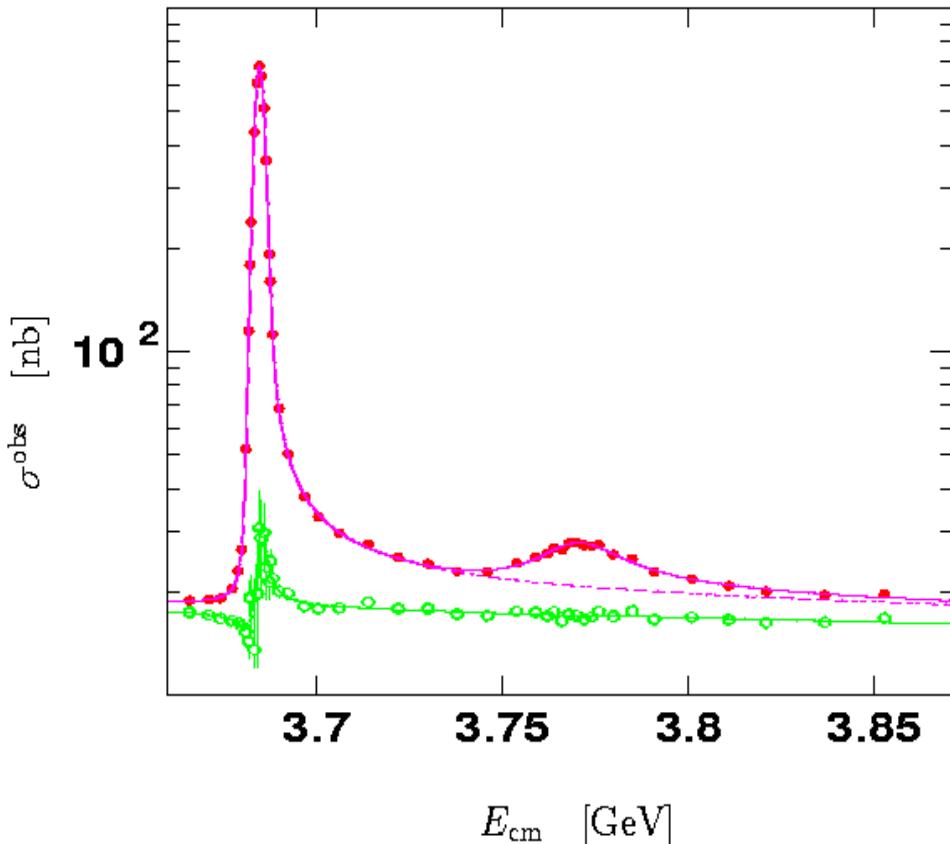
BES-III Detector

BESIII Detector

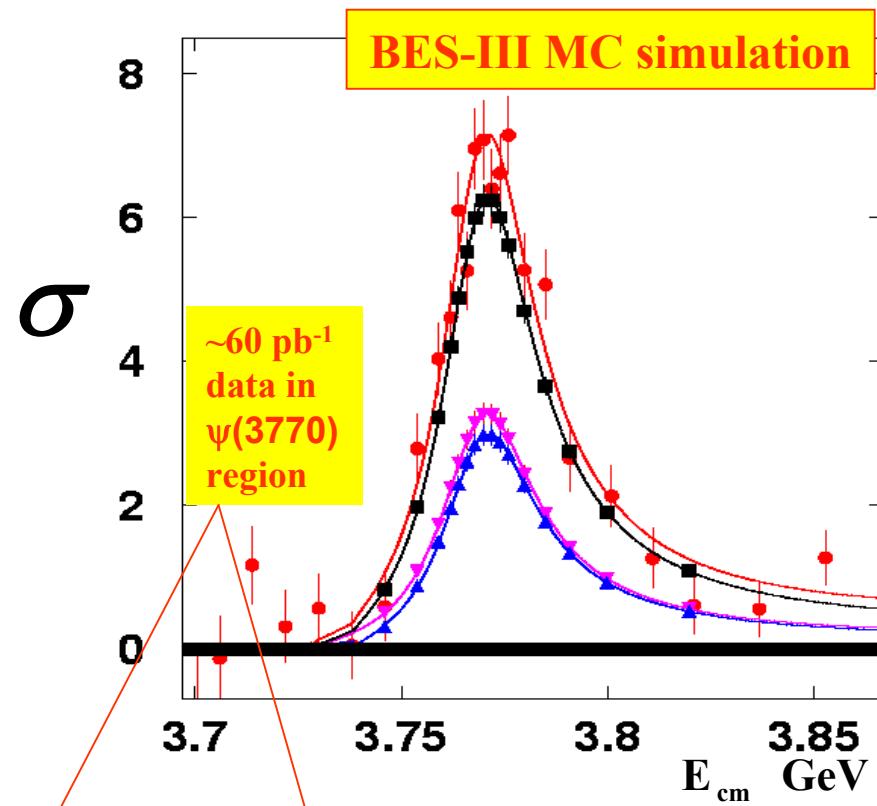
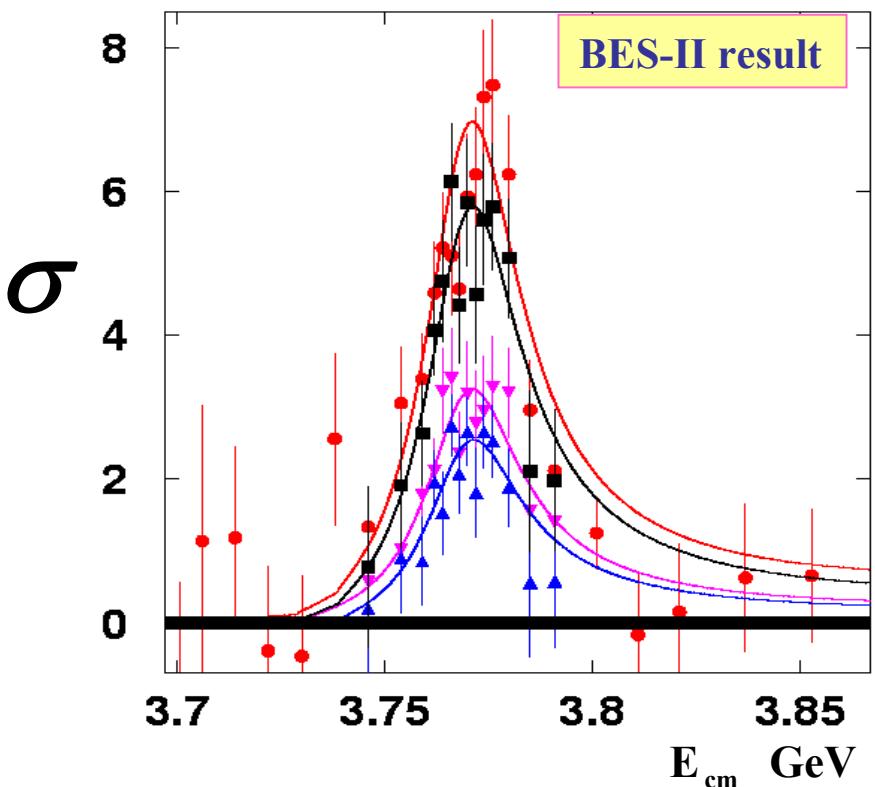


The detector is hermetic for neutral and charged particle with excellent resolution ,PID, and large coverage.

$\psi(3770)$ Parameters and $B[\psi(3770) \rightarrow \text{non-}D\bar{D}]$



$\psi(3770)$ Parameters and $B[\psi(3770) \rightarrow \text{non-}D\bar{D}]$



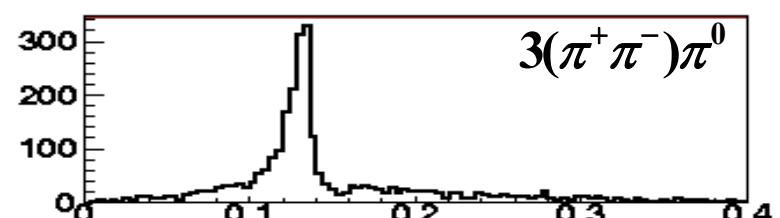
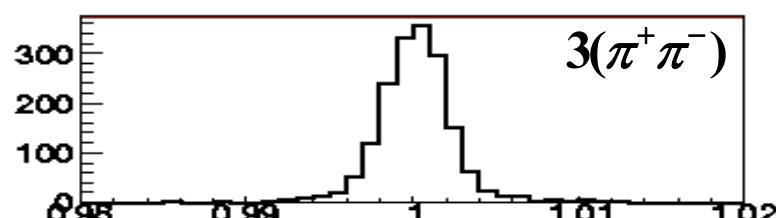
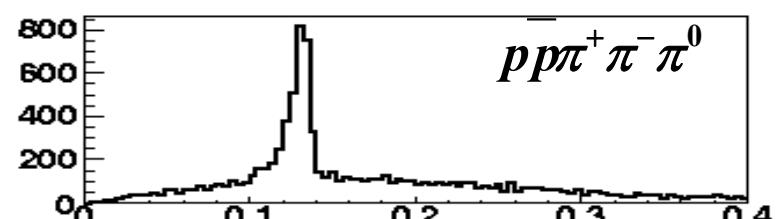
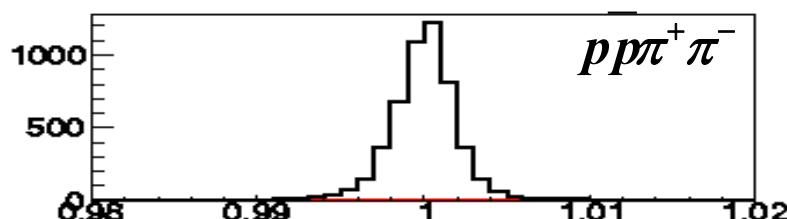
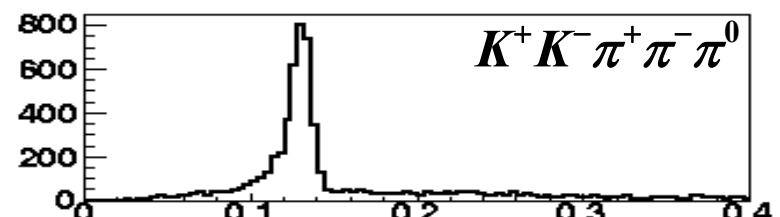
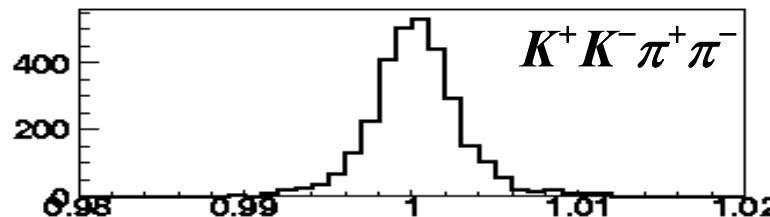
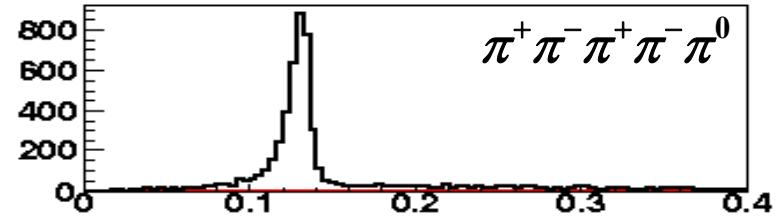
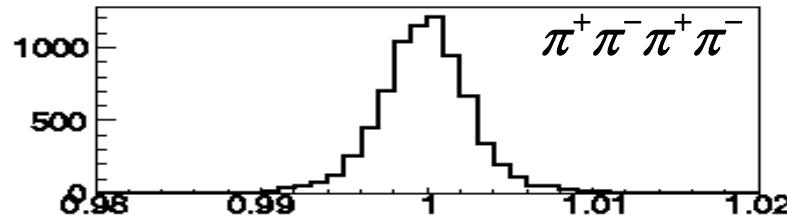
$\Gamma_{\psi(3770)}^{\text{tot}}$	$26.8 \pm 0.5 \text{ MeV}$	26.9 MeV
$\Gamma_{\psi(3770)}^{\text{ee}}$	$256 \pm 9 \text{ eV}$	251 eV

Measured value Input value

$B[\psi(3770) \rightarrow D\bar{D}]$	$(88.2 \pm 2.4 \pm \sim 2.0) \%$	Measured value
	89%	Input value

$\psi(3770) \rightarrow$ light hadrons

These are simple BES-III MC simulation only !

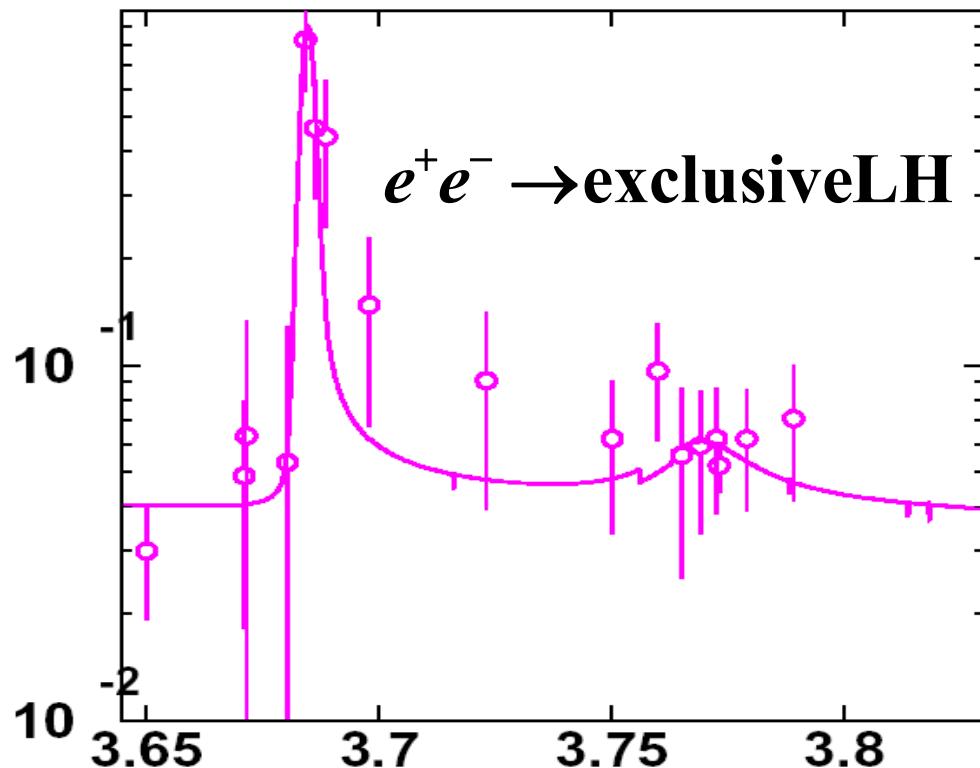


$E_{\text{measure}}/E_{\text{cm}}$

$M_{\gamma\gamma}$

$\psi(3770) \rightarrow$ light hadrons

Measurements of branching fractions for
 $\psi(3770) \rightarrow$ light hadrons with BES-III at BEPC-II



这将是在BES-III/BEPC-II上精细研究 charmless
衰变的主要方法之一。它可以分离出QED和共振
态衰变的贡献，并且测定其位相差。

The way to measure the branching fractions for $\psi(3770) \rightarrow$ light hadrons is to analyze the energy dependent cross sections, since there are interferences between the amplitudes of the exclusive final states from resonance and from the continuum. But needing large cross section scan data samples!

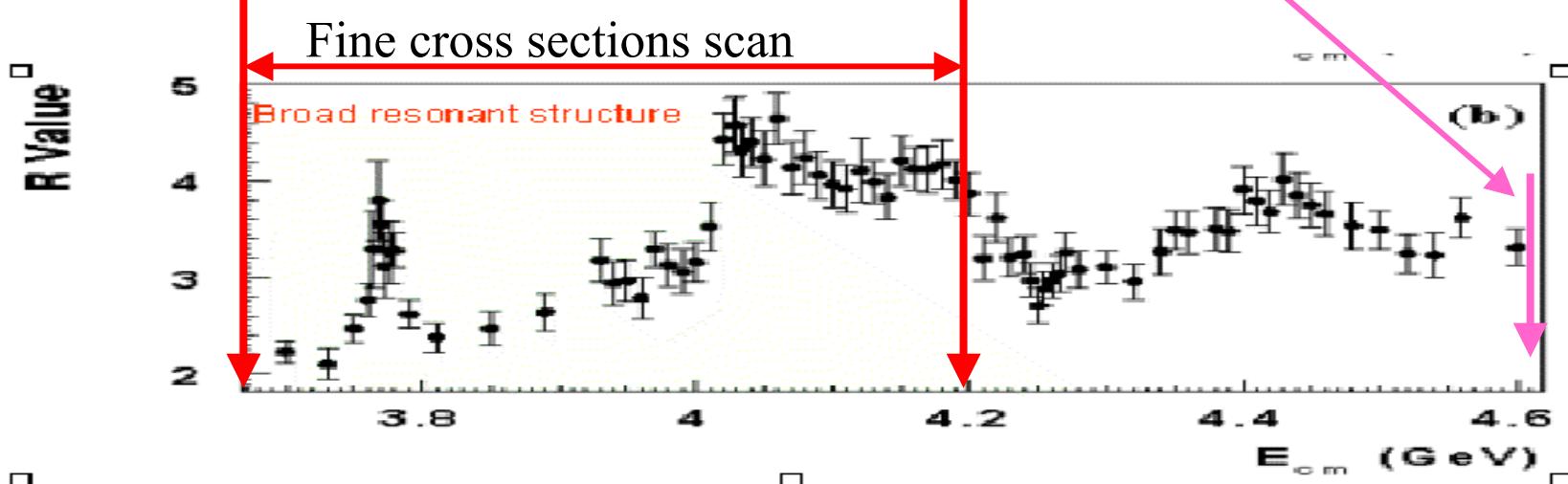
Search for new 1^- states

BES-III will collect data at 3.773 GeV, 4.03 GeV and 4.14 (4.17) GeV, and perform finer cross section scans covering the resonances.

“Finer resonance line-shape analysis” provide an opportunity to search for heavy hybrid, DD-bar molecular, and four-quark states.

Analysis of the fine cross section scan data may probe new structures associated with hybrid charmonium, DD-bar molecular or other exotic states in this energy region...

If BEPC-II maximum energy can extend more than 4.2 GeV, that will be nice.



Search for new 1^- states

Measurements of the line-shapes of the cross sections for the exclusive processes:

$$e^+ e^- \rightarrow D^0 \bar{D}^0, D^+ D^-, D_s^+ D_s^-$$

$$e^+ e^- \rightarrow \omega \eta_c, \dots$$

$$e^+ e^- \rightarrow J/\psi \pi^+ \pi^-, J/\psi \eta, J/\psi \eta', J/\psi X, \dots$$

$$e^+ e^- \rightarrow \varphi K^+ K^-, \varphi \pi^+ \pi^- \dots$$

$$e^+ e^- \rightarrow \chi_{cJ(J=0,1,2)} \rho, \chi_{cJ(J=0,1,2)} \omega \dots$$

and comparing the line-shapes with these for the inclusive hadron production, one may find something new.

BES-II made finer cross section scan from 3.66 to 3.88 GeV, and studied the line-shapes of the inclusive hadron production, DD-bar production and some exclusive charmless final states production. But data sample is too small. **We hope that BES-III make the finer cross section scan covering the resonances with large samples to carefully study the structures.**

Summary

BES-II/BEPC

发现 非- $D\bar{D}$ 衰变: $\psi(3770) \rightarrow J/\psi \pi^+ \pi^-$

发现在3.77 GeV 附近 非- $D\bar{D}$ 强子截面增强

首次测定 $Br[\psi(3770) \rightarrow \text{non-}D\bar{D}]$

测定 $e^+e^- \rightarrow LH$ 截面， 设定 $\psi(3770) \rightarrow LH$ 分支比上限。

精密的测定 R_{uds} , $\psi(3770)$ 和 $\psi(3686)$ 的共振参数， 等。

观测到 $e^+e^- \rightarrow \text{hadrons}$ 截面反常奇变。

BES-III/BEPC-III

- To uncover the puzzle of $\psi(3770)$ production & decays
- To search for new particles in the range from 3.7 to 4.8 GeV
- To study something more

The END

c quark proposed

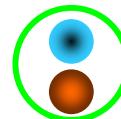
三夸克模型

1974年前，人们认识到强子是由两种或三种不同的夸克组成的。

Naive Quark model

- one up quark (charge +2/3) : u
- one down quark (charge -1/3) : d
- one strange quark (charge -1/3): s

Meson : ($q\bar{q}$)



Charged pion

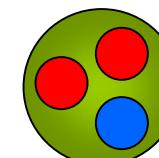
$\pi^+ (u\bar{d})$
 $\pi^- (\bar{u}d)$

Baryon: ($q q q$)



proton

p(uud)



neutron

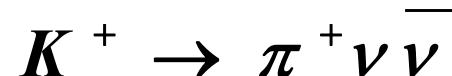
n(udd)

三夸克模型于1964年分别由盖尔曼 (Gell-Mann) 和兹韦格 (Zweig) 独立提出 [SU(3) 模型]。该模型理论成功的解释了当时已知的强子谱并成功地描述相互作用的一些特征。

c quark proposed

粲夸克“c”的引入

实验上观测不到奇异数改变($|\Delta S|=1$)的中性流过程，例如：



分支比的上限为：
$$\frac{\Gamma(K^+ \rightarrow \pi^+ \nu \bar{\nu})}{\Gamma(K^+ \rightarrow \pi^0 \mu^+ \nu_\mu)} \leq 10^{-5}$$

为了解释这个实验现象，1970年 **GIM (Glashow, Iliopoulos & Maiani)** 在理论上引入一个新夸克，即“c”夸克来解释实验上观测不到弱作用过程中奇异数改变的中性流过程。

根据夸克模型的理论，如果存在“c”夸克，就应当存在一系列由“c”和“ \bar{c} ”及“c”和其它夸克($\bar{u}, \bar{d}, \bar{s}$)组成的强子。