J/ψ 的两体非轻弱衰变

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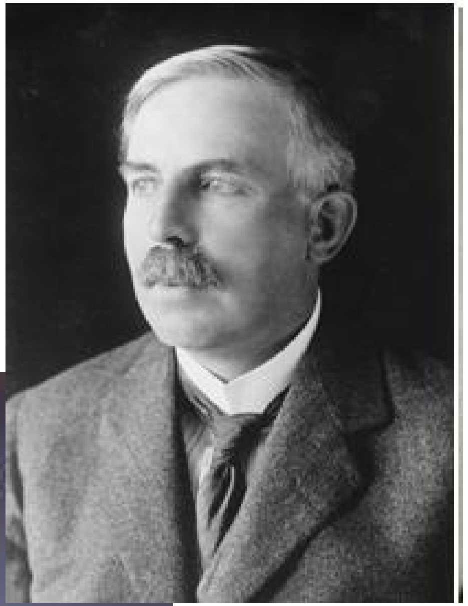
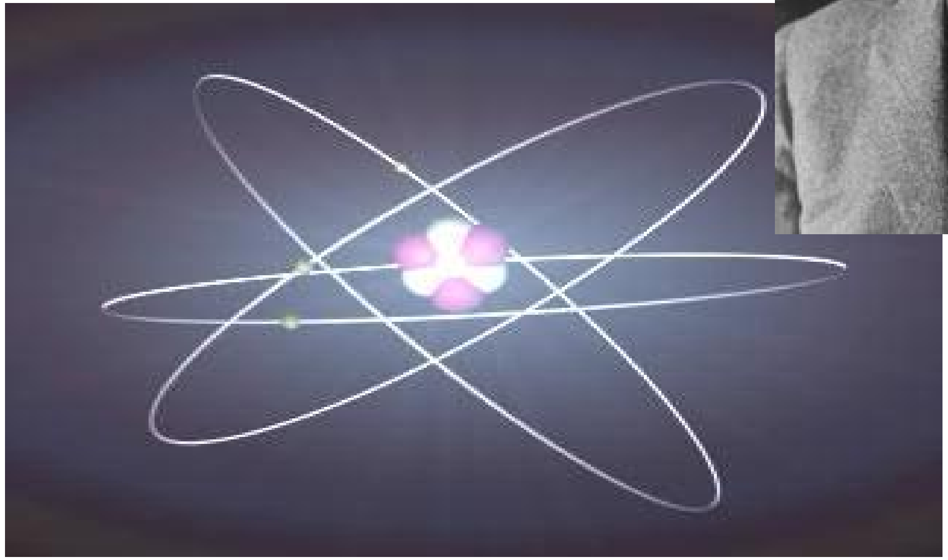
Outline

- *Motivation*
- $J/\psi \to PP$
- $J/\psi \to DM(M=P,V)$
- $\psi(4040),\psi(4160) \to D_{\mathrm{s}}^{\pm} D_{\mathrm{d}}^{\mp}$
- $\eta_{\mathrm{c}}(1S) \to PP$
- 小结

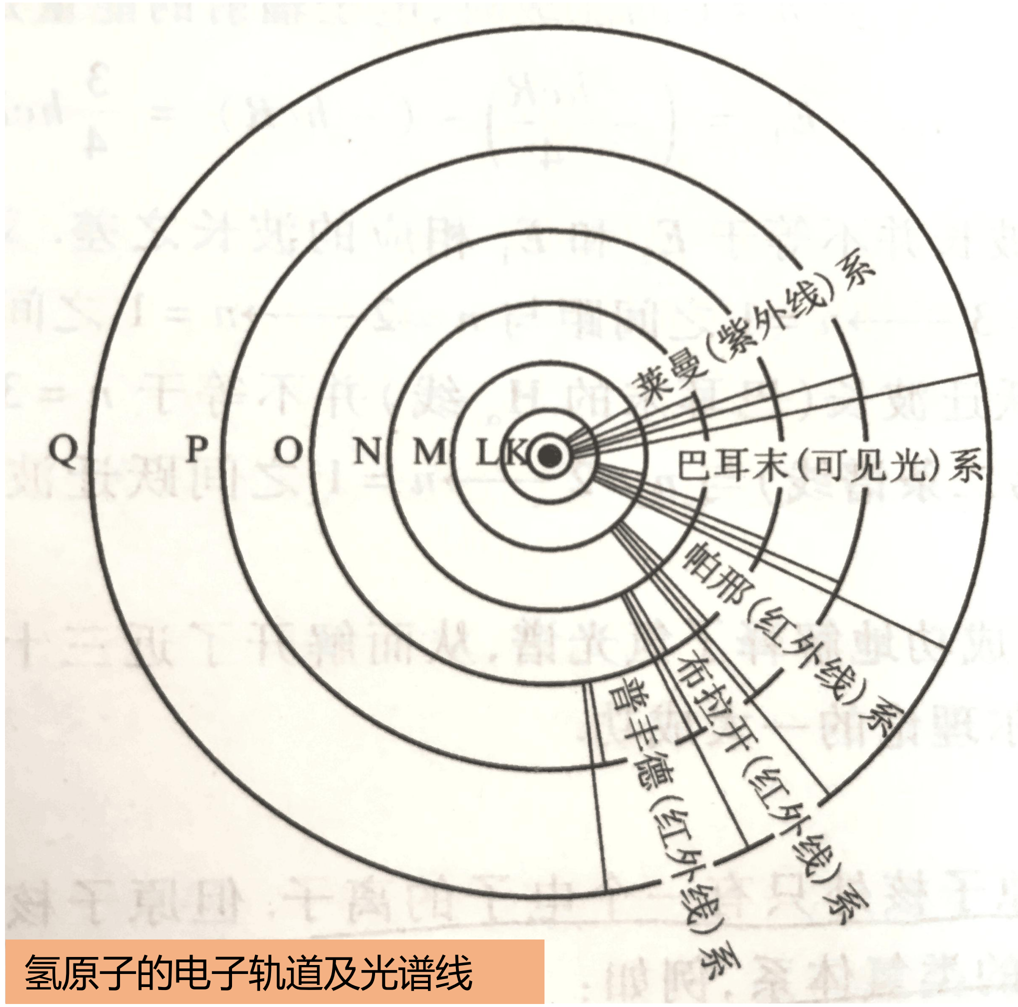
Motivation

卢瑟福





原子核式结构模型



氢原子的电子轨道及光谱线

Motivation

1. Large generation cross section

2. High yield

3. Small resonance background

4. There are definite initial energy and momentum.

Motivation

Experimental aspects

10 billion J\psi events collected [1]

Efficiency:1%

Process with measurable branching ratio of 10^{-8}

Theoretical aespcts

Branching ratio of J / psi weak decay

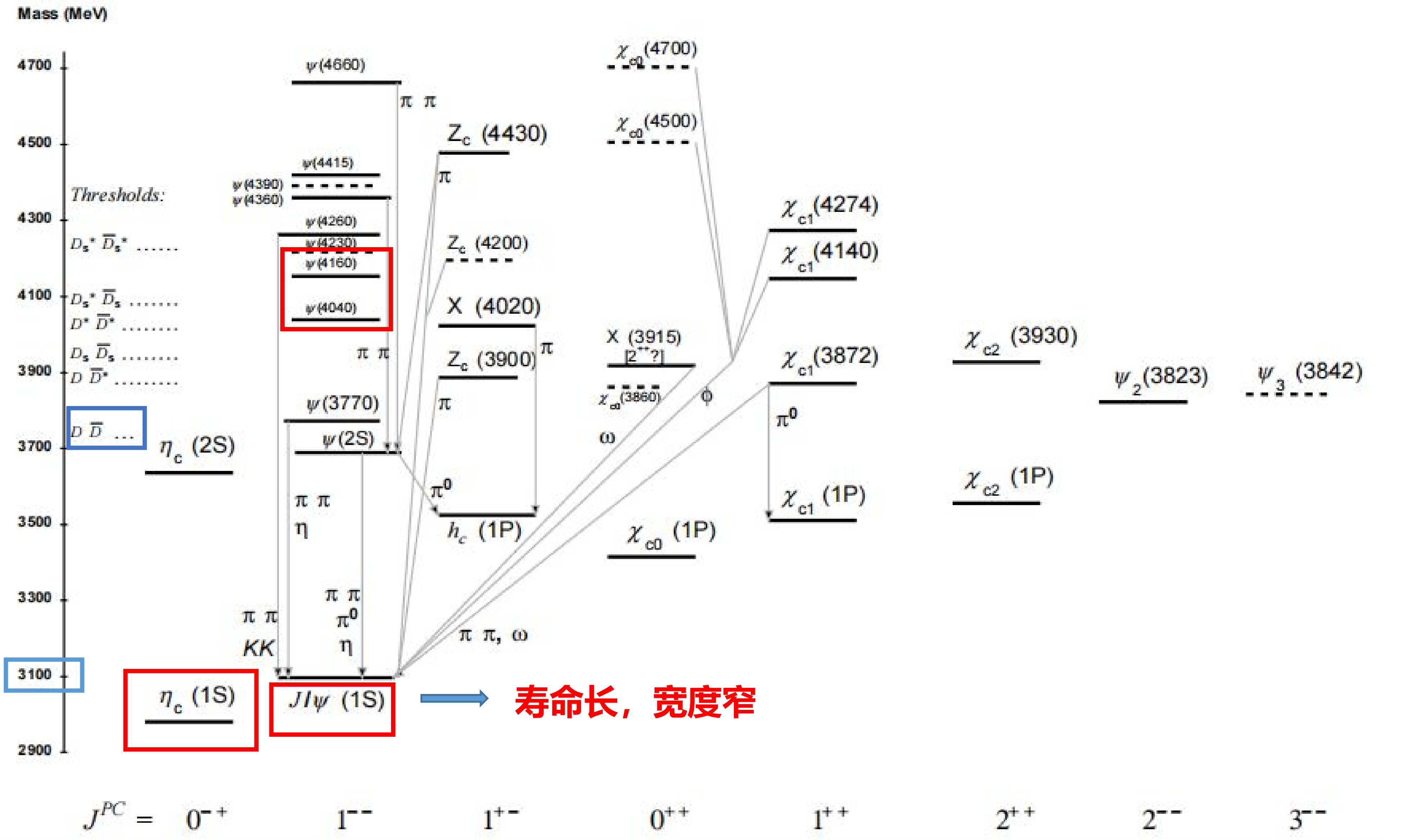
$2 / \tau_D \Gamma_\psi \sim 10^{-8}$

[1] http://english.ihep.cas.cn/bes/doc/2250.html.

Motivation

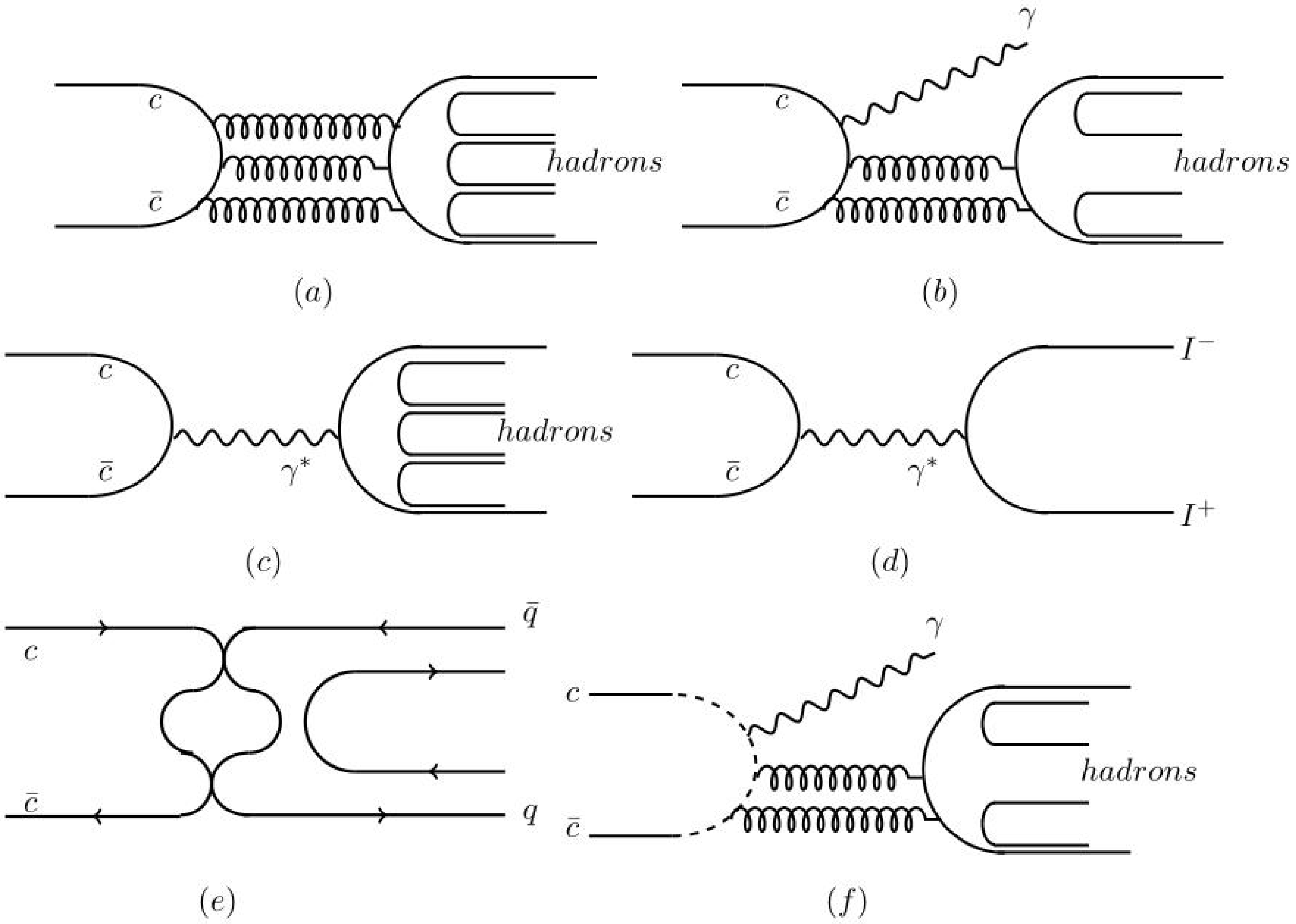
The decay of J/ψ particle is an ideal place to study new physics

Charmonium System



寿命长，宽度窄

J/ψ 衰变方式的最低阶费曼图



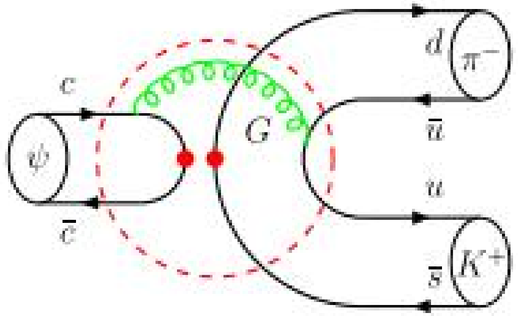
Mode ($J/\psi \to PV$)	Experiment(B. R)
$J/\psi \to \rho\pi$	$(1.6 \pm 0.15)\%$
$J/\psi \to \rho^0\pi^0$	$(5.6 \pm 0.7)\times 10^{-3}$
$J/\psi \to K^+K^*(892)^-$	$(6.0^{+0.8}_{-1.0})\times 10^{-3}$
$J/\psi \to K^0\overline{K}^*(892)^0$	$(4.2 \pm 0.4)\times 10^{-3}$
$J/\psi \to \omega\eta$	$(1.74 \pm 0.20)\times 10^{-3}$
$J/\psi \to \phi\eta$	$(7.4 \pm 0.8)\times 10^{-4}$
$J/\psi \to \omega\pi^0$	$(4.5 \pm 0.5)\times 10^{-4}$
$J/\psi \to \phi\eta'(958)$	$(4.6 \pm 0.5)\times 10^{-4}$
$J/\psi \to \eta\rho$	$(1.93 \pm 0.23)\times 10^{-4}$
$J/\psi \to \omega\eta'(958)$	$(1.89 \pm 0.18)\times 10^{-4}$
$J/\psi \to \rho\eta'(958)$	$(8.1 \pm 0.8)\times 10^{-5}$

Mode ($J/\psi \to PP$)	Experiment(B. R)
$J/\psi \to \pi^+\pi^-$	$(1.47 \pm 0.14)\times 10^{-4}$
$J/\psi \to K_s^0K_s^0$	$\prec 1.4\times 10^{-8}$

$J/\psi \to PP$

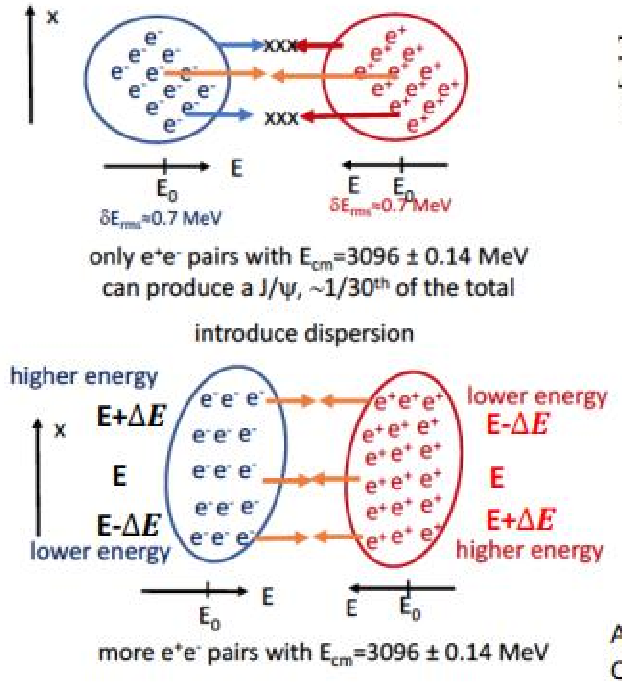
$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_{q_1,q_2} V_{cq_1} V_{cq_2}^* \{C_1(\mu) O_1(\mu) + C_2(\mu) O_2(\mu)\} + \text{h.c.}$$

$$\mathcal{A}(J/\psi \to PP) = \frac{G_F}{\sqrt{2}} \sum_{q_1,q_2} V_{cq_1} V_{cq_2}^* \sum_{i=1}^{2} C_i(\mu) \langle PP|O_i(\mu)|J/\psi\rangle$$



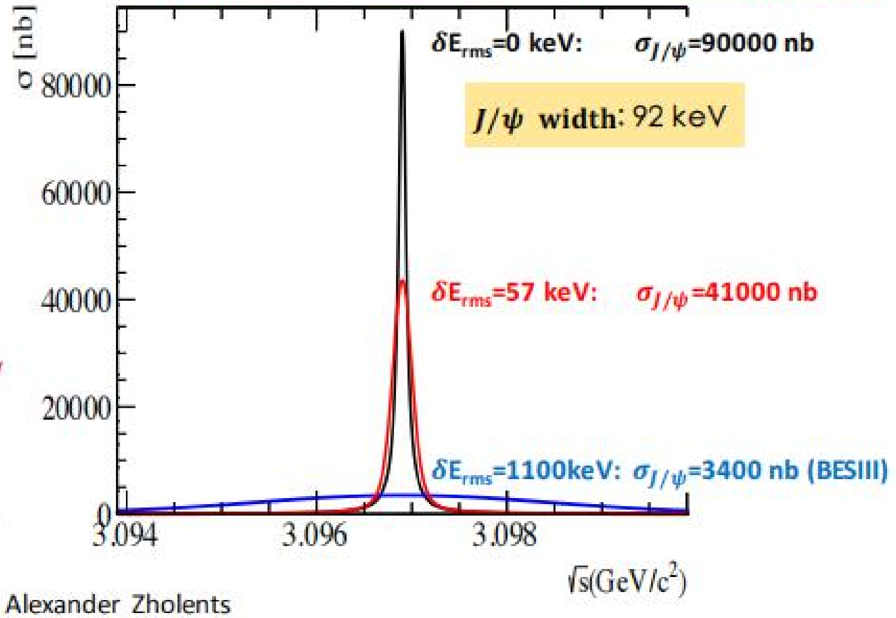
C parity violating decay modes			
mode	$\mathcal{B}r$	mode	$\mathcal{B}r$
$J/\psi \to \pi^0\eta$	$(2.32^{+0.81}_{-0.24})\times10^{-14}$	$J/\psi \to \eta\eta'$	$(3.01^{+0.78}_{-0.55})\times10^{-11}$
$J/\psi \to \pi^0\eta'$	$(1.45^{+0.50}_{-0.15})\times10^{-14}$		
the strangeness changing decay modes			
mode	$\mathcal{B}r$	mode	$\mathcal{B}r$
$J/\psi \to \pi^-K^+$	$(0.99^{+0.33}_{-0.15})\times10^{-12}$	$J/\psi \to K^0\eta$	$(0.84^{+0.25}_{-0.22})\times10^{-13}$
$J/\psi \to \pi^0K^0$	$(0.49^{+0.16}_{-0.08})\times10^{-12}$	$J/\psi \to K^0\eta'$	$(1.94^{+0.30}_{-0.25})\times10^{-12}$

Monochromatic collision: factor of 10 from reduction of e^+e^- CM spread



J/ψ production cross-section

Xiaoshuai Qin



Alexander Zholents
CERN SL/92-27/AP

Future J/ψ factory

BESIII collected 10 billion J/ψ

Current technology "Topup" ×2 +
"improved technology "monochromatic collision" ×10 +
Someday with new facility (J/ψ factory) ×100

10^{13} J/ψ per year at a super J/ψ factory

Long time ago…

- 1993, Dubna JINR (E_{cm}= 2 GeV, L=9.4×10^{32} cm^{-2} sec^{-1})
- 1994, Argonne National Laboratory (E_{cm}=3-5 GeV, L= 10^{33} cm^{-2} sec^{-1})
- 1995, BINP, round beams (E_{cm}= 2.0-4.2 GeV, L= 10^{33} cm^{-2} sec^{-1})
- 1996, Spain & France (E_{cm}= 4 GeV, L= 10^{33} cm^{-2} sec^{-1})
- 1997, Beijing IHEP (E_{cm}= 2.0-4.2 GeV, L= 10^{33} cm^{-2} sec^{-1})

A project of
SUPER CHARM-TAU FACTORY
in Novosibirsk

E. Levichev

21-25 May, CHARM2018, BINP, Novosibirsk,

First Novosibirsk project

- E = 700 – 2500 MeV
- Round beams L = 10^{34} cm^{-2}s^{-1}
- Monochromatization L ~ 10^{32} cm^{-2}s^{-1}
- Long. Polarization L ~ 10^{34} cm^{-2}s^{-1}
- Transverse polarizatio for precise energy calibration

More than $10^{13} J/\psi$ events can be collected in the future.

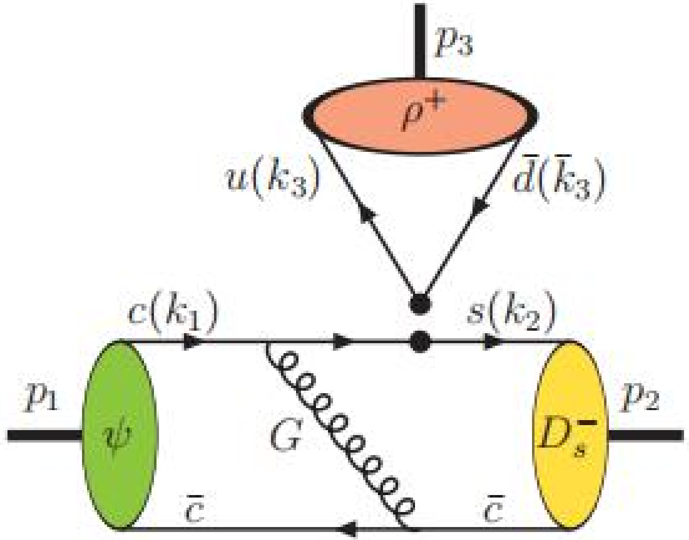
↓

A process of order of magnitude at 10^{-11} can be observed

↓

The large deviation between experimental and theoretical values may hide the direction of new physics.

$J/\psi \to DM(M=P,V)$



Mode	Theory(B. R)	Experiment(B. R)
$J/\psi \to D_s\pi$	4.3×10^{-10}	$\prec 1.3\times10^{-4}$
$J/\psi \to D_sK$	2.69×10^{-11}	---
$J/\psi \to D_d\pi$	2.09×10^{-11}	---
$J/\psi \to D_dK$	1.34×10^{-12}	---
$J/\psi \to D_s\rho$	3.33×10^{-9}	$\prec 1.3\times10^{-5}$
$J/\psi \to D_sK^*$	1.86×10^{-10}	---
$J/\psi \to D_d\rho$	1.32×10^{-10}	---
$J/\psi \to D_dK^*$	0.8×10^{-11}	---

Charmonium System

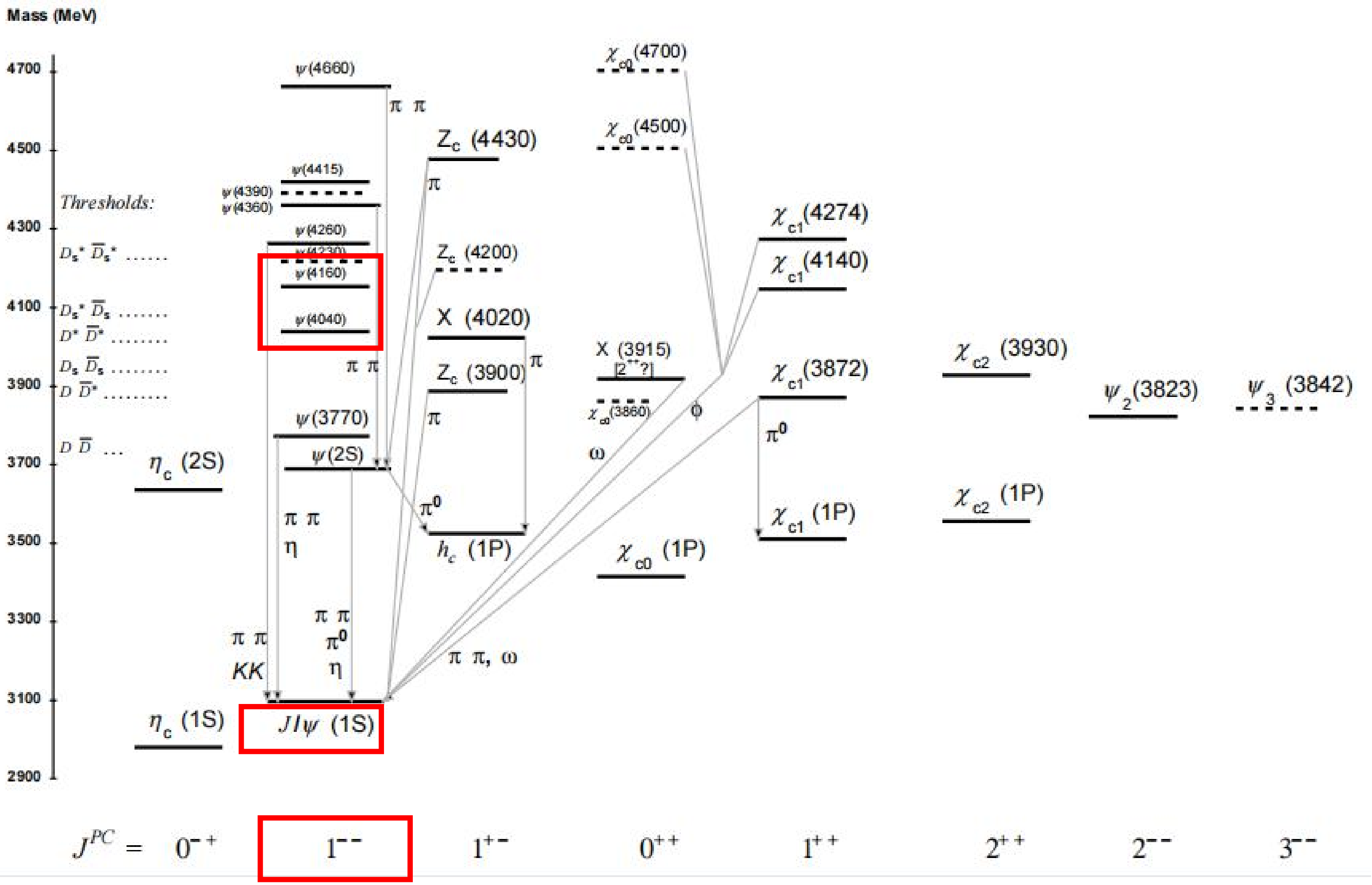


Table 1 The properties of charmonium with the quantum numbers of $I^G J^{PC} = 0^- 1^{--}$, where Γ denotes the full decay width, $\mathcal{B}r_{ee}$ and Γ_{ee} denote the branching ratio and partial electromagnetic width for the pure leptonic $\psi \to e^+e^-$ decay [1]

Meson	$I^G J^{PC}$	Mass (MeV)	Γ (keV)	$\mathcal{B}r_{ee}$	Γ_{ee} (keV)
1^3S_1 $J/\psi(1S)$	0^-1^{--}	3096.900 ± 0.006	92.9 ± 2.8	$(5.971 \pm 0.032)\%$	5.55 ± 0.14
2^3S_1 $\psi(2S)$	0^-1^{--}	3686.097 ± 0.025	296 ± 8	$(7.89 \pm 0.17) \times 10^{-3}$	2.34 ± 0.04
1^3D_1 $\psi(3770)$	0^-1^{--}	3773.13 ± 0.35	$(27.2 \pm 1.0) \times 10^3$	$(9.6 \pm 0.7) \times 10^{-6}$	0.262 ± 0.018
3^3S_1 $\psi(4040)$	0^-1^{--}	4039 ± 1	$(80 \pm 10) \times 10^3$	$(1.07 \pm 0.16) \times 10^{-5}$	0.86 ± 0.07
2^3D_1 $\psi(4160)$	0^-1^{--}	4191 ± 5	$(70 \pm 10) \times 10^3$	$(6.9 \pm 3.3) \times 10^{-6}$	0.48 ± 0.22
3^3D_1 $\psi(4415)$	0^-1^{--}	4421 ± 4	$(62 \pm 20) \times 10^3$	$(9.4 \pm 3.2) \times 10^{-6}$	0.58 ± 0.07

1. Patrignani, C. et al.: Particle data group. Chin. Phys. C **40**, 100001 (2016)

$\psi(4040), \psi(4160) \to D_s^{\pm} D_d^{\mp}$

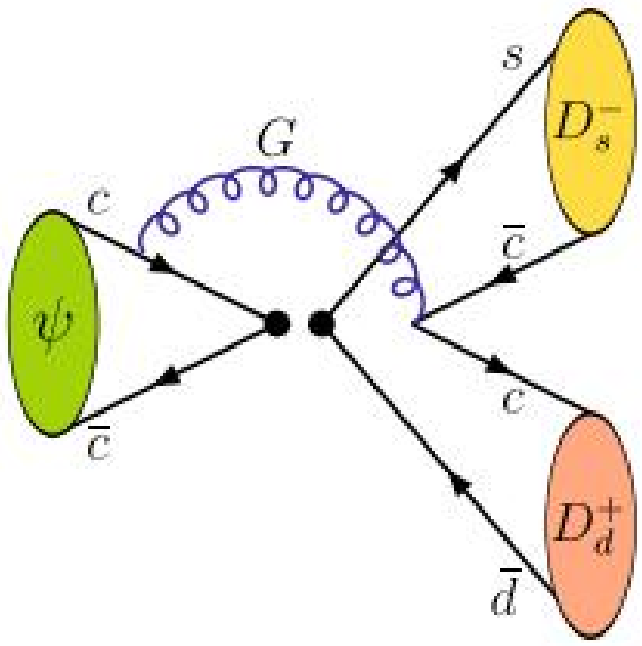
由正反费米子构成的复合粒子系统J^{PC}量子数的可能取值

L	S = 0	S = 1
0	0^{-+}	$\boxed{1^{--}}$
1	1^{+-}	$0^{++}, 1^{++}, 2^{++}$
2	2^{-+}	$\boxed{1^{--}}, 2^{--}, 3^{--}$
3	3^{+-}	$2^{++}, 3^{++}, 4^{++}$

$\psi(4040), \psi(4160) \to D_s^{\pm} D_d^{\mp}$

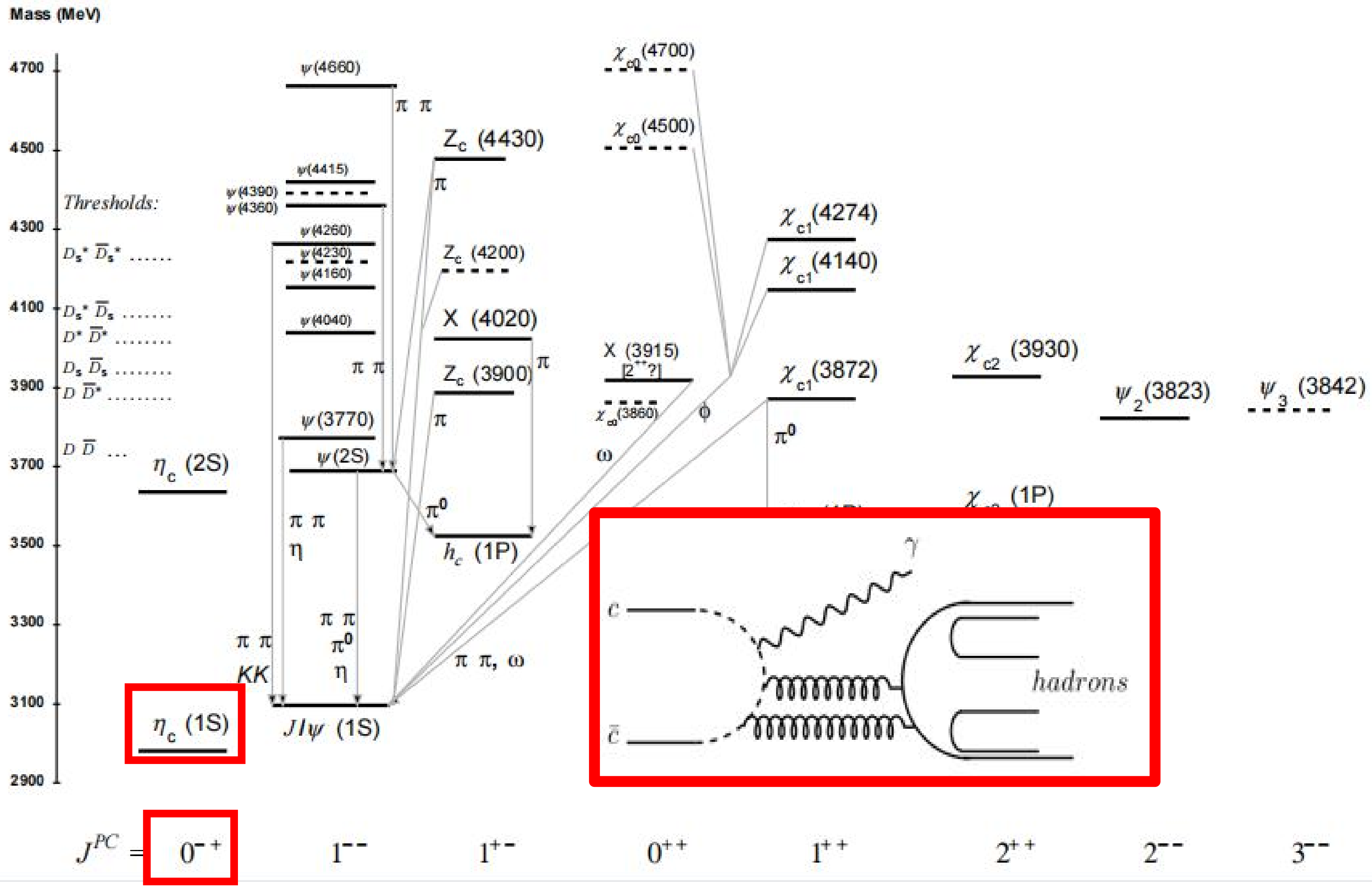
Branching ratio for the $\psi(4040)$, $\psi(4160) \to D_d^{\pm} D_s^{\mp}$ decays with different mixing angle θ of the $3S$ and $2D$ states, where theoretical uncertainties come from scale $(1\pm0.1)t_i$, mass m_c, decay constant f_ψ,

1



θ	$\mathcal{B}r\,(\psi(4040)\to D_d^{\pm} D_s^{\mp}) \times 10^{-17}$	$\mathcal{B}r\,(\psi(4160)\to D_d^{\pm} D_s^{\mp}) \times 10^{-17}$
$-30°$	$2.94^{+0.11+0.03+0.22}_{-0.09-0.02-0.21}$	$2.50^{+0.10+0.02+1.55}_{-0.08-0.00-1.18}$
$-20°$	$2.92^{+0.11+0.03+0.23}_{-0.09-0.02-0.22}$	$2.59^{+0.10+0.04+1.59}_{-0.09-0.02-1.21}$
$-10°$	$2.93^{+0.11+0.03+0.24}_{-0.09-0.02-0.23}$	$2.68^{+0.11+0.05+1.63}_{-0.09-0.03-1.24}$
$0°$	$2.97^{+0.11+0.03+0.25}_{-0.09-0.01-0.24}$	$2.77^{+0.11+0.07+1.66}_{-0.09-0.04-1.27}$
$10°$	$3.03^{+0.12+0.03+0.27}_{-0.10-0.00-0.26}$	$2.83^{+0.12+0.08+1.68}_{-0.10-0.05-1.29}$
$20°$	$3.11^{+0.12+0.04+0.29}_{-0.10-0.01-0.27}$	$2.87^{+0.12+0.08+1.68}_{-0.10-0.06-1.29}$
$30°$	$3.20^{+0.13+0.05+0.30}_{-0.11-0.03-0.29}$	$2.88^{+0.12+0.08+1.67}_{-0.10-0.06-1.29}$

Charmonium System



$(J/\psi \to \gamma\,\eta_c) = (1.7 \pm 0.4)\%$

There are expected to be 10^{11} η_c events.

Experimental value of $\eta_c \to P\,P$

$\pi^+\pi^-$	$< 1.1 \times 10^{-4}$
$\pi^0\pi^0$	$< 4 \times 10^{-5}$
K^+K^-	$< 6 \times 10^{-4}$
$K^0_S\,K^0_S$	$< 3.1 \times 10^{-4}$

Branching ratios for the $\eta_c \to P P'$ decays, where the uncertainties come from m_c, μ_P and a_2^P, respectively

modes	branching ratio	modes	branching ratio
$\eta_c \to K^+ K^-$	$\left(1.47^{+0.14+0.63+0.22}_{-0.13-0.48-0.19}\right) \times 10^{-15}$	$\eta_c \to \overline{K}^0 \eta$	$\left(4.36^{+0.12+1.07+14.18}_{-0.12-0.95-\ 1.60}\right) \times 10^{-17}$
$\eta_c \to K^0 \overline{K}^0$	$\left(1.55^{+0.15+0.67+0.22}_{-0.13-0.51-0.20}\right) \times 10^{-15}$	$\eta_c \to \overline{K}^0 \eta'$	$\left(1.84^{+0.08+0.57+1.89}_{-0.08-0.46-1.24}\right) \times 10^{-16}$
$\eta_c \to \pi^+ K^-$	$\left(5.15^{+0.41+1.61+17.00}_{-0.38-1.22-\ 4.32}\right) \times 10^{-17}$	$\eta_c \to \pi^0 \eta$	$\left(9.18^{+0.85+4.15+1.35}_{-0.77-3.07-1.18}\right) \times 10^{-19}$
$\eta_c \to \pi^0 \overline{K}^0$	$\left(2.65^{+0.21+0.81+8.55}_{-0.19-0.62-2.22}\right) \times 10^{-17}$	$\eta_c \to \pi^0 \eta'$	$\left(5.71^{+0.53+2.58+0.84}_{-0.48-1.91-0.73}\right) \times 10^{-19}$
$\eta_c \to \pi^+ \pi^-$	$\left(1.38^{+0.13+0.62+0.20}_{-0.12-0.46-0.18}\right) \times 10^{-18}$	$\eta_c \to \eta\eta$	$\left(5.08^{+0.47+2.18+1.02}_{-0.42-1.54-0.92}\right) \times 10^{-16}$
$\eta_c \to \pi^0 \pi^0$	$\left(6.91^{+0.64+3.12+1.02}_{-0.58-2.32-0.89}\right) \times 10^{-19}$	$\eta_c \to \eta\eta'$	$\left(1.30^{+0.12+0.55+0.26}_{-0.11-0.39-0.24}\right) \times 10^{-15}$
		$\eta_c \to \eta'\eta'$	$\left(9.12^{+0.84+3.89+1.84}_{-0.76-2.75-1.66}\right) \times 10^{-16}$

Thank you for your attentions!