

## Probing for New Physics in $J/\psi$ Decays

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**Abstract** Beijing Spectrometer (BES) at Beijing Electron Positron Collider (BEPC), IHEP has accumulated  $2.5 \times 10^7$   $J/\psi$  events and plans to increase this number to  $10^8$ — $10^9$  in the near future. In this paper I review and summarize the recent studies on the possibilities of probing for new physics at BES. This includes the theoretical works on and experimental attempt performed at BES in searching for flavor changing neutral current, CP violation and lepton flavor violation in the processes of  $J/\psi$  decays.

**Key words** new physics at BES,  $J/\psi$  decays, CP violation

### 1 Lepton Flavor Violating $J/\psi$ Decays

The  $J/\psi$  rare decay processes  $J/\psi \rightarrow \bar{l}l'$  ( $l, l' = \tau, \mu, e$ ) conserve total lepton number, but violate the individual lepton numbers. In the standard model the lepton flavor symmetries are conserved, but speculated to be violated in many extensions of the standard model, such as supersymmetric standard models, left-right symmetric models and models where electroweak symmetry is broken dynamically. Recent Super-Kamiokande experimental results indicate that neutrinos have non-vanishing masses, mix with each others and consequently that lepton flavor symmetry and/or lepton number symmetry are broken symmetries. In cosmology mystery of matter and antimatter asymmetry might be understood in terms of the breakdown of the lepton number symmetry together with the non-perturbative effects (Sphaleron) of the standard electroweak theory.

There has been a lot of studies both theoretically and experimentally on testing the lepton flavor conservation law. At present we have various bounds listed in the particle data book from  $\mu$  decays,  $\tau$  and  $Z$  gauge boson decays<sup>[1]</sup>. With a large sample of  $J/\psi$ , BES will be able to make an additional experimental searching for lepton flavor violation.

To estimate the branching ratio of lepton flavor violating  $J/\psi$  decays allowed by the current experimental data, Peccei, Wang and I<sup>[1]</sup> took a model-independent approach to new physics and introduced a four-fermion contact interaction

$$\frac{4\pi}{\Lambda^2} \bar{c} \gamma^\mu c \bar{l} \gamma_\mu l', \quad (1)$$

where  $\Lambda$  is the new physical cutoff. This effective operator is forbidden in the standard model, how-

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1) Probing for lepton flavor violation in decays of charmonium and bottomonium systems. Peccei R D, WANG Jian-Xiong, ZHANG Xin-Min. 1998, May, Note unpublished; ZHANG Xin-Min. Invited talked given at the national conference on high energy physics, Chengde, China, 1998, April

ever will be generated in theories where lepton flavor is not conserved, such as the minimal supersymmetric standard model with and / or without  $R$ -parity, models with large extra dimension<sup>[2]</sup>. Therefore, any observed signal is a direct evidence for non-standard physics and will improve our understanding of flavor dynamics, especially in the lepton sector.

There is no direct experimental limit on  $\Lambda$  in Eq. (1). However, at one-loop, attaching the neutral gauge boson  $Z$  to the charm quark loop generates an effective coupling of  $Z$  to  $\bar{l}l'$ . From the limits given in the particle data book on  $Br(Z \rightarrow \bar{l}l')$ <sup>[1]</sup>, we obtained the lower bounds on the branching ratio of the  $J/\psi$  decay into leptons:

$$Br(J/\psi \rightarrow \tau^+ e^-) < 2.7 \times 10^{-5}; \quad (2)$$

$$Br(J/\psi \rightarrow \tau^+ \mu^-) < 4.9 \times 10^{-5}; \quad (3)$$

$$Br(J/\psi \rightarrow \mu^+ e^-) < 8.3 \times 10^{-6}. \quad (4)$$

Recently Nussinov, Peccei and I<sup>[3]</sup> have examined "unitarity inspired" relations between two- and three-body lepton flavor violating decays and found that the existing strong bounds on  $\mu \rightarrow 3e$  and  $\mu \rightarrow e\gamma\gamma$  severely constrain two-body lepton flavor violating decays of vector bosons [ $J/\psi$ ,  $\Upsilon$ , and  $Z^0$ ] or pseudoscalars [ $\pi^0$ ,  $\eta$ ] into  $\mu^+ e^-$  final states. However the bounds derived in Ref. [3] can be avoided if there is a kinematical suppression or as a result of some cancellations. Searching for lepton flavor violating decays of vector bosons such as  $J/\psi$  remains a worthwhile experimental challenge.

BES started one year ago<sup>1)</sup> and has been working on an experiment of searching for  $J/\psi \rightarrow e^+ \mu^\pm$ . They will publish their result officially in the near future.

## 2 Single D Meson Production in $J/\psi$ Decays

Kinematically  $J/\psi$  can not decay into D meson pairs, however it is able to decay into single D meson. In the standard model, these Cabbibo suppressed and /or favored weak decays have a typical branching ratio  $\sim 10^{-8}$  or smaller, which is unobservable and because of which these processes serve as a probe of new physics. Recently Datta, O'Donnell, Pakvasa and I<sup>[4]</sup> have studied the possibility of searching for new flavor changing neutral current in the decay of  $J/\psi$ . The purpose of the study is to answer whether new physics can enhance sufficiently for the processes to be observable in the near future experiments. We first perform a model independent analysis, then examine the predictions of the models, such as Top Color models, minimal supersymmetric standard model with  $R$ -parity violation and the two Higgs doublet model. We found that the branching ratio of  $J/\psi \rightarrow D/\bar{D}X_u$  could be as large as  $10^{-5}$ <sup>[4]</sup>.

Experimentally with BES-I data  $\sim 8 \times 10^6 J/\psi$ , BES found no signal of single D production in  $J/\psi$  decays, and put limits on decay rates<sup>2)</sup> (at 90% C. L.):  $Br(J/\psi \rightarrow \bar{D}^0 \rho^0) \leq 1.25 \times 10^{-5}$ ;  $Br(J/\psi \rightarrow D_s^+ K^-) \leq 2.8 \times 10^{-5}$ , and  $Br(J/\psi \rightarrow D/\bar{D}X_u) \leq 1.7 \times 10^{-4}$ . These are preliminary results.

Next year BES will have collected  $\sim 5 \times 10^7 J/\psi$ . The upper limit on  $Br(J/\psi \rightarrow D/\bar{D}X_u)$  is expected to be reduced to  $\sim 3 \times 10^{-5}$ , which is very close to the theoretical prediction. If there is still no signal found, it will put some constraints on models beyond the standard electroweak theory<sup>[4]</sup>.

## 3 CP Violation in $J/\psi$ Decays

The origin of CP violation remains one of the outstanding problems in particle physics and cosmology. To pin down the sources and nature of CP violation in or beyond the Cabbibo-Kabayashi-Maskawa model, it would be necessary to consider different observations of CP violation in different

1) TONG G J et al. Private communication

2) RONG G et al. in preparation

channels from the K system, B system, etc. The reaction of interest at BES is<sup>1)</sup>

$$e^+(p) + e^-(p) \rightarrow J/\psi \rightarrow A(q_-) + \bar{B}(q_+) + X, \quad (5)$$

where A ( $\bar{B}$ ) are charged particles, for instance  $\pi^\pm$  in the processes of three or five pions decay of the  $J/\psi$ , and  $p, q_-$  and  $q_+$  are corresponding momentum in the laboratory frame. Define CP/T-odd operator

$$O_1 = \frac{\mathbf{p} \cdot \mathbf{q}_+ \times \mathbf{q}_-}{|\mathbf{p} \cdot \mathbf{q}_+ \times \mathbf{q}_-|}. \quad (6)$$

If there exists CP violating interaction in  $J/\psi$  decays, one would expect a non-vanishing expectation value of operator  $O_1$ . Theoretically there could be many sources responsible for the CP violation in the process. One of them is the Chromo-dipole moment of the charm quark  $ig_c \frac{d_g}{2} c \sigma_\mu \gamma_5 \lambda^a c G_a^{\mu\nu}$  where  $d_g$  has [mass]<sup>-1</sup> dimension and the  $g_c$  the strong interaction coupling constant.

Consider the process of three pion decay of the  $J/\psi$ . Its branching ratio is around 1.5%. With  $10^8 - 10^9$   $J/\psi$  at BEPC II there will be around  $10^6 - 10^7$  available for the analysis of CP violation. To estimate the experimental sensitivities to  $d_g$ , let us consider only the statistical uncertainties. Neglecting the systematical uncertainties one expects to be able at BES to probe for  $d_g$  as small as  $(1/\sqrt{10^6 - 10^7}) \times (1/m_c) \leq 10^{-17}$  cm.

One can easily construct different kind of CP/T-odd operators of three momentum products ( $p, q_-, q_+$ ) for the analysis of CP violation in  $J/\psi$  decays. For instance,

$$O_2^i \sim (\mathbf{q}_+ - \mathbf{q}_-)^i \cdot (\mathbf{q}_+ \times \mathbf{q}_-)^j + (i \leftrightarrow j). \quad (7)$$

The initial electron and/or positron beams are not polarized at BEPC, otherwise one would be able to construct observables with the initial polarization vector  $\sigma$

$$O_3 \sim \sigma \cdot \mathbf{q}_- \times \mathbf{q}_+. \quad (8)$$

There has been proposal to measure CP violation in  $e^+e^- \rightarrow J/\psi \rightarrow \Lambda \bar{\Lambda}$ . With a large sample of  $J/\psi$ , one expects to probe for and put a strong bound on the electric dipole moment of  $\Lambda$ <sup>[5]</sup>.

#### 4 Conclusion and Comments

In this paper I have concentrated on three kind of processes to probe for new physics in the decay of  $J/\psi$ . There are some other rare decay modes which are interesting, but not reviewed. For instance, with a large sample of  $J/\psi$ , it is possible and physically interesting to search for Goldstone or Pseudo-Goldstone J, such as Axion in the process

$$J/\psi \rightarrow \gamma + J. \quad (9)$$

Another example is the invisible decay of  $J/\psi$  investigated by Chang, Lebedev and Ng<sup>[6]</sup> recently in models with extra Z-bosons, minimal supersymmetric standard model with R-parity violation and decays into Goldstinos. The third example is provided by Bijnens and Maul<sup>[7]</sup>, who recently have calculated in detail the branching ratio of  $J/\psi$  decay into photon + missing energy in the popular theory these days with large extra dimension. They found that the branching ratio could be as large as  $10^{-5}$ , which is measurable at BES. Before conclusion, we point out that even though we focus our discussions here on  $J/\psi$  decays, it is quite easy to apply the studies in this paper for  $\psi'$  and  $\Upsilon$  system<sup>2)</sup>

*I am grateful to my collaborators and colleagues for discussions.*

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2) It has been proposed to probe for CP violation in the process  $\psi' \rightarrow J/\psi + \pi^+ + \pi^-$ . ZHANG Xin-Min, DU Dong-Sheng, WANG Ping et al. 1998, May note, unpublished; The experimental analysis started already. LI Jin, GUO Zhi-Jin private communication

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在  $J/\psi$  衰变中寻找新物理

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**摘要** 北京谱仪(BES)已收集了  $2.5 \times 10^7$  个  $J/\psi$  事例,并计划增加到  $10^8$ — $10^9$  个。本文综述近年来在 BES 上寻找新物理的研究,包括在  $J/\psi$  衰变过程中探测新的味改变中性流,CP 破坏和轻子味破坏。

**关键词** BES 新物理  $J/\psi$  衰变 CP 破坏

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