Search for the semi-muonic weak decay

$J/\psi \to D^- \mu^+ \upsilon_\mu + c.c.$

Zhi-Jun Li

on behalf of the BESIII collaboration

1 INTRODUCTION

➢ BESIII and BEPCII

—The BESIII detector at the symmetric e^+e^- collider BEPCII is a large solid-angle magnetic spectrometer running in τ-charm energy region with a geometrical acceptance of 93% of 4π solid angle.

—BESIII consists of 4 sub-detectors:

- Main drift chamber (MDC)
- Time-of-Flight system (TOF)
- Electromagnetic Calorimeter (EMC)
- Muon chamber system (MUC)

—$N_{J/\psi} = (10087 \pm 44) \times 10^6$ at $\sqrt{s} = 3.097$ GeV

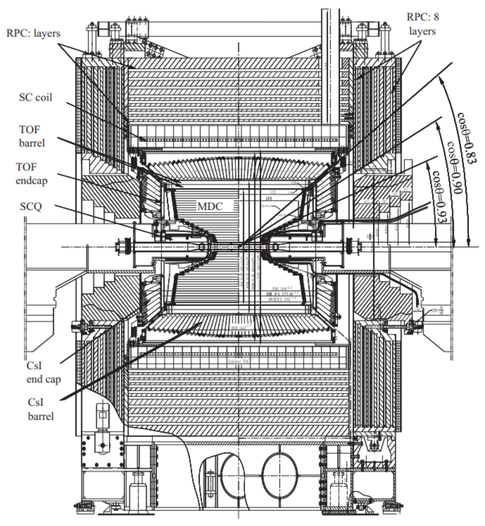


Fig.1 **BE**ijing **S**pectrometers **III**

➢ Motivation

—J/ψ meson can decay into a single charmed meson accompanied by light hadrons or leptons via weak decay. The inclusive branching fraction (BF) of J/ψ weak decays to a single charmed meson was predicted to be at the order of 10^{-8} or below in the Standard Model (SM). So far, weak decays of the J/ψ meson have not yet been observed.

—Some new physics models can enhance the BF of J/ψ weak decay to 10^{-5}. e.g. Top-color model, two-Higgs doublet model.

—Muon channel of J/ψ weak decay have no been reported.

—Searching semi-muonic decay of J/ψ not only tests the SM prediction but also probes new physics theories beyond the SM.

2 EVENT SELECTION

➢ Tracking and PID

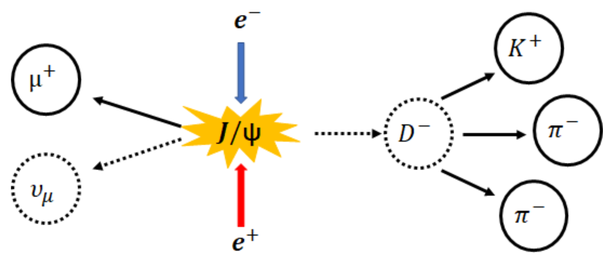


Fig.2 Event reconstruction of $J/\psi \to D^- \mu^+ \upsilon_\mu$

—$D^- \to K^+\pi^-\pi^-$ mode is used to reconstruct the D meson

—$K^\pm\pi^\mp\pi^\mp\mu^\pm$ will be detected and identified

—Neutrino is missing

➢ Further selections

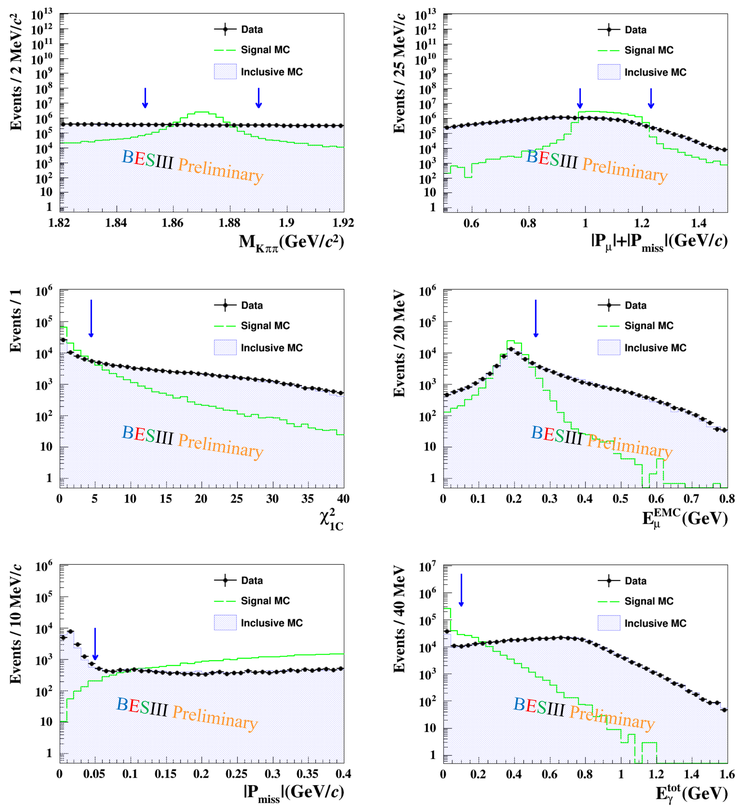


Fig.3 Further selections of $J/\psi \to D^- \mu^+ \upsilon_\mu$

— $M_{K\pi\pi}$: The invariant mass of $K\pi\pi$, should be in [1.85, 1.89] GeV/c²

— $|P_{\rm miss}|$: Missing momentum, > 0.05 GeV/c for neutrino candidates

— χ^2_{1C}: 1C kinematic fit for $K^+\pi^-\pi^-$ to D mass, > 4.4 for D candidates

— $E_\mu^{\rm EMC}$: The deposited energy of μ in EMC, < 0.26 GeV for μ candidates

— $E_\gamma^{\rm tot}$: The energy of photons, <0.1 GeV to suppress the photon background

—Punzi model is performed to optimize the selections

FOM $= S/\sqrt{3/2 + B}$, where $S(B)$ is the number of signals(background).

3.1 BACKGROUND SUPPRESSIONS I

—$J/\psi \to K^+\pi^-\pi^+\pi^-\pi_0$, $J/\psi \to K^+\pi^-\pi^+\pi^-$ background

- have the process $K_S \to \pi^+\pi^-$
- $M_{\pi\pi} = \sqrt{(\sum_{\pi,\pi} E_i)^2 - |\sum_{\pi,\pi} \vec{P}_i|^2}$, where $E_\pi = \sqrt{M_\pi^2 + P_\pi^2}$

—$J/\psi \to K^+K^-\pi^+\pi^-$ background

- have the process $K^+ \to \mu^+\nu_\mu$ or $K^+ \to \pi^0\mu^+\nu_\mu$
- Bad kaon : the kaon which has decay
  Good particle : the particle which does not decay
- $M_{2K2\pi} = \sqrt{|\sum E_{K,\pi,\pi}^{\rm Good} + E_K^{\rm Bad}|^2 - |(\sum \vec{P}_{K,\pi,\pi}^{\rm Good}) + \vec{P}_K^{\rm Bad}|^2}$

where $\vec{P}_K^{\rm Bad}$ is from recoiling, and $E_K^{\rm Bad} = \sqrt{M_K{}^2 + \vec{P}_K^{\rm Bad\,2}}$

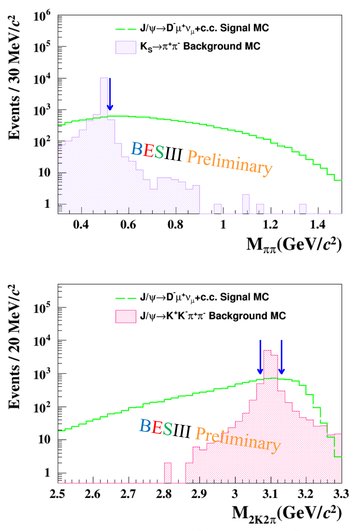


Fig.4 Veto cuts for K_S and $KK\pi\pi$ background

3.2 BACKGROUND SUPPRESSIONS II

—$J/\psi \to \pi^+\pi^-\pi^+\pi^-\pi^0$ background

- $M_{4\pi\pi^0} = \sqrt{|(\sum E_\pi) + E_{\pi^0}|^2 - |(\sum \vec{P}_\pi) + \vec{P}_{\pi^0}|^2}$

where $\vec{P}_{\pi^0}$ is from recoiling, and $E_{\pi^0} = \sqrt{M_{\pi^0}^2 + \vec{P}_{\pi^0}^2}$

—$J/\psi \to K^+\pi^-\pi^+\pi^-K_L$ background

- $M_{K3\pi K^0} = \sqrt{|(\sum E_{K3\pi}) + E_{K^0}|^2 - |(\sum \vec{P}_{K3\pi}) + \vec{P}_{K^0}|^2}$

where $\vec{P}_{K^0}$ is from recoiling, and $E_{K^0} = \sqrt{M_{K_L}^2 + \vec{P}_{K^0}^2}$

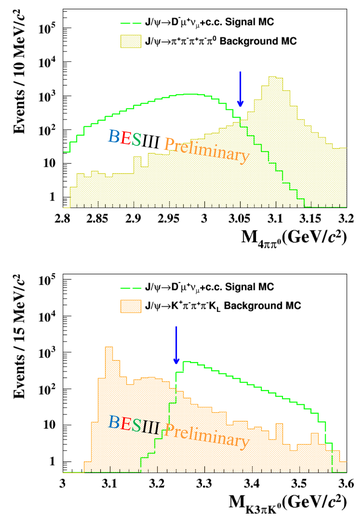
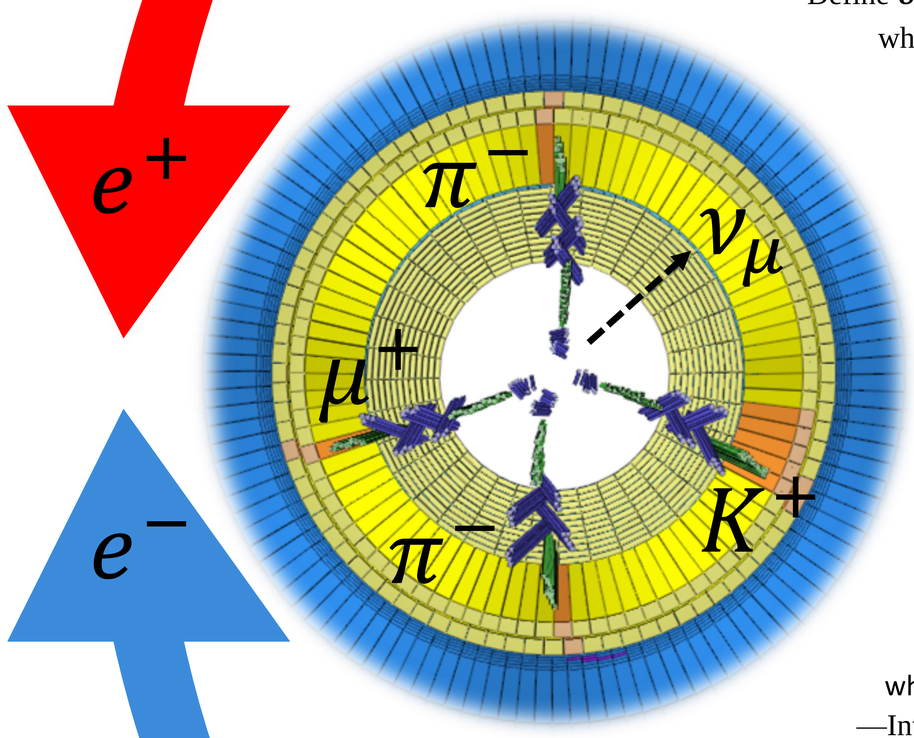


Fig.5 Veto cuts for $4\pi\pi^0$ and $K3\pi K_L$ background

4 SIGNAL EXTRACTION AND UPPER LIMIT



—Define $U_{\rm miss}$ as the blind parameter: $U_{\rm miss} = E_{\rm miss} - |\vec{P}_{\rm miss}| \cdot c$,

where $E_{\rm miss} = E_{J/\psi} - E_D - E_\mu$, $\vec{P}_{\rm miss} = \vec{P}_{J/\psi} - \vec{P}_D - \vec{P}_\mu$

— Unbinned extended maximum likelihood fit in U_{miss}

—$F_{\rm fit} = N_{\rm sig} \times PDF_{\rm sig} \otimes G(\mu,\sigma) + N_{\rm bkg} \times {\rm poly}(c_0, c_1)$

- $PDF_{\rm sig}$: Signal shape of U_{miss} spectrum from signal MC
- $G(\mu,\sigma)$: The resolution difference between data and MC
- $poly(c_0, c_1)$: 2nd-Chebychev to describe the backgrounds
- $N_{\rm sig}$ ($N_{\rm bkg}$): Signal (background) events number, floating

—$N_{\rm sig} = 35 \pm 28$, no significant signals above background

— $\mathrm{BF}(J/\psi \to D^-\mu^+\upsilon_\mu + c.c.) = \frac{N_{\rm sig}}{N_{J/\psi} \times \hat{\epsilon} \times \mathrm{BF}(D^+ \to K^-\pi^+\pi^+)}$

where $\hat{\epsilon} = (14.29 \pm 0.05)\%$ (signal efficiency)

— Fit curve of likelihood: $L_1(B) \propto \exp(-\frac{(B-\hat{B})^2}{2\sigma_B^2})$

— Convoluted curve of likelihood: to consider the uncertainty

$$L_2(B) \propto \int_0^1 \exp[-\frac{(\frac{\epsilon B}{\hat{\epsilon}} - \hat{B})^2}{2\sigma_B^2}] \times \frac{1}{\sqrt{2\pi}\sigma_\epsilon} \exp[-\frac{(\epsilon - \hat{\epsilon})^2}{2\sigma_\epsilon^2}] d\epsilon$$

where $\sigma_\epsilon = \Delta_{\rm sys} \cdot \hat{\epsilon}$, $\Delta_{\rm sys} = 9.5\%$ (systematic uncertainty)

—Integral of the likelihood curve out to 90%

- $\mathbf{BF}(J/\psi \to D^-\mu^+\upsilon_\mu + c.c.) < 5.6 \times 10^{-7}$ **@90% C.L.**

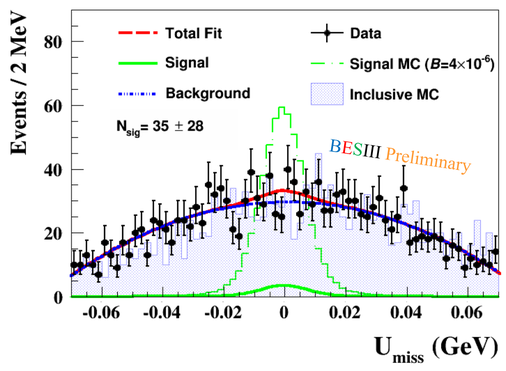


Fig.6 Signal extraction in data

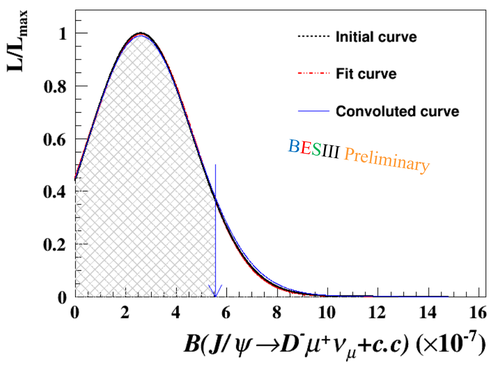


Fig.7 Upper limit scan in likelihood

5 SUMMARY

Using $(10087 \pm 44) \times 10^6$ J/ψ events collected with BESIII, we present the first search for the semi-muonic weak decay $J/\psi \to D^-\mu^+\upsilon_\mu + c.c.$ and the upper limit of the BF to be $\mathrm{BF}(J/\psi \to D^-\mu^+\upsilon_\mu + c.c.) < 5.6 \times 10^{-7}$ @90% C.L. This result is compatible with the SM.

Reference

[1] M. Ablikim et al. (BESIII Collaboration), Nucl. Instrum. Meth. A 614, 345 (2010).
[2] M. Ablikim et al. [BESIII Collaboration], Chin. Phys. C 46, 074001 (2022).
[3] M.A. Sanchis-Lonzano, Z. Phys. C 62, 271 (1994) .
[4] A. Datta, P. J. O'Donnell, S. Pakvasa and X. Zhang, Phys. Rev. D 60, 014011 (1999).
[5] G. Punzi, eConf C030908, MODT002 (2003)
[6] X. X. Liu, X. R. Lü and Y. S. Zhu, Chin. Phys. C 39, 103001 (2015).

Address: No.135, Xingang Xi Road, Guangzhou, 510275, P.R. China

Email: lizhj37@mail2.sysu.edu.cn