Search for the rare weak decay $J/\psi \to D^- e^+ \nu_e + c.c.$

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Introduction

J/ψ meson can decay into a single charmed meson accompanied by light hadrons or leptons via weak decay of one of the charm quarks. The inclusive branching fraction (BF) of weak decays to a single charmed meson was predicted to be at the order of 10^{-8} or below in the Standard Model (SM). Therefore, searching for these decays not only tests the SM prediction but also probes new physics theories beyond the SM. So far, weak decays of the J/ψ meson have not yet been observed.

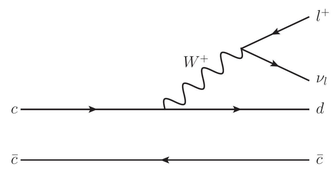


Fig.1. Feynman diagrams of J/ψ semi-leptonic weak decays

BEPCII and BESIII

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

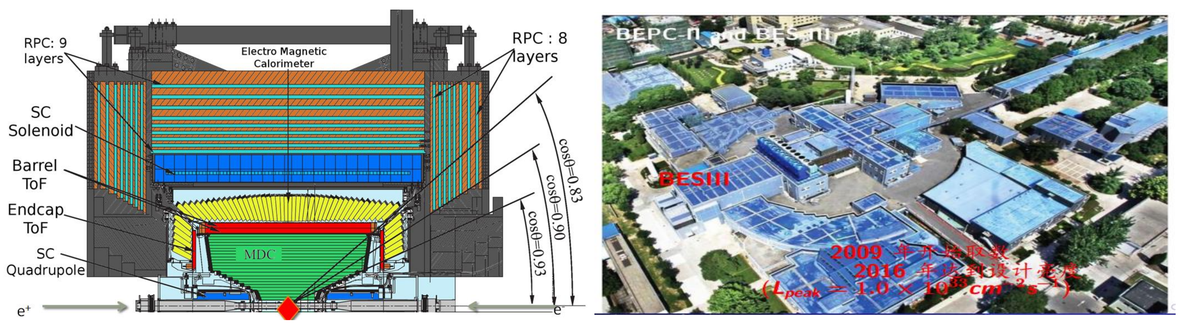


Fig.2. **BE**ijing **S**pectrometers **III** and **B**eijing **E**lectron **P**ositron **C**ollider **II**

- Main drift chamber (MDC): $\Delta P/P = 0.5\%$
- Time-of-Flight system (TOF): $\sigma_T = 60 \sim 68$ ps
- Electromagnetic Calorimeter (EMC): $\Delta E/E = 2.5\%$
- Muon chamber system (MUC): $\sigma_{z,\phi} = 2$ cm
- Superconductor (SC): 1.0 $Tesla$
- Data using: 2009-2019 J/ψ data
- Center-of-mass energy: 3.097 GeV
- $N_{J/\psi} = (10087 \pm 44) \times 10^6$

Event selection

➢ Decay chain: $J/\psi \to D^- e^+ \nu_e, D^- \to K^+\pi^-\pi^-$, only $K^\pm\pi^\mp\pi^\mp e^\pm$ will be detected.

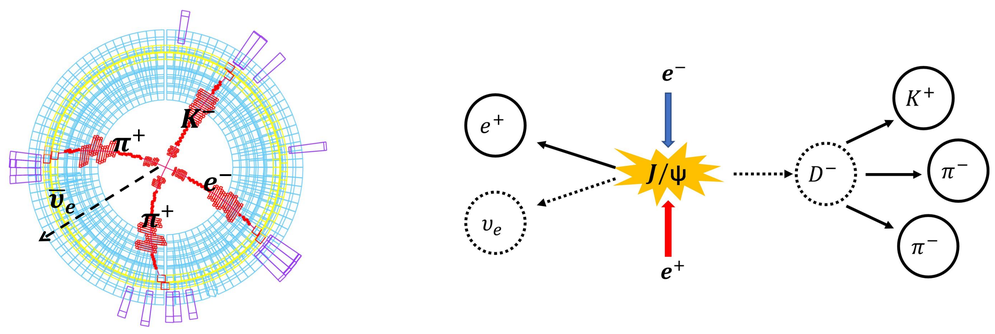
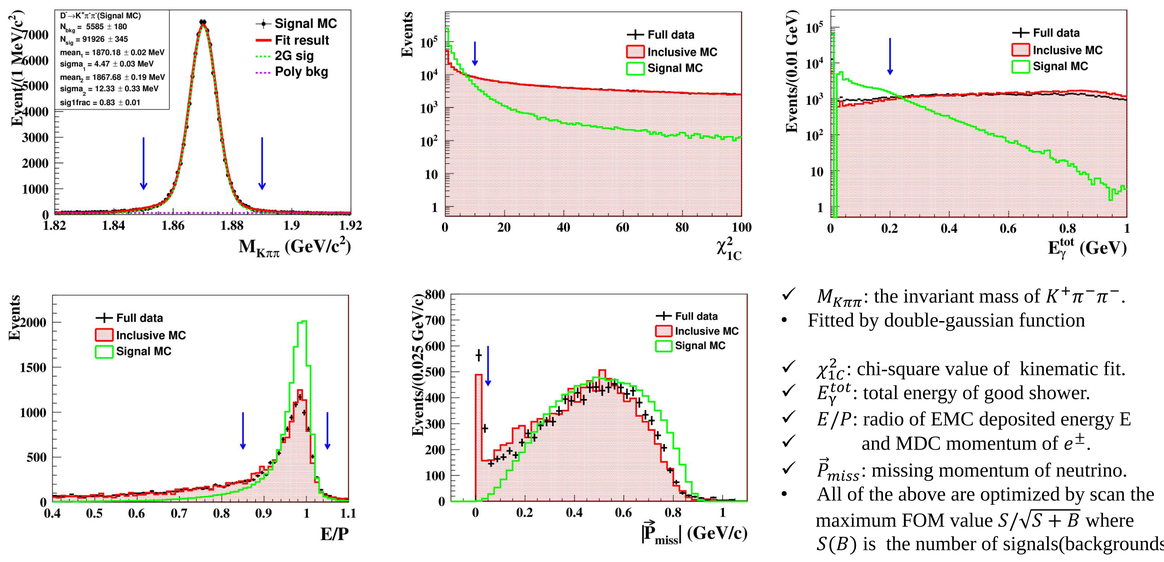


Fig.3. Event reconstruction of $J/\psi \to D^- e^+ \nu_e + c.c.$

➢ Further selection



- ✓ $M_{K\pi\pi}$: the invariant mass of $K^+\pi^-\pi^-$.
- Fitted by double-gaussian function
- ✓ χ^2_{1C}: chi-square value of kinematic fit.
- ✓ E_γ^{tot}: total energy of good shower.
- ✓ E/P: radio of EMC deposited energy E and MDC momentum of $e^\pm$.
- ✓ $\vec{P}_{miss}$: missing momentum of neutrino.
- All of the above are optimized by scan the maximum FOM value $S/\sqrt{S+B}$ where $S(B)$ is the number of signals(backgrounds).

Fig.4. Further selection of $J/\psi \to D^- e^+ \nu_e + c.c.$

➢ Efficiency of signal is from signal MC, $\epsilon^{MC}_{sig} = \sum \epsilon^i_{sig} \times \frac{n^i}{N} = (29.93 \pm 0.10)\%$, where n^i is the number of J/ψ in each year and N is the total number.

Table 1: Cut flows and signal efficiencies.

Cut flow	Efficiency 2009(%)	Efficiency 2012(%)	Efficiency 2018(%)	Efficiency 2019(%)
Generated(200,000)	100	100	100	100
$N^{good}_{charged} = 4, \sum Q = 0$	58.36	57.74	58.65	58.43
π, K, e PID	50.93	50.60	51.55	51.81
1.85 GeV < $M_{K\pi\pi}$ < 1.89 GeV	45.88	45.88	46.22	46.50
χ^2_{1C} < 10	43.36	43.93	43.34	43.82
E^{tot}_γ < 0.2 GeV	37.26	37.89	37.15	37.55
0.85 < E/P < 1.05	30.99	31.71	30.86	30.92
P_{miss} > 0.05 GeV	30.95	31.68	30.82	30.29
−0.067 GeV < U_{miss} < 0.070 GeV	29.80	30.46	29.64	30.11

Backgrounds study

➢ Two main backgrounds:
(1) Gamma conversion with e misidentified as π/K: $J/\psi \to \rho\pi \to \gamma\gamma\pi\pi \to \gamma e^+e^-\pi\pi$;
(2) π/K misidentified as e: $J/\psi \to \gamma\eta(1405) \to \gamma K K^0\pi \to \gamma\pi\pi\pi K$

☐ Define $U_{miss} = E_{miss} - c|\vec{p}_{miss}|$
- ✓ Neutrino missing-energy: $E_{miss} = E_{J/\psi} - E_{D^-} - E_{e^+}$
- ✓ Neutrino missing-momentum: $\vec{p}_{miss} = \vec{p}_{J/\psi} - \vec{p}_{D^-} - \vec{p}_{e^+}$
- ✓ If there are signals in real data, it will have a peak around 0 in U_{miss}

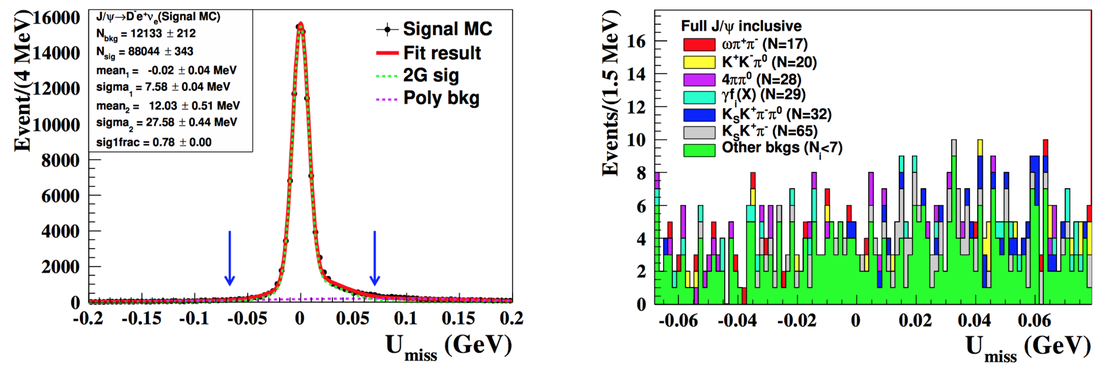


Fig.5. U_{miss} signal region and the main background distribution.

Signal extraction

➢ We use a fit on U_{miss} distribution to extract the signal.
- $PDF_{total} = \sum PDF^i_{sig} + poly(c_0)$, where PDF^i_{sig} is from signal MC and i indicates different years.
- $BF(J/\psi \to D^- e^+ \nu_e + c.c.) = \frac{N_{signal}}{N_{J/\psi} \times \epsilon \times BF(D^- \to K^+\pi^-\pi^-)}$, where signal efficiency ϵ is determined from MC samples and N_{signal} is determined from fitting.

Table 2: Summary of systematic uncertainties (%).

Sources	Relative uncertainties
Tracking	4.0
Particle ID	4.0
Signal MC model	3.0
E^{tot}_γ requirement	2.1
E/p requirement	0.3
$\lvert\vec{p}_{miss}\rvert$ requirement	0.3
BF of the $D^- \to K^+\pi^-\pi^-$ decay	1.7
Number of J/ψ events	0.5
Total	7.0

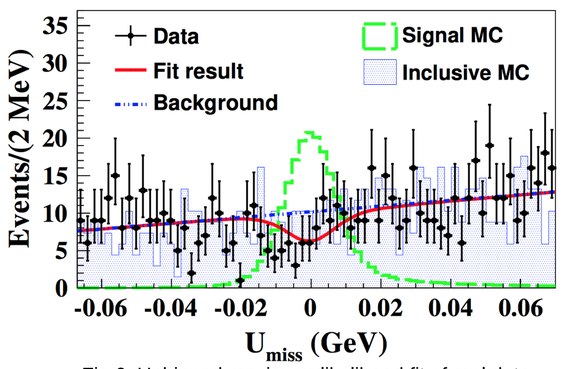


Fig.6. Unbinned maximum likelihood fit of real data.

Results and summary

➢ No excess of events is observed above the background.
➢ An upper limit on $J/\psi \to D^- e^+ \nu_e + c.c.$ will be given.

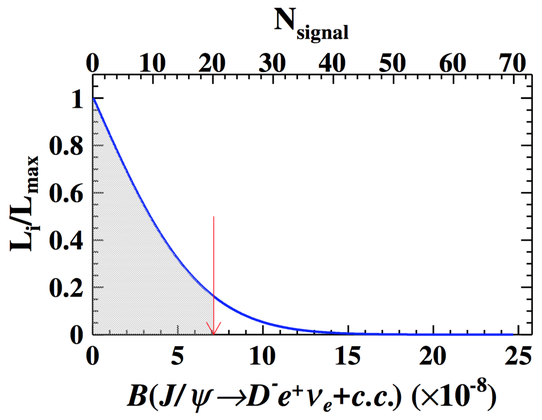


Fig.6. The likelihood curve and UL at 90% CL.

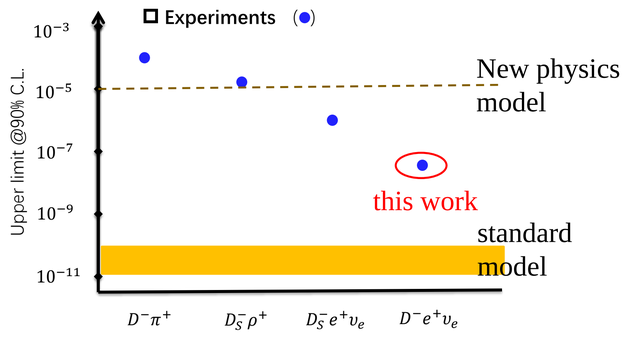


Fig.7. Part of the results of weak decay of J/ψ up to now.

The resulting UL on the BF is $\mathcal{B}(\mathrm{J/\psi \to D^- e^+ \nu_e + c.c.}) < 7.1 \times 10^{-8}$ at 90% CL based on 10.1 billion J/ψ events. Our result improves this limit by a factor of 170. This is the most sensitive search for the $\mathrm{J/\psi \to D^- e^+ \nu_e}$ decay. This measurement is compatible with the SM theoretical predictions, and puts a stringent constraint on the parameter spaces for different new physics models predicting BFs of the order of 10^{-5}. The results of $\mathrm{J/\psi \to D_s^{(*)-} e^+ \nu_e}$, $\mathrm{D^0 e^+ e^-}$, $\mathrm{\bar{D}^0\pi^0}$, $\mathrm{\bar{D}^0\rho^0}$, $\mathrm{\bar{D}^0\eta}$, $\mathrm{D^-\pi^+}$, $\mathrm{D^-\rho^+}$ using full J/ψ data are coming soon...

References

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