The first search for the weak interaction between muon and charmonium

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JHEP01(2024)126
arXiv: 2403.11597

ONE QUESTION: HOW MANY DUCKS(DARK SECTOR)?

1. INTRODUCTION

The muon's weak interaction with the quarkonium $q\bar{q}$ has not been studied in experiments until now, but it can be accessed through the charmonium weak decay to the muon, $J/\psi \to D^-\mu^+\nu_\mu + c.c.$. The semi-muonic weak decay of J/ψ is extremely rare ($\sim 10^{-10}$) in the standard model (SM), making it a **golden probe for exploring new physics** (NP) beyond the SM, such as the impact from lepton-quark, Top-color model, two-Higgs doublet model. The rarity of the process in the SM provides a cleaner environment for NP.

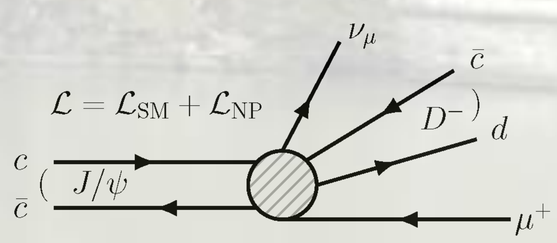

Fig.1 Feynman diagrams of $J/\psi \to D^-\mu^+\nu_\mu + c.c.$, where the circle includes both the SM and NP contribution

2. BEPCII AND BESIII

The **BE**ijing **S**pectrometers **III** detector at the **B**eijing **E**lectron **P**ositron **C**ollider **II** is a large solid-angle magnetic spectrometer running in τ-charm energy region with a geometrical acceptance of 93% of 4π solid angle. Up to now, it has collected the largest charmonium events in the world, including $(10087 \pm 44) \times 10^6$ J/ψ events and other excited charmonium state events.

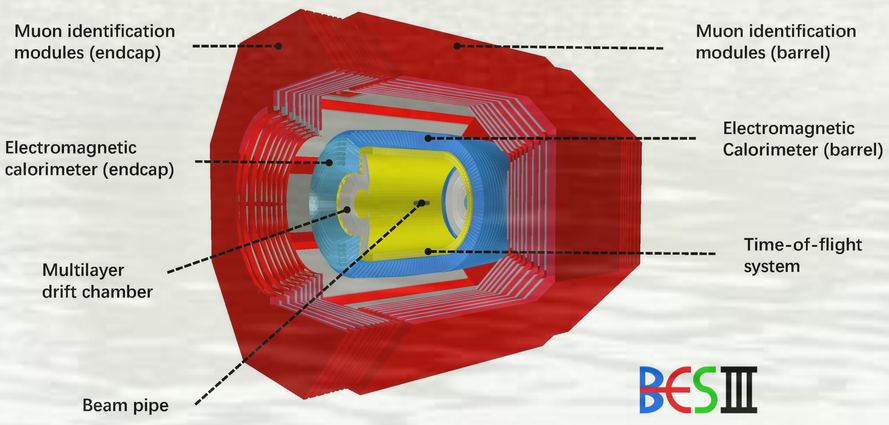

Fig. 2 **BE**ijing **S**pectrometers **III detector**

3. BASIC EVENT SELECTIONS

The basic tracking and particle identification (PID) are performed. Since the final neutrino ν_μ has no interaction with the detector, a large missing momentum P_{miss} is expected in the interested candidate. Further more, with no extra hard photon in the final state, a clean cluster unassociated with the charged track is required. Some additional standard selections are also necessary.

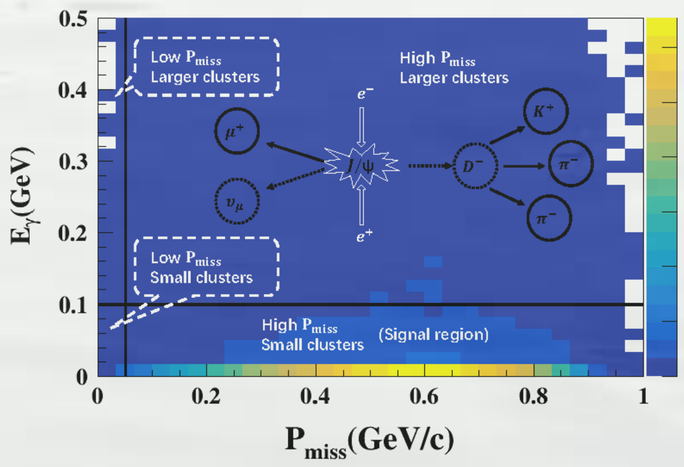

Fig. 3 Event selections associated with missing momentum and clusters

The lifetime of D meson is extremely short compared to the scale of BESIII, causing it to decay rapidly near the interaction point of e^+e^-. As a result, it can only be reconstructed through its final states, such as $D^- \to K^+\pi^-\pi^-$. The lifetime of muon is relatively long at BESIII, allowing to be detected directly. However, due to the low momentum of muons in the three-body decay, most muons do not provide effective information in the muon identifier, leading to a **significant background from muon-pion misidentification**. Additionally, the large branching fraction (BF) of J/ψ hadronic decay also results in substantial background from kaon-pion misidentification.

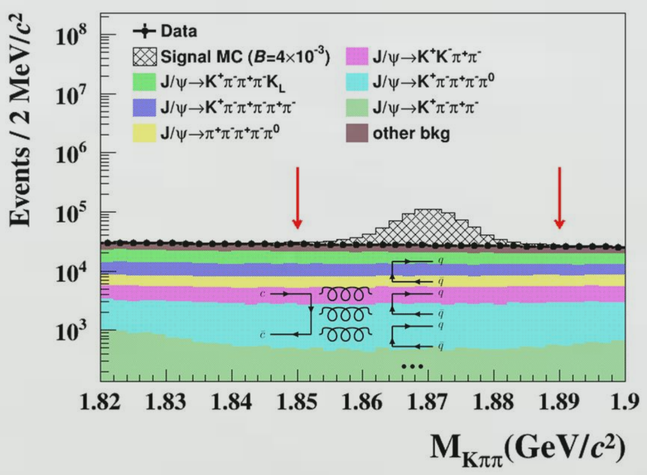

Fig. 4 The reconstruction of D meson, which still include a huge background in the D mass range.

4. KINEMATIC-BASED PID

Due to the large branching fraction of J/ψ hadronic decay, the traditional PID method does not meet the requirements for searching rare processes. The differences in particle mass can manifest as distinct kinematic characteristics in the entire event, leading to the development of a kinematic-based PID method to further identify particles and effectively suppress misidentified hadronic background. After implementing the kinematic-based PID, **over 95% of the background can be reduced**, significantly improving the sensitivity to NP.

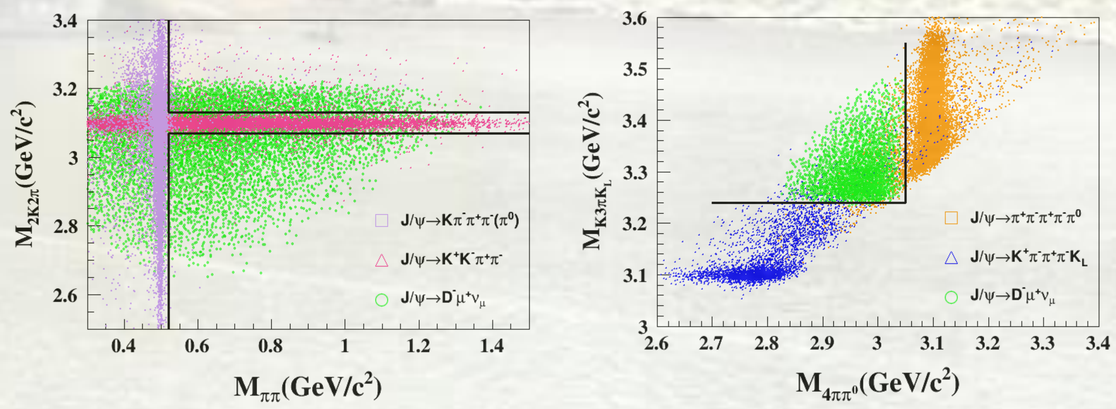

Fig. 5 Kinematic-based PID to further suppress the background, where the green dots are the signal events from simulation.

5. SIGNAL EXTRACTION AND CONSTRAINT

The J/ψ semi-muonic decay signal yields are extracted through an unbinned extended maximum likelihood fit in U_{miss} spectrum, where $U_{miss} = E_{miss} - P_{miss} \cdot c$, with E_{miss} representing the missing energy and P_{miss} representing the missing momentum. If there is a signal present in the data sample, a peak around zero in U_{miss} spectrum is anticipated. However, with a maximum local significance of less than 2σ, **no evidence** of NP is found.

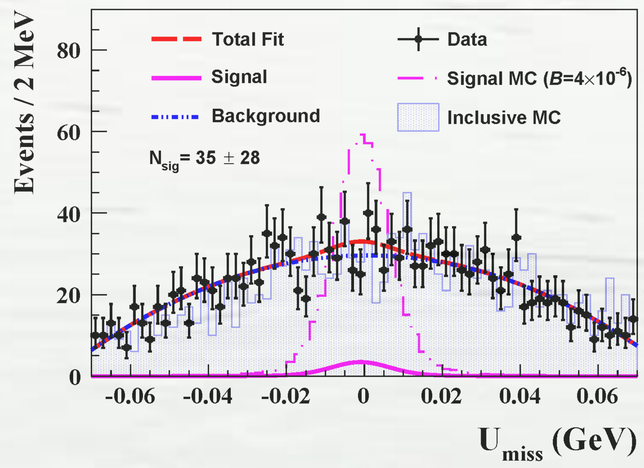

Fig. 6 The signal extraction in U_{miss} spectrum.

Since no significant excess of signal above the background is observed, an upper limit (UL) on the BF is set with a Bayesian approach. Different signal yields are tested in the unbinned extended maximum likelihood fit, and the UL is firstly set to 5.6×10^{-7} at 90% confidence level in the world.

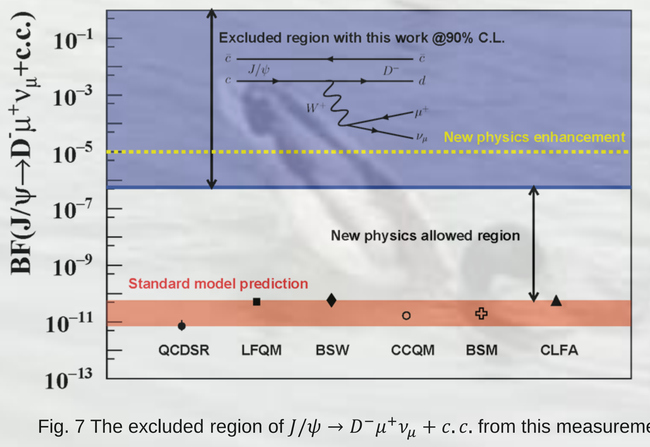

Fig. 7 The excluded region of $J/\psi \to D^-\mu^+\nu_\mu + c.c.$ from this measurement.

6. SUMMARY

No exotic phenomenon have been found, and the first excluded region of muon's weak interaction with the charmonium has been determined, while still allowing a wide region for NP exploration.

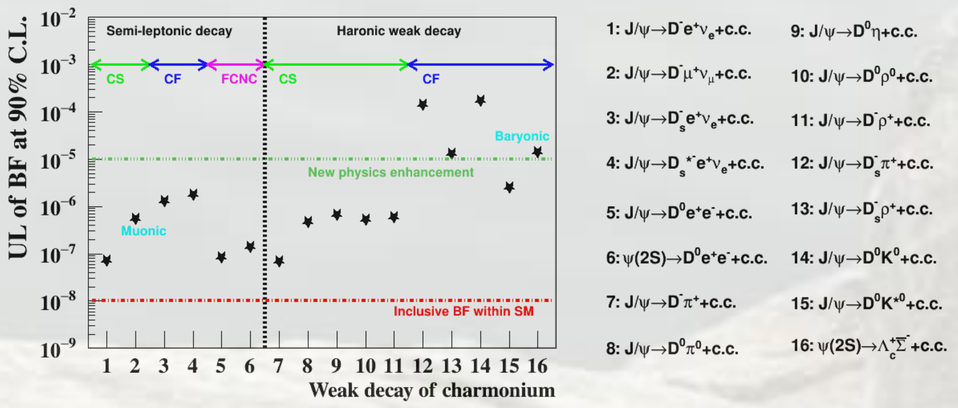

Fig. 8 The summary of charmonium weak decay, where the muonic kind is the first search from this measurement.

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