Probing dark force at BES-III/BEPCII

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We study an experimental search of a GeV scale vector boson at BES-III/BEPCII. It is responsible for mediating a new $U(1)_d$ interaction, as recently exploited in the context of weakly interacting massive particle dark matter. At low energy $e^+e^-$ colliders this dark state can be efficiently probed.

We discuss the direct productions of this light vector $U$ boson and the decay of this state with BES-III data and its foreseen larger data. In particular, we show that Higgs’-strahlung in the dark sector can lead to multilepton signatures, which probe the physics range for kinetic mixing parameter $\epsilon \sim 10^{-4} - 10^{-3}$ over a large portion of the parameter space.

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INTRODUCTION

In recent years, many astrophysical and cosmological experiments have indicated the presence of dark matter (DM). The leading candidate for this DM is a particle [1]. There are many pieces of evidence that the DM component of the universe may be light and at GeV scale. The DM of this scale has been invoked to explain several recent experimental results [2–5], including the annual modulation of the DAMA/LIBRA [6] and the 511 keV photon signal from the SPI/INTEGRAL [7]. Sub-GeV scale bosons have also been used to interpret the excess in the cosmic ray positron reported by PAMELA [8] and the total electron and positron flux measured by ATIC [9], as well as preliminary result from Fermi-LAT [10].

The light U boson may couple to the SM charged particles with a much suppressed coupling which has been considered in various contexts [2, 11–15]. We consider the new Abelian gauge group $U(1)_d$ which has a gauge-invariant kinetic mixing with the SM hypercharge $U(1)_Y$ [16–18]. After electroweak symmetry breaking, we have the Lagrangian

\[ \mathcal{L} = \mathcal{L}_{SM} + \epsilon_V F^{\mu\nu}_Y F^{d}_{\mu\nu} + m_u^2 A_{d,\mu} A^{d,\mu}, \]

where $\mathcal{L}_{SM}$ is the SM Lagrangian, $F^{\mu\nu}_Y$ and $F^{d}_{\mu\nu}$ are the field strength for $U$ boson and the gauge boson $B$ of $U(1)_Y$, $A^d$ is the gauge field of a massive dark $U(1)_d$ gauge group [17]. The second term in Eq. (1) is kinetic mixing operator, and $\epsilon \sim 10^{-3} - 10^{-2}$ is generated at any scale by loops of heavy fields charged under both $U(1)_d$ and $U(1)_Y$. In a supersymmetry theory, the kinetic mixing operator induces a mixing between the D-terms associated with $U(1)_d$ and $U(1)_Y$. The hypercharge D-term gets a vacuum expectation value from electroweak symmetry breaking and induces a weak-scale effective Fayet-Iliopoulos term for $U(1)_d$. Consequently, the $U(1)_d$ symmetry breaking scale is naturally suppressed by loop factor or by $\sqrt{\epsilon}$, leading to MeV to GeV-scale U boson mass [16, 18]. The parameters of concern in this Letter are $\epsilon$ and $m_U$. It is also natural to conceive the existence of an elementary Higgs-like boson, the $h'$, which spontaneously breaks the symmetry as argued in reference [19]. Although the $U$ boson will in general have a substantial branching ratio to lepton pairs, the decays of the Higgs’ will depend on its mass relative to that of the $U$ boson. If the Higgs’ is light it will decay via loop processes to leptons and possible hadrons, in which case it is long-lived and will most likely appear as missing energy. Otherwise, if it is heavy, it will decay to double $U$ bosons, and finally can be seen in multiple lepton final states.

An interesting consequence of the above hypotheses is that they must induce observable effects in low energy $e^+e^-$ colliders, such as the existing or future super-flavor factories. A more comprehensive discussion of these effects can be found in references [19, 20, 21, 22].

Both the $U$ boson and the $h'$ can be produced at BEPCII, if their masses are less than charmonium states. Although the luminosity of BEPCII is order of magnitude lower than that at B factories, the production cross-sections scale as $1/s$, which essentially compensates the lower luminosity at BEPCII. Furthermore, BEPCII is better suited for detecting particles with mass around 1 GeV, and also is a great lab to look for $U$ boson and $h'$ in $\psi$ decays, which will be produced with huge sample ($10^{10}$ $J/\psi$ decays events per year at BEPCII). These considerations motivate searching for dark-sector events in various channels at BEPCII/BES-III. We will mainly argue the following processes at BES-III:

- $e^+e^- \rightarrow \gamma + U \rightarrow \gamma l^+l^-$, where $U \rightarrow l^+l^-$, $l$ could be electron or muon;
 STATUS OF BES-III

The BES-III detector consists mainly of a cylindrical main draft chamber (MDC) with momentum resolution $\sigma_{p_t}/p_t \sim 0.5\%$ for a charged particle with momentum at 1.0 GeV, the time-of-flight (TOF) system with two layers of plastic scintillator counters located outside of MDC, and highly hermetic electromagnetic calorimeter (EMC) with energy resolution of $\sigma_E/E = 2.5\%/\sqrt{E(\text{GeV})}$ [23]. The MDC has its first sensitive layer at a radius of 6.0 cm from the interaction point (IP), and the MDC combined with a B field of 1.0 T, provide a precise momentum measurements of charged particles with transverse momentum greater than 50 MeV. Photons of energy down to 20 MeV and polar angle in the range $21^0 < \theta < 159^0$ can be detected with good efficiency by EMC.

BES-III has so far acquired about $1.0 \times 10^8$ and $2.0 \times 10^8$ at $\psi(2S)$ and $J/\psi$ peaks, respectively. In the next few years, by year 2014, $10^{10}$ events on $J/\psi$ peak and $3 \times 10^9$ events on $\psi(2S)$ peak will be collected. The expected data samples per year running at BES-III are summarized in Table I. For this Letter, the sensitivity studies are based on 3 fb$^{-1}$ luminosity at the $J/\psi$ or $\psi(2S)$ peak and 20fb$^{-1}$ at the $\psi(3770)$ peak for the searching for the dark sector.

| TABLE I: $\tau$-Charm productions at BEPCII in one year’s running ($10^7$ s). |
|---------------|--------------|
| Data Sample   | Central-of-Mass (MeV) | #Events  |
| $J/\psi$      | 3097         | $10 \times 10^7$ |
| $\tau^+\tau^-$| 3670         | $12 \times 10^6$ |
| $\psi(2S)$    | 3686         | $3.0 \times 10^9$ |
| $D^0\bar{D}^0$| 3770         | $18 \times 10^6$ |
| $D^+D^-$      | 3770         | $14 \times 10^6$ |
| $D^+_sD^-_s$  | 4030         | $1.0 \times 10^6$ |
| $D^+_sD^-_c$  | 4170         | $2.0 \times 10^6$ |

REACH OF U BOSON SEARCH AT BES-III

In this section, we discuss the constraints and discovery potential for the $U$ boson at Beijing electron-positron collider II (BEPCII) [23]. Since the $U$ boson couples mainly to the SM electromagnetic current [21]. Its production at BEPCII is the same as that of photon, although with a much suppressed rate. Therefore, any process which produces a large number of detectable photons will have a chance to produce $U$ boson as well.

1. $e^+e^- \rightarrow U\gamma$ events

The process of $e^+e^- \rightarrow U\gamma$ is one of the most interesting processes, which had been discussed previously in references [12, 14, 15, 21]. It has the advantage of being independent of details of the Higgs’ sector [19]. The on-shell $U$ boson will decay to a pair of leptons, leading to a signal of $l^+l^-\gamma$. The SM background $e^+e^- \rightarrow \gamma^*\gamma \rightarrow l^+l^-\gamma$, although large for this process, is not a severe problem as the kinematics of the signal are quite distinct. The invariant mass of the lepton pair is just within a single bin due to the tiny width of the vector and can be distinguished from the QED background. Over a large range of parameters, the cross-sections for the production of $U$ boson scale as $\sigma_s = \alpha^2\epsilon^2/s \sim \sigma_0\epsilon^2$, where $\sigma_s$ is the signal cross-section for the $e^+e^- \rightarrow U\gamma$, and $\sigma_0$ is the cross-section for the analogous QED process $e^+e^- \rightarrow \gamma\gamma$. The value of the cross-section for $e^+e^- \rightarrow \gamma\gamma$ is about 42 nb at $\sqrt{s} = 3.773$ GeV, and assuming $\epsilon = 10^{-3}$, the cross-section for $U$ boson production could be 42 fb. We estimate the expected numerical results based on the significance

$$S = \frac{\sigma_s \times L}{\sqrt{\sigma_{th-bin} \times L}} \times BR(U \rightarrow l^+l^-) = \sqrt{\frac{\epsilon^2\sigma_0}{\sigma_{th-bin}}} \times BR(U \rightarrow l^+l^-),$$

(2)
where $\mathcal{L}$ is integrated luminosity at BES-III, the $BR(U \to l^+l^-)$ is the branching ratio of $U$ boson decay into lepton pair which is discussed in reference [19], and $\sigma_{th-bin}$ is the effective cross-section from QED background $e^+e^- \to \gamma^*\gamma \to e^+e^-\gamma$ in the $i$-th bin on the distribution of $m_{l^+l^-}$. The effective cross-section can be estimated based on the resolution function at BES-III, we have

$$\sigma_{th-bin} = \sigma(e^+e^- \to \gamma^*\gamma \to e^+e^-\gamma) \frac{N_{th-bin}}{N_{total}}, \tag{3}$$

where $N_{th-bin}$ is the number of events in the $i$-th bin with size $\delta m$ and $N_{total}$ is the total number of observed events of QED background. The size of the bin is in the window of the size $\delta m$ around $m_{l^+l^-} = m_U$, here $\delta m$ is the mass resolution of $m_{l^+l^-}$ in the BES-III detector. The width of $U$ boson is much smaller than the typical detector resolution, so it is important to understand the mass resolution of BES-III. We simulated the QED background $e^+e^- \to e^+e^-\gamma$ by considering full BES-III detector within GEANT4 framework. We obtain the following resolution functions:

$$\delta m(\mu^+\mu^-) = \left(2.5 + 1.7 \left(\frac{m_U}{1.0\text{GeV}}\right) + 0.6 \left(\frac{m_U}{1.0\text{GeV}}\right)^2\right) \text{(MeV)}, \tag{4}$$

$$\delta m(e^+e^-) = \left(4.1 + 0.3 \left(\frac{m_U}{1.0\text{GeV}}\right) + 1.1 \left(\frac{m_U}{1.0\text{GeV}}\right)^2\right) \text{(MeV)}. \tag{5}$$

To obtain the resolution function, we require that the reconstructed tracks must be within the the fiducial volume of the MDC, and the photon must be in the EMC. In order to reconstruct charged tracks with good quality and neutral tracks without dilution of detector noises, we ask $p_t > 80\text{MeV}$ and $E_\gamma > 20\text{MeV}$, where $p_t$ and $E_\gamma$ are transverse momentum of charged track in the MDC and deposit energy of photon in the EMC, respectively. We assume that the inefficiency along the invariant mass distribution of $m_{l^+l^-}$ is flat, and the resolution, $\delta m$ is plotted against $m_{l^+l^-}$ in Fig. 4.

In Fig. 2 we show the reach of the parameter $\epsilon$ by defining $S/\sqrt{B} = 5$ in Eq. 2. The signal events are generated with different choice of $m_U$, and passing the same cuts as in the above discussion. We count the number of events in the window of one resolution $\delta m$ for both signal and background. It is important to know the $BR(U \to e^+e^-)$ and $BR(U \to \mu^+\mu^-)$ in the estimation of the reach in Fig. 2. The branching ratios of $U$ boson decay into lepton pair and hadron states, such as $\pi^+\pi^-$ have been discussed in reference [19], in which the hadronic decay rate is extracted from the $R$ values measured in $e^+e^-\to$hadron processes [19]. The reach of $l^+l^-$ is degraded if the $U$ boson mass is in the region of $\rho$ resonance, because the branching ratio of $U \to l^+l^-$ is becoming small due the open of hadron $\pi^+\pi^-$ channel in that region. For this estimation, we assume 20fb$^{-1}$ data sample collected at $\psi(3770)$ peak at BES-III.

There is another background which is not considered here for $e^+e^- \to U\gamma$. It is a relevant instrumental background that has to be taken into account for this channel, namely $e^+e^- \to \gamma\gamma$ with subsequent conversion of one of the two photons on the beam pipe and inner wall of the MDC, with a probability of $\sim 2\%$. Since, for the $\gamma$-conversion, the $e^+e^-$ is not from interaction point, the invariant mass is peak near zero and the open angle between two electrons is small, this background can be rejected by requiring cuts on the reconstructed invariant mass and vertex of the pair as done for instance in the analysis of [24]. For $m_U$ larger than 500 MeV, assuming the energy resolution in the calorimeter is $\sim 20\text{MeV}$ for photons of 500 MeV, one finds that this background is negligible. In Fig. 4 we only plot the reach for the invariant mass larger than 500 MeV.
FIG. 2: Illustrative plot of the reach of vector boson at BES-III in the channel of $e^+ e^- \rightarrow \gamma U \rightarrow \gamma l^+ l^-$. Note that the sensitivity of $\epsilon$ is becoming worse at large mass of $U$ boson due to the large background from Bhabha scattering.

FIG. 3: Illustrative plot of the reach of vector boson at BES-III in the channel of $J/\psi \rightarrow e^+ e^- U \rightarrow e^+ e^- \mu^+ \mu^-$. 

2. $U$ boson in $J/\psi$ decays

A study of $U$ boson in the decay of $J/\psi \rightarrow e^+ e^- U$ for in a lower mass range, $m_U \leq 50\text{MeV}$ has been considered in Ref. [14]. We will have $10^{10}$ $J/\psi$ events at BES-III with one year luminosity $[23]$. The background process $J/\psi \rightarrow \gamma e^+ e^-$ has branching ratio of $8.4 \times 10^{-3}$ which is measured by Fermilab E760 experiment with $E_\gamma > 100\text{MeV}$ [25], which is consistent with the SM predictions. This decay rate is large enough and can be used to detect the $U$ boson via $J/\psi \rightarrow e^+ e^- U$ channel. The mode $J/\psi \rightarrow \gamma \mu^+ \mu^-$ has also been measured [26]. With $10^{10}$ $J/\psi$ events at BES-III, the reach in the channel $J/\psi \rightarrow e^+ e^- U$ could be at the level of $\epsilon \sim 10^{-3}$, which is competitive with the process $e^+ e^- \rightarrow U \gamma$. Of course there could be also an $e^+ e^- \rightarrow e^+ e^- U$ final state, with a large background from QCD process $e^+ e^- \rightarrow e^+ e^- l^+ l^-$

$$
\sigma_{e^+ e^- \rightarrow e^+ e^- l^+ l^-} = \frac{\alpha^4}{\pi m_l^2} \left( \log \frac{s}{m_e^2} \right)^2 \frac{s}{m_l^2}; \quad l = e \text{ or } \mu,
$$

(6)
for the $e^+e^- \rightarrow e^+e^- \mu^+\mu^-$ process, the production cross-section is about 69 nb at $J/\psi$ peak. However, the electrons in the two-photon process move primarily in the direction of the beam pipe. Small angle and invariant mass cuts should help to reduce the background. Moreover, the signal $U$ boson decay events will have a significant peak, and make this kind of background rejection somewhat easier. In Fig. 3 we show the reach of the parameter $\epsilon$ by defining $S/\sqrt{B} = 5$ in the channel $J/\psi \rightarrow e^+e^- U$ ($U \rightarrow \mu^+\mu^-$), in which backgrounds from $J/\psi \rightarrow \gamma e^+e^- \rightarrow \mu^+\mu^-\epsilon\epsilon$ and QED process $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ are considered. Again, the reach is degraded if the $U$ boson mass is in the region of $\rho$ resonance.

There are another interesting channels such as $J/\psi \rightarrow \eta U$ and $\eta' U$ which can be used to search for $U$ boson, since the branching ratios of $J/\psi$ decay into $\eta + X$ and $\eta' + X$ are percentage level. The reach of these channels could be at the level of $\epsilon \sim 10^{-3}$ at BES-III. The irreducible backgrounds in these channels are from $J/\psi \rightarrow \eta/\eta' V$, where the $V$ denotes $\rho^0$, $\phi$ and $\omega$ vector mesons which can decay into $e^+e^-$ pair.

3. $U$ boson in $\psi(2S) \rightarrow U + \chi_{c1,2}$ decays

At the BES-III experiment, we will collect about $3 \times 10^9 \psi(2S)$ events in one year luminosity as listed in table 1. Two interesting decay modes are $\psi(2S) \rightarrow \gamma \chi_{c1}$ and $\chi_{c2}$ with branching fractions at the level of 10%. It is important to note that both $\chi_{c1}$ and $\chi_{c2}$ can be reconstructed from $\chi_{c1,2} \rightarrow \gamma J/\psi \rightarrow \gamma l^+l^-\gamma$, and the combined branching fraction could be about 40%. The narrow $J/\psi$ peak can be used to tag $\chi_{c1,2}$ decays. There will be huge amount of events observed in $\psi(2S)$ decays. There is about 176 MeV (130 MeV) of phase space for $\psi(2S) \rightarrow \gamma \chi_{c1}$ ($\psi(2S) \rightarrow \gamma \chi_{c2}$). It will be interesting to look for a low mass, ~100 MeV, $U$ boson in these modes.

The dominant background is $\psi(2S) \rightarrow \gamma\chi_{c1,2} \rightarrow e^+e^-\chi_{c1,2}$, where $m_{e^+e^-} = q_{\gamma\gamma} = m_U$. Since the $BR(\psi(2S) \rightarrow \gamma\chi_{c1,2})$ is well measured, typically, we have

$$BR(\psi(2S) \rightarrow \gamma\chi_{c1,2} \rightarrow e^+e^-\chi_{c1,2}) \sim 10^{-2} \times BR(\psi(2S) \rightarrow \gamma\chi_{c1,2}).$$

As discussed in Ref. [21], the number of background events in the window of $\delta m$ (resolution of $m_{e^+e^-}$) around $m_{e^+e^-} = m_U$ is about

$$N_B = N_{\psi(2S)} BR(\psi(2S) \rightarrow \gamma\chi_{c1,2} \rightarrow e^+e^-\chi_{c1,2}) \frac{\delta m}{m_U \log[(m_{\psi(2S)} - m_{\chi_{c1,2}})/2m_e]},$$

where $\delta m$ is the resolution for reconstructed invariant mass $m_{e^+e^-}$ at the BES-III experiment; $m_{\psi(2S)}$, $m_{\chi_{c1,2}}$ and $m_e$ are the nominal masses of $\psi(2S)$, $\chi_{c1,2}$ and electron, respectively; and $N_{\psi(2S)}$ is the total number of $\psi(2S)$ decay events. By replacing the photon by $U$ boson, the signal rate can be estimated to be $BR(\psi(2S) \rightarrow U\chi_{c1,2}) \sim e^2 BR(\psi(2S) \rightarrow \gamma\chi_{c1,2})$. Thus, the expected number of signal events is about

$$N_S = N_{\psi(2S)} \times e^2 BR(\psi(2S) \rightarrow \gamma\chi_{c1,2}) \times BR(U \rightarrow e^+e^-),$$
where \( BR(U \to e^+e^-) = 1 \) since the \( U \) boson can only decay into electron-positron pair due to the limit of phase space. Combining Eqs. (8) and (10), we obtain the signal significance as

\[
\frac{S}{\sqrt{B}} = \frac{N_S}{\sqrt{N_B}} = \sqrt{\frac{N_{\psi(2S)} e^2 BR(\psi(2S) \rightarrow \gamma \chi_{c1,2}) BR(U \rightarrow e^+e^-)}{BR(\psi(2S) \rightarrow \gamma \chi_{c1,2} \rightarrow e^+e^-)} \times \frac{m_U}{\delta m} \log \left( \frac{m_{\psi(2S)} - m_{\chi_{c1,2}}}{2m_e} \right)}.
\]

Therefore, with \( 3 \times 10^9 \psi(2S) \) events, the reach for \( U \) boson searching can be \( \epsilon \sim 10^{-3} \) in \( \psi(2S) \rightarrow U \chi_{c1,2} \) decay. In Fig. [III] we show the reach of the parameter \( \epsilon \) by defining \( S/\sqrt{B} = 5 \) for different mass of \( U \) boson.

From experimental side of view, one can measure the following ratio:

\[
\mathcal{R} = \frac{BR(\psi(2S) \rightarrow U \chi_{c1,2})}{BR(\psi(2S) \rightarrow \gamma \chi_{c1,2})},
\]

where the \( \chi_{c1,2} \) can be reconstructed in the \( \chi_{c1,2} \rightarrow \gamma J/\psi \rightarrow \gamma t^+l^- \) decay. Since the width of \( J/\psi \) is narrow, we use a kinematic fit that constrains the decay of \( J/\psi \rightarrow t^+l^- \) to \( J/\psi \) mass, so that the resolution of invariant mass \( m_{t^+l^-} \) can be greatly improved. At BEPCII, the central-of-mass energy is known at \( \psi(2S) \) peak, one can define the missing mass squared, \( MM^2 \), recoiling against the \( \chi_{c1,2} \) tagged by \( \gamma J/\psi \)

\[
MM^2 = (m_{\psi(2S)} - E_{\chi_{c1,2}})^2 - (p_{\chi_{c1,2}})^2,
\]

where \( E_{\chi_{c1,2}} \) and \( p_{\chi_{c1,2}} \) are the energy and three-momentum of the fully reconstructed \( \chi_{c1,2} \). Real \( \psi(2S) \rightarrow \gamma \chi_{c1,2} \) will congregate near zero \( MM^2 \), while real \( \psi(2S) \rightarrow U \chi_{c1,2} \) will peak near \( MM^2 = m_U^2 \) which deviated from zero. By looking at the missing mass squared \( MM^2 \), one can extract the ratio \( \mathcal{R} \). In this method, the \( U \) boson decay and radiative photon are missed in the reconstruction. We note that the reconstruction efficiencies are the same for both decays of \( \psi(2S) \rightarrow U \chi_{c1,2} \) and \( \psi(2S) \rightarrow \gamma \chi_{c1,2} \), and the uncertainties due to the reconstructions of charged tracks and neutral tracks cancel in the measurement of the ratio \( \mathcal{R} \). It is also interesting that the measurement will be independent from the total number of \( \psi(2S) \) decays. With \( 3 \times 10^9 \psi(2S) \) events at BES-III, assuming that no signal events is observed for the \( \psi(2S) \rightarrow U \chi_{c1,2} \) decay, one can measure the ratio \( \mathcal{R} \) to be \( 3 \times 10^{-7} \) at 90% confidence level.

For the \( U \) boson search, we can reach \( \epsilon \sim 10^{-3} \) for in the mass range less than 176 MeV.

4. The higgs’-strahlung process \( J/\psi \rightarrow Uh' \)

A possible existence of a light Higgs’ boson has been discussed in Ref. [19]. At the BES-III, an interesting process is the higgs’-strahlung \( J/\psi \rightarrow Uh' \), which can be looked for if \( m_U + m_{h'} < m_{J/\psi} \). There are two cases to consider: either the Higgs’ is heavier than that of the \( U \) boson, or vice versa. These cases will lead to different experimental signatures at BES-III.

If the case \( m_{h'} < m_U \), the Higgs’ is extremely narrow and very long-lived [19], so that the signature of the process will be \( J/\psi \rightarrow Uh' \rightarrow l^+l^- \) events with the photon lost in the calorimeter, is suppressed due to the high detection efficiency at BES-III. Secondly, since the missed particle is photon, the missing momentum will be equal to the missing energy, one can define the observable: \( U_{miss} = E_{miss} - |P_{miss}| \), which peaks at zero for photon, while is far away from zero for Higgs’ with non-zero mass. Thirdly, in term of both background rejection and detection efficiency, the angular distribution of the signal process is proportional to \( \sin^4(\theta) \), which peaks at \( \theta = \pi/2 \) [27]. With \( 10^6 \) \( J/\psi \) decay events at BES-III, the reach of \( \epsilon \) could be less than \( 10^{-3} \) in this process.

For the case \( m_{h'} > m_U \), the Higgs’ decays almost exclusively to two \( U \) bosons. For \( m_{h'} > 2m_U \), three pairs of leptons will have an invariant mass peaked very narrowly around the mass of the \( U \) boson. The process \( J/\psi \rightarrow Uh' \rightarrow 3(e^+e^-) \) will suffer huge background from QED process \( e^+e^- \rightarrow 3(e^+e^-) \) which has the production cross-section [28]

\[
\sigma_{e^+e^- \rightarrow 3(e^+e^-)} = \frac{\alpha^6}{\pi^3 m_e^2} \left( \log \frac{s}{m_e^2} \right)^4 = 2.4 \times 10^{12} \text{ fb}.
\]

However, as discussed in Ref. [19], the signal events will have large transverse momentum \( p_T \). For the background case, the background events by contrast will have two electrons down to the beam pipe, with \( \theta < m_e/\sqrt{s} \). Thus, a
small angle cut will reduce the background significantly. From experimental point of view, we would suggest that \( J/\psi \to U^h \to 3(\mu^+\mu^-) \) process will be important since the QED background in this case should be negligible as it cannot proceed via the two-photon mechanism, and the cross-section will decrease as \( 1/s \). Although there will be a large number of fake events from \( e^+e^- \to e^+e^-3(\mu^+\mu^-) \) arising from a two-photon process, they can be easily removed since \( e^+e^- \) pair will be lost down the beam pipe leading to missing energy. Therefore, the process \( J/\psi \to U^h \to 3(\mu^+\mu^-) \) could be efficiently used as a “discovery mode” for the \( U \) boson with huge \( J/\psi \) decay events. In the allowed kinematic region, the reach of this mode could be \( \epsilon \sim 10^{-4} \). 

**SUMMARY**

Dark matter experiments suggest new low-energy gauge interactions beyond the Standard Model. If a dark sector exists, it will dramatically refresh our understanding of the nature. In this Letter, following the work in reference [21], we have investigated the signatures of a hidden \( U(1)_d \) sector at the BES-III experiment, and find that the BES-III should have an intrinsic sensitivity to the kinetic mixing parameter \( \epsilon \) in the range of \( 10^{-4} - 10^{-3} \). Especially, the Higgs'-strahlung process will be potential mode to detect multilepton final states, which has the advantage of leading novel discovery.

Beginning in mid-2008, the BEPCII/BES-III was operated at center-of-mass energies corresponding to \( \sqrt{s} = 2.0-4.6 \) GeV. The design luminosity over this energy range ranges from \( 1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1} \) down to about \( 0.6 \times 10^{33} \text{cm}^{-2}\text{s}^{-1} \), yielding around 5 fb\(^{-1} \) each year at \( \psi(3770) \) above \( DD \) threshold and 3 fb\(^{-1} \) at \( J/\psi \) peak in one year’s running with full luminosity \( 23 \). The BES-III will be able to test the new interaction in detail, and the \( U \) boson and light Higgs can be looked for in the mass range of a few hundred MeV to GeV scale.

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