Search for a dark photon in π^0 Dalitz decays by PHENIX experiment at RHIC

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Several models of dark matter suggest the existence of a "dark photon," an $U(1)$ gauge boson in the dark matter sector that mixes with an ordinary photon[1)]. In these models, a dark photon is responsible for annihilation of a pair of dark matter particles into an e^+e^- pair. Such annihilation can explain the positron excess observed by PAMELLA, FERMI, and AMS-2 satellite experiments. A dark photon can also explain the 3 σ level deviation of the anomalous magenetic moment of the muon (muon $g-2$) from the Standard Model calculation.

In the simplest version of these models, a dark photon U mixes with a QED photon γ with a very small mixing term of the Lagrangian

$$\mathcal{L}_{\rm mix} = -\frac{\epsilon}{2} F_{\mu\nu}^{\rm QED} F_{\rm dark}^{\mu\nu},$$

where ϵ is the mixing parameter.

The dark photon can have a small mass M_U. If M_U is greater than twice the electron mass m_e, it can decay into an e^+e^- pair. In the natural version of the model, this is the only decay mode. This means the following:

(1) A dark photon can be produced in any process that can produce virtual photon with a small fraction ϵ^2.
(2) Once produced, it decays exclusively into an e^+e^- pair.
(3) The decay width of dark photon is very narrow and practically zero due to the small coupling ϵ^2

Therefore, if the mass of the dark photon is less than that of π^0, a clear signal of dark photon should show up as a narrow peak in e^+e^- pair mass spectrum of π^0 Dalitz decays $\pi^0 \to e^+e^-\gamma$.

We searched for the signal of dark photon in π^0 Dalitz decay data measured by PHENIX experiment at RHIC. PHENIX is very well suited for this search since it has a very good electron identification capability, a high mass resoluiton of low mass e^+e^- pairs, and a high statistics data sample of π^0 Dalitz decay. We used the data set of $p+p$ collision in 2006 run and d+Au collisions in 2008 run, both at $\sqrt{s_{NN}}$ = 200 GeV. We analyzed approximately 1.3 million e^+e^- pairs for the search.

We did not find any significant peak in the Dalitz pair mass spectrum. Thus, we set the upper limit on the mixing parameter ϵ^2 as a function of dark photon mass M_U from our null search result. In setting the upper limit, we employed the CLs method, a statistical method now widely used by the LHC experiments for new particle searches.

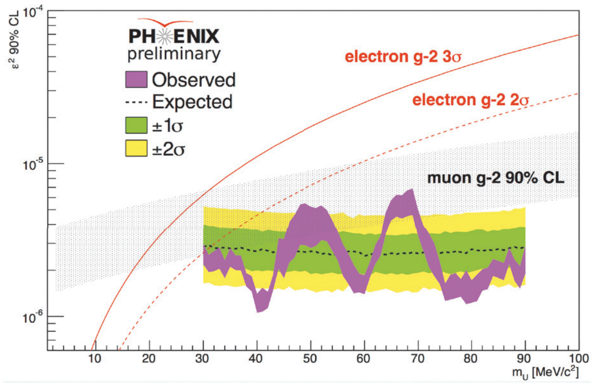

Fig. 1. Limit on the dark photon mixing parameter ϵ^2 as a function of dark photon mass. See the text for details.

The preliminary results of the search is shown in Fig.1. The magenta band shows the observed 90 % CL upper limit on ϵ^2. The width of the band represents the systematic uncertainty of the limit. The fluctuation of the limit is due to statistical fluctation of the background continuum, i.e., Dalitz pair mass spectrum. If the background e^+e^- mass spectrum fluctuate up (down), the upper limit on the dark photon becomes higher (lower). The dashed curve represents the "expected level" of the upper limit if there is no such statistical flucutation. The green and yellow bands are expected statistical fluctuation of the upper limit at 1σ and 2σ level, respectively. The fluctuation of the observed limit is within approximately 2σ level.

The gray band in the figure shows the 90 % CL region that can explain the muon $g-2$ deviation. The dashed curve shows the upper limit on ϵ^2 from electron $g-2$ at 2σ level. Together with the limit from electron $g-2$, our results have excluded almost all region of the muon $g-2$ band.

We are now working to finalize the data. We will publish the final results soon.

References

1) Nima Arkani-Hamed et al., Phys. Rev. D79: 015014 (2009).

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