Search for dark photons from neutral meson decays in $p+p$ and d+Au collisions at $\sqrt{s_{NN}}$=200 GeV[†]

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The standard model (SM) of particle physics provides unprecedented numerical accuracy for quantities such as the anomalous magnetic moment of the electron $(g-2)_e$. Hence, measurements that lie outside SM predictions warrant a special investigation. One such result is the measured value of $(g-2)_\mu$, which deviates from SM calculations by 3.6σ. An intriguing explanation for this discrepancy has been proposed by adding a "dark photon"[1]. This possibility has recently gained more relevance because it provides a simultaneous explanation of various beyond-the-standard-model phenomena in addition to $(g-2)_\mu$. These includes the positron excess observed by PAMELLA, FERMI, and AMS-2 satellite experiments.

A simple formulation of the dark sector postulates a "dark photon" U of mass m_U that mixes with the QED photon via the "kinetic coupling" term in the Lagrangian

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

where ε parameterizes the mixing strength. Dark photons can then mix with the QED photon through all processes that involves QED photons.

The PHENIX experiment searched for possible decays of π^0, $\eta \to \gamma U$, $U \to e^+e^-$ by examining the invariant mass m_{ee} of e^+e^- pairs in a large sample of Dalitz decays, $\pi^0, \eta \to \gamma e^+e^-$ for $30 < m_U < 90$ MeV/c^2 in the dark photon parameter space. The weak coupling of the dark photon with the QED photon implies that the natural width of the dark photon is very narrow. Thus if the dark photon mass is in this range, a clear dark photon signal should appear as a narrow peak in the e^+e^- mass spectrum.

We used the data set of $p+p$ collisions in the 2006 and 2009 runs and d+Au collisions in the 2008 run, at $\sqrt{s_{NN}} = 200$ GeV, but did not find any significant signal. Thus, we set the upper limit on the mixing parameter ε^2 as a function of the dark photon mass m_U.

Fig.1 shows the limits determined by the PHENIX along with the 90% confidence level (CL) limits from other experiments and the 2σ upper limit theoretically calculated from $(g-2)_e$. The band indicates the range of parameters that would allow the dark photon to explain the $(g-2)_\mu$ anomalies with 90% CL. The PHENIX experiment limits exclude the values of the coupling favored by the $(g-2)_\mu$ anomaly above $m_U > 36$ MeV/c^2. Recently, BaBar reported stricter limits from a search of the reaction $e^+e^- \to \gamma U, U \to l^+l^-$, excluding values of the preferred $(g-2)_\mu$ region for $m_U > 32$ MeV/c^2[2]. As a result, nearly all the available parameter space that would allow the dark photon to explain the $(g-2)_\mu$ results are ruled out at 90% CL by independent experiments. The entire parameter space to explain the $(g-2)_\mu$ anomaly by the dark photon can be excluded at 85% CL by the PHENIX data alone. The level of compatibility between our data and the coupling strength favored for the $(g-2)_\mu$ anomaly is 10% with a statistical test.

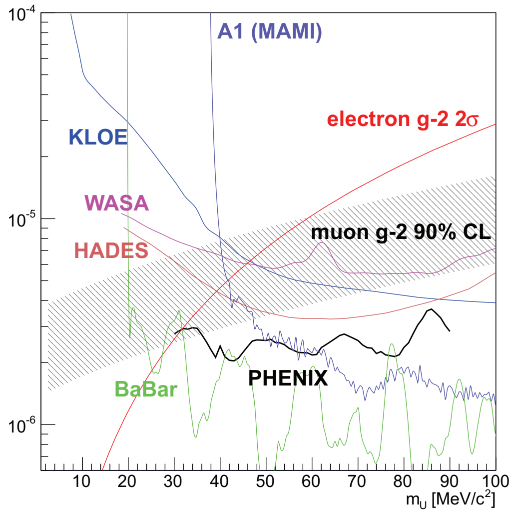

Fig. 1. A compilation of the limits of the U^γ mixing parameter, showing the PHENIX results, together with other experiments and the band indicating the range of mass and coupling parameters favored by the $(g-2)_\mu$ anomaly at 90% CL. Also shown is the 2σ upper limit obtained from $(g-2)_e$.

In summary, the PHENIX results set limits for the coupling of a dark photon to the QED photon over the mass range $30 < m_U < 90$ MeV/c^2. Combining with the BaBar results, the dark photon is ruled out at 90% CL as an explanation for the $(g-2)_\mu$ anomaly for $m_U > 32$ MeV/c^2, leaving only a small remaining part of the parameter space in the region $29 < m_U < 32$ MeV/c^2.

References
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