Search for dark photons in heavy-ion collisions

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(cf. "Snowmass 2021 White Paper" arXiv:2203.05939)

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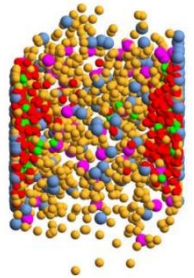
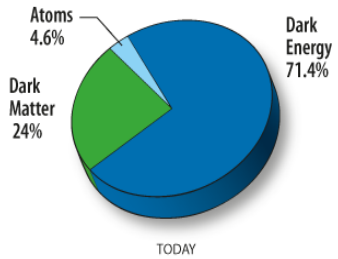
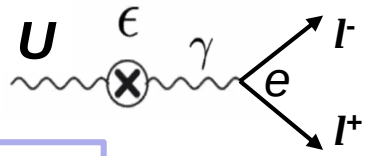


Vector portal for dark photons (A′ or U-bosons)



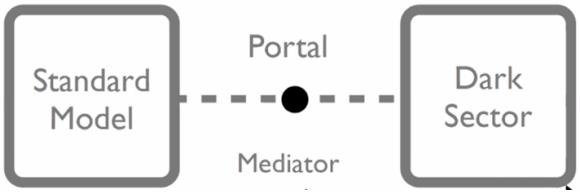
The 'vector' portal : existence of a U(1)-U(1)′ gauge symmetry group mixing

$$\mathcal{L} \supset -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}m^2_{A'}A'^{\mu}A'_{\mu} + \epsilon e A'^{\mu} J^{EM}_{\mu}$$



B. Holdom, PL B 166, 196 (1986)
B. Batell et al., PRD 80, 095024 (2009)

Unknown: kinetic mixing parameter ϵ and mass M_U



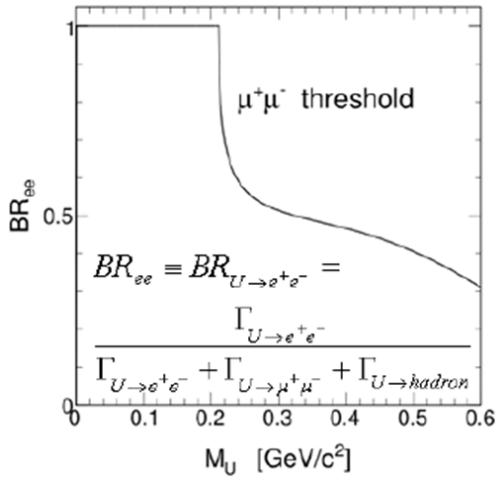
The dilepton yield from U-boson decay of mass M_U:

$$N^{U\to e^+e^-} = N^{U\to e^+e^-}_{\pi^0} + N^{U\to e^+e^-}_{\eta} + N^{U\to e^+e^-}_{\Delta}$$
$$= Br^{U\to e^+e^-}\left(N_{\pi^0\to\gamma U} + N_{\eta\to\gamma U} + N_{\Delta\to NU}\right),$$

$\pi^0 \to \gamma+U$,
$\eta \to \gamma+U$, $U\to e^+e^-$
$\Delta \to N+U$

- **Ratio of the partial widths $\pi^0(\eta) \to \gamma+U$ and $\pi^0(\eta) \to \gamma+\gamma$:**

$$\frac{\Gamma_{i\to\gamma U}}{\Gamma_{i\to\gamma\gamma}} = 2\epsilon^2 |F_i(q^2 = M_U^2)| \frac{\lambda^{3/2}(m_i^2, m_\gamma^2, M_U^2)}{\lambda^{3/2}(m_i^2, m_\gamma^2, m_\gamma^2)} \quad i = \pi^0, \eta$$



- **Similar: $\Delta \to$ N+U, $\Delta \to \gamma$+N (including Δ spectral function)**

Procedure to obtain constraints on $\varepsilon^2(M_U)$

Goal: estimate the upper limit for the kinetic mixing parameter $\varepsilon^2(M_U)$ of the U-boson from the theoretically calculated dilepton spectra using the microscopic Parton-Hadron-String Dynamics (PHSD) transport approach

PHSD: W. Cassing, E. Bratkovskaya, PRC 78 (2008) 034919; NPA831 (2009) 215; W. Cassing, EPJ ST 168 (2009) 3

1) Calculate dilepton production from 'Standard Model' sources within the PHSD – good description of exp. data on dilepton production!

2) For each bin $[M_U, M_U + dM]$ calculate the sum of all U→e+e- contributions (kinematically possible in this mass bin) keeping ε^2 as a free parameter

$$\frac{dN}{dM}^{total} = \frac{dN}{dM}^{sumSM} + \frac{dN}{dM}^{sumU} = \frac{dN}{dM}^{sumSM} + \epsilon^2 \frac{dN^{sumU}_{\epsilon=1}}{dM}.$$

3) Obtain constraints by requesting that dN^{total}/dM cannot exceed the sum of SM channels (i.e. exp. data!) by more than a factor C_U in each bin dM, i.e.

$$\frac{dN}{dM}^{total} = (1 + C_U)\frac{dN}{dM}^{sumSM}$$

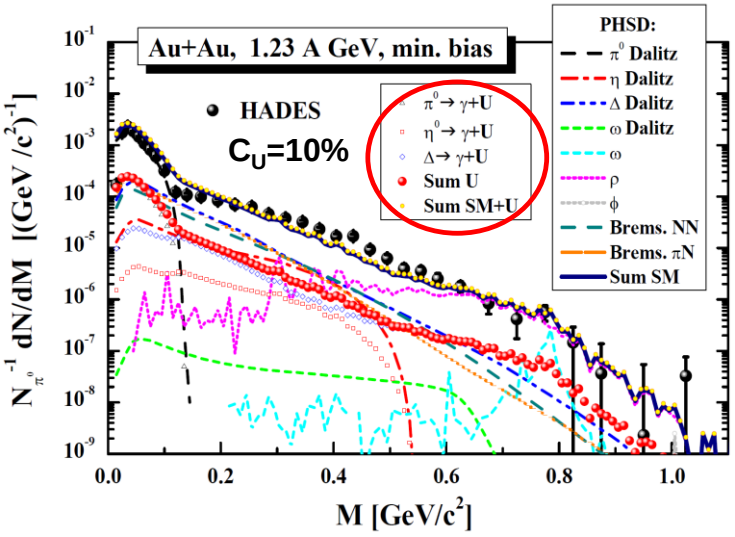
C_U controls the additionally "allowed" dilepton yield resulting from dark photons on top of the total SM yield

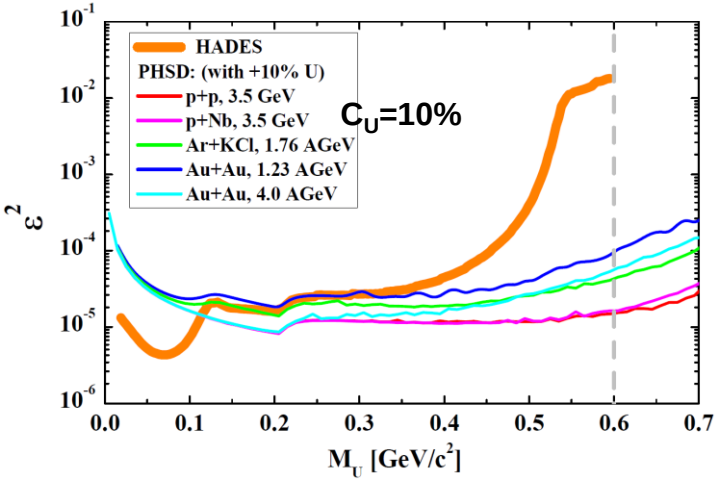
4) Calculate $\varepsilon^2(M_U)$ by assuming C_U : e.g. C_U =0.1 → 10% DM extra yield to the SM yield

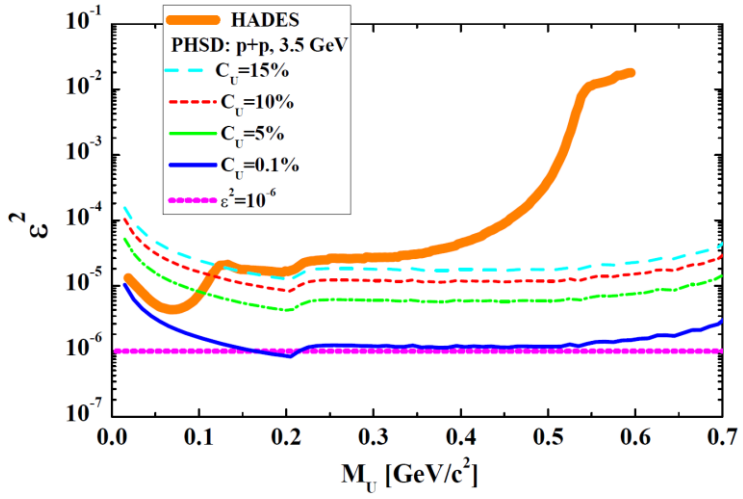
$$\epsilon^2(M_U) = C_U \cdot \left(\frac{dN}{dM}^{sumSM}\right) \Big/ \left(\frac{dN^{sumU}_{\epsilon=1}}{dM}\right)$$

Light dark photons searches with heavy ions

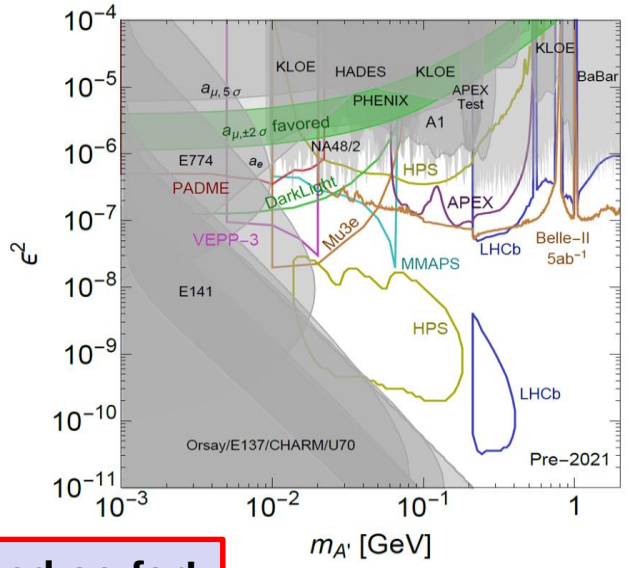
The upper limit for the kinetic mixing parameter $\varepsilon^2(M_U)$ of light dark photons extracted from the PHSD dilepton spectra - with C_U allowed surplus of the total SM yield by an additional DM yield at given M:







Compilation of world wide exp. data (arXiv:1707.04591) on the upper limit of the mixing parameter ε^2



PHSD: PRD 104 (2021) 015008

HADES: PLB 731 (2014) 265

Dark photons are not observed so far!

Summary

- We presented microscopic transport calculations, based on the PHSD approach, for the dilepton yield from the decay of hypothetical dark photons (or U-bosons), U→e+e- from p + p, p + A and heavy-ion collisions at SIS18 energies

- For that we incorporated in the PHSD the production of U-bosons by the Dalitz decay $\pi^0 \rightarrow \gamma + U$, $\eta \rightarrow \gamma + U$, $\Delta \rightarrow N + U$ with further dilepton decays $U \rightarrow e^+e^-$ based on the theoretical model by Batell, Pospelov and Ritz which describes the interaction of DM and SM particles by the U(1)-U(1)′ mixing

- We introduced a procedure to define theoretical constraints on the upper limit of the kinetic mixing parameter $\varepsilon^2(M_U)$:
  Since dark photons are not observed in dilepton experiments so far, we can require that their contribution can not exceed some limit which would make them visible in experimental data

- We found that the extracted upper limit of $\varepsilon^2(M_U)$ is consistent with the experimental results of the HADES experiment for $0.15 < M_U < 0.4$ GeV, as well as with the world-wide experimental compilation

➔ Proposed theoretical procedure allows:

- to check any theoretical ideas on the $\varepsilon^2(M_U)$ independent on exp. data
- to study the influence of exp. acceptance, system and centrality selection
- to perform the simulation for testing experimental set-ups for the search of U-bosons