PHENIX Searches for Low Mass Dark Photons

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Muon g-2 anomaly

- Observed 3.6σ discrepancy from SM prediction is one of possible BSM phenomena.
- Dark photon can explain this discrepancy as well as other astrophysical anomalies.
- Many experiments contributed for the dark photon search.
  - Theory curves from Hye-Sung Lee & Bill Marciano.
- Muon g-2 explainable band (90% CL) still survives for 30-50 MeV.

- Getting more important as a candidate of the cause for the muon g-2 anomaly due to the recent SUSY result at LHC.
- Short-term aim: Covering the entire region of the muon g-2 explainable band.
Search in $\pi^0/\eta$ Dalitz decays

Measurement of $\pi^0/\eta \rightarrow \gamma U \rightarrow \gamma e^+e^-$ in Dalitz decays

- Aim to detect possible $e^+e^-$ pairs from the dark photons in the $\pi^0/\eta$ Dalitz decayed $e^+e^-$ pairs
  - The dark photon exclusively decays into $e^+e^-$ pair.
  - Its natural width is very narrow.
    - Expected peak width = detector mass resolution
  - Same approach with COSY-WASA & HADES

Important requirements for this measurement

1. A large data sample of $e^+e^-$ from $\pi^0/\eta$ Dalitz decays
2. A very good mass resolution of $e^+e^-$
Relativistic Heavy Ion Collider at BNL

- Collision species: \( p+p, d+Au, Au+Au, Cu+Cu, U+U, \ldots \)
- Maximum collision energy: 200 (for HI), 500 (for \( p+p \)) GeV
- Running since 2001

PHENIX experiment is originally designed for the study of Quark Gluon Plasma.

- Excellent capability for \( e^+e^- \) measurements
How to measure electrons

- Central arm at mid-rapidity: $|\eta| < 0.35$
- Momentum measurement of charged tracks by DC & PC
  - $\delta p/p = 1\% \oplus 1.1\% \times p$ [GeV/c]
- Electron identification by RICH & E/p matching
  - Charged hadron rejection power $\sim 10^3$
  - Electron trigger requires with a coincidence of a RICH hit & correlated EMCal energy deposit
- Promising measurements of $e^+e^-$ with high statistics
2006 p+p & 2008 d+Au datasets were analyzed.

- Background pairs: **combinatorial** pairs, **semi-correlated jet** pairs, **cross** pairs from double Dalitz decays
- Each BG contribution was evaluated using Like-sign pairs.
Background pairs (cont.)

- **Jet & cross** pair contributions are consistent for both p+p and d+Au as expected
  - ✓ p+p & d+Au datasets are normalized in $m_{ee} < 30$ MeV
  - → Background contributions are very well understood.
Measured $e^+e^-$ spectra can be well described by a "cocktail" of hadron decays + BG.

- 400k (p+p) + 1.0M (d+Au) = total 1.4M $e^+e^-$ Dalitz pairs
- No significant dark photon signal
Mass resolution of the PHENIX detector was calculated by the GEANT-based simulation tuned to match the real data.

✓ Considering the real $e^+e^-$ $p_T$ spectrum, an expected dark photon peak width is about 3 MeV (for inclusive $p_T$).
Confidence level calculation

**CLs approach**

- Widely accepted way to compute confidence levels for hypotheses with limited signal sensitivities
- Famous “Brazil band plot” for Higgs search at LHC
- Relative likelihoods of how well the data is described by:
  a. Only background (Dalitz continuum)
  b. Signal (dark photon) + Background

Famous ATLAS Brazil band plot
Expected reach with 1.4M events & 3 MeV of $\sigma_{ee}$
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📍 1, 2$\sigma$ statistical fluctuations of the expected reach
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1, 2$\sigma$ statistical fluctuations of the expected reach

Observed upper limit with the PHENIX detector

- Including systematic errors from uncertainties on the Dalitz continuum & $\sigma_{ee}$
Summary and outlooks

- Dark photon search is being conducted at the PHENIX experiment.
  - Searching for the dark photon in $\pi^0/\eta$ Dalitz decays
  - 1.4M pairs in p+p (2006) and d+Au (2008) datasets
  - Good mass resolution at PHENIX ~ 3MeV
    → Improved upper limits of the dark photon in 30-90MeV, but a small region in the muon g-2 explainable band still survives.

- Future plan of the dark photon search at PHENIX
  - Increase of statistics by adding the 2009 p+p data
    • Comparable statistics to the 2006 p+p data & an additional detector installed near the beam pipe
    • Paper preparation is now ongoing, and we hope to submit the paper soon.
  - Long-lived dark photon search with the 2014 Au+Au data
    • Secondary vertex measurement by VTX