Dark Sector Searches at MAMI/MESA

Search for Long Lived Particles at the LHC, 4th Workshop LHC LLP
Amsterdam, October 24, 2018
Achim Denig
Dark Sector Searches

keV  MeV  GeV  TeV  DM Mass

WIMPs

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Dark Sector Searches

Dark Photon - Messanger
New massive force carrier of extra $U(1)_d$ gauge group

- Could explain large number of astrophysical anomalies
  Arkani-Hamed et al. (2009)
  Andreas, Ringwald (2010);

- Could explain deviation of $3.7\sigma$ between $(g-2)_\mu$ SM prediction and direct $(g-2)_\mu$ measurement
  Pospelov(2008)
Model 1: $m_{\gamma'} \ll m_{DM}$

Dark Photon decaying into SM particles – coupling $\epsilon$

Holdom [1986]
**Dark Photon**

**Model 1:** \( m_{\gamma'} \ll m_{\text{DM}} \)

Dark Photon decaying into SM particles – coupling \( \epsilon \)

Model 2: \( m_{\gamma'} > 2m_{\text{DM}} \)

Dark Photon decaying into Dark Matter
→ invisible decay experiments
→ LDM detection

Holdom [1986]
Dark Photon Searches at MAMI / MESA
(Model 1)

Light Dark Matter Search at MESA
(Model 2)
Dark Photon Status in 2010

Year 2010

Coupling

allowed parameter range for $(g-2)_\mu$ explanation

Mass

$10^{-3}$

$(g-2) \pm 2\sigma$
favored

$\sim\gamma$

$\mu^+$

$\gamma'$

$\mu^+$

$\sim\gamma$

$\sim\gamma$

 terra incognita

white region motivated by dark matter!
Searches using Fixed-Target Experiments

Bjorken, Essig, Schuster, Toro (2009)

Low-energy, high-intensity accelerators on the GeV scale are ideally suited for Dark Photon searches

Bump hunting!

1. High luminosity e- beam
2. Excellent mass resolution
3. Detection at small angles

→ MAMI / JLAB
→ Spectrometers
Mainz Microtron MAMI

Electron Accelerator for Fixed Target Experiments

$E = 0.185 - 1.6 \text{ GeV}$

$I_{\text{max}} \sim 100 \mu\text{A}$

Continuous Wave (CW)

- Emittance $25 \text{ nm rad}$
- Resolution $\sigma_E < 0.100 \text{ MeV}$
- Polarization 85%
- Reliability: 7000 hours / year
A1 High Resolution Spectrometers

Spectrometer A:
- $\alpha > 20^\circ$
- $p < 735 \text{ MeV}_c$
- $\Delta \Omega = 28 \text{ msr}$
- $\Delta p/p = 20\%$

Spectrometer B:
- $\alpha > 8^\circ$
- $p < 870 \text{ MeV}_c$
- $\Delta \Omega = 5.6 \text{ msr}$
- $\Delta p/p = 15\%$

MAMI Beam:< 1.6 GeV

high momentum resolution $\sim 10^{-4}$
Results from A1

Merkel et al. [A1]
PRL ’11
PRL ‘14

- $E_{\text{beam}}$ 180 - 855 MeV
- 100 μA beam current
- Stack of Ta targets
- 22 kinematic settings
- O(1 month) of beam time
Results from A1

Merkel et al. [A1]
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- $E_{beam}$ 180 - 855 MeV
- 100 µA beam current
- Stack of Ta targets
- 22 kinematic settings
- O(1 month) of beam time

→ at time of publication most stringent limit ruling out major part of the parameter range motivated by $(g-2)_\mu$

Achim Denig
Situation as of today

Year 2017

\[ \gamma_{m^2} - 2 \times 10^{-1} \]

\[ \varepsilon_{(g-2)} \]

KLOE 2013

KLOE 2015

KLOE 2016

KLOE 2014

WASA

HADES

PHENIX

A1

APEX

BESIII

BABAR 2009

BABAR 2014

E774

E141

NA48/2

Merkel et al. [A1]

PRL '11

PRL '14

\( (g-2)^e \)

\( (g-2) \) favored

\( \sigma_2 \pm \mu_1 \) (g-2) favored

E141

BABAR 2014

BABAR 2009

\[ m_{\gamma^*} \text{ [GeV/c}^2\text{]} \]

10^-4

10^-3

10^-2

10^-1

1
Mainz Microtron MAMI

Electron Accelerator for Fixed Target Experiments

E = 0.185 - 1.6 GeV

I_max ~ 100 µA

Continous Wave (CW)
Mainz Microtron MAMI

Electron Accelerator for Fixed Target Experiments
\( E = 0.185 - 1.6 \ \text{GeV} \)
\( I_{\text{max}} \sim 100 \ \mu\text{A} \)
Continuous Wave (CW)

MESA
Mainz Energy-Recovering Superconducting Accelerator

Status of the MESA Project
Mainz Energy-Recovering Superconducting Accelerator

Recirculating ERL Mode

\[ E_{\text{max}} = 155 \text{ MeV} \]

\[ I_{\text{max}} > 1 \text{ mA} \]

Beam Polarization

**ERL-Mode Internal Target**

**MAGIX Experiment**
Operation of a high-intensity (polarized) ERL beam in conjunction with light internal target
→ a novel technique in nuclear and particle physics
→ precise measurement of low momenta tracks at competitive luminosities
The MAGIX Spectrometers

High resolution spectrometers MAGIX:

- double arm, compact design
- momentum resolution: $\Delta p/p < 10^{-4}$
- acceptance: ±50 msr
- GEM- or TPC-based focal plane detectors

- Gas Jet or polarized T-shaped target for polarized target measurements

GEM technology for focal plane
Latest design: GEM-TPC
Dark Sector Searches at MAGIX

Features:

- Xe gas target
- Luminosity $10^{35}$ cm$^{-2}$s$^{-1}$
- 6 month of data taking

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Dark Photon Searches at MAMI /MESA
(Model 1)

Light Dark Matter Search at MESA
(Model 2)
Beam Dump Experiment (BDX) @ MESA

Electron Scattering (MESA) on Beam Dump → Collimated pair of Dark Matter particles!

10,000 hours data taking @ 150 µA → $>10^{22}$ electrons on target (EOT)
Beam Dump Experiment (BDX) @ MESA

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- Extracted Beam
  P2 Experiment

- Extracted beam
  BDX Experiment

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Simulation BDX @ MESA

- Full GEANT4 simulation (P2 target, beam dump, BDX detector volume, walls etc.)
- Addition of 2.5 mm W plate before beam dump to increase (dark) photon rate?
- No neutrino background due to low beam energy, reduced neutron background

![Copper, Water, Aluminum diagram]

\[ E_{\text{beam}} = 140 \text{ MeV} \]
\[ \chi \text{ elastic scattering kinematics} \]

assume 14 MeV detector cut off as experimentally verified
Detector Concept for BDX @ MESA

Ideal Requirements:
1. Large Surface (Acceptance)
2. Large thickness (Int. Prob.)
3. High density (Int. Prob.)
4. Reliability (long running time)
5. Background rejection
   - Cosmics
   - Natural Backgrounds
   - Beam Backgrounds (Neutrons)
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Baseline Concept
Inorganic crystal calorimeter (high density)
   - Cherenkov (fast, no neutrons)
   - Scintillator (higher light yield)
Test Beam BDX @ MESA

Adjustable table

Fiber Detector (trigger)

14 MeV

MAMI beam

Measurements:
Light Yield
Position dependence
PMT voltage scan

Crystal investigated
SF5 (Pb-Glass, Schott AG)
SF6 (Pb-Glass, Schott AG)
SF57HTultra (Pb-Glass, Schott AG)
BGO (from L3-LEP)
PbF$_2$ (from A4/MAMI)

< p.e. > = 12.9
FWHM = 6.9

Counts

PbF$_2$
Sensitivity BDX @ MESA
Dark Sector Searches at MAMI / MESA

- GeV scale Dark Photon searches motivated by
  - Astrophysical anomalies
  - $(g-2)_\mu$

- Low-energy electron fixed-target accelerators ideally suited for Dark Photon searches

- Results from A1/MAMI and from JLAB

- New MESA accelerator < 155 MeV up to 1 mA beam current becoming operational in 2023
  - MESA allows to cover low-mass region for Dark Photon

- Competitive Beam Dump Experiment (BDX) at MESA
Dark Sector Searches at MAMI / MESA

- GeV scale Dark Photon searches motivated by
  - Astrophysical anomalies
  - $\mu (g-2)$

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New Collaborators welcome