Dark Photon Searches at MAMI and MESA / Mainz
**Dark Photon**

New massive force carrier of extra $U(1)_d$ gauge group; predicted in almost all string compactifications

- $\alpha' = \varepsilon^2 \cdot \alpha_{em}$

Search for the $O(\text{GeV/c}^2)$ mass scale in a world-wide effort

- Could explain large number of **astrophysical anomalies**
  - Arkani-Hamed et al. (2009)
  - Andreas, Ringwald (2010); Andreas, Niebuhr, Ringwald (2012)

- Could explain presently seen deviation of $3.6\sigma$ between $(g-2)_\mu$
  - Standard Model prediction and direct $(g-2)_\mu$ measurement
  - Pospelov (2008)
Outline

• Visible Dark Photon searches at the existing MAMI accelerator

• Perspectives for future MESA accelerators

• Possibilities for Beam Dump Experiments at MESA and MAMI (?)
Dark Photon Searches at A1/MAMI
MAMI Hallmarks

- Electron and Photon Beam $E_{\text{max}} = 1.6$ GeV
- Intensity max. 140 $\mu$A
- Resolution $\sigma_E < 0.100$ MeV
- Polarization 85%
- Reliability: 7000 hours / year
- 11 m underground
MAMI Hallmarks

- Electron and Photon Beam $E_{\text{max}} = 1.6$ GeV
- Intensity max. 140 $\mu$A
- Resolution $\sigma_E < 0.100$ MeV
- Polarization 85%
- Reliability: 7000 hours / year
- 11 m underground
A1: High-Resolution Spectrometers
**A1: High-Resolution Spectrometers**

**Experiment A1: Electron Scattering**
- 4 magnetic focussing spectrometers
- Resolution: $\delta p/p < 10^{-4}$
- Angular acceptance: <30 mrad
Results from A1/MAMI

Low-Energy Electron Acceler. with high intensity suited for DP search

Bjorken, Esssig, Schuster, Toro (2009)

Signal processes

\[ \text{Signal processes: } e^{-} \rightarrow \gamma' \rightarrow e^{-}, e^{+} \]\n
Time difference \( T_{AB} \) between both spectrometers

Achim Denig

Dark Photon Searches at MAMI and MESA
Results from A1/MAMI

Low-Energy Electron Accelerator with high intensity suited for DP search

Bjorken, Essig, Schuster, Toro (2009)

Signal processes

Hypothetical Dark Photon signal: bump in one single bin

2010 test run
Invariant Mass of e+e−
Results from A1

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

$\rightarrow$ at time of publication most stringent limit ruling out major part of the parameter range motivated by $(g-2)_\mu$
Results from A1

Merkel et al. [A1]
PRL '11
PRL '14

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

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

\[ (g-2)_{\mu} = 2 \sigma \]
\[ \epsilon \]
\[ 10^{-3} \]

KLOE 2013
WASA
HADES
PHENIX
\[ \sigma \]
\[ \pm \]
\[ \mu \]

E774
E141

\[ (g-2)_{e} \]
\[ \text{favored} \]

BESIII
BESIII projection

\[ \gamma_{\text{ISR}} \]
\[ e^+/\mu^+ \]
\[ e^-/\mu^- \]

B\Bar{B}AR 2009
B\Bar{B}AR 2014
Dark Photon
Search at MESA
Mainz Microtron MAMI

New exptl. hall (CFP) funded in 2016

MESA accelerator & experiments

Achim Denig

Dark Photon Searches at MAMI and MESA
NEW: MESA Accelerator

Mainz Energy-Recovering Superconducting Accelerator

Recirculating ERL

$E_{\text{max}} = 155$ MeV

$I_{\text{max}} > 1$ mA (ERL)

commissioning 2020
NEW: MESA Accelerator

Mainz Energy-Recovering Superconducting Accelerator

Recirculating ERL

$E_{\text{max}} = 155 \text{ MeV}$

$I_{\text{max}} > 1 \text{ mA (ERL)}$

commissioning 2020

Mode 1: Extracted Beam
P2 Experiment

Mode 2: ERL
Internal Target
MAGIX Experiment
Operation of a high-intensity ERL beam in conjunction with light internal target → a novel technique in nuclear and particle physics

High resolution spectrometers MAGIX:

- double arm
- compact design
- momentum resolution: $\Delta p/p < 10^{-4}$
- acceptance: $\pm 50$ mrad
- GEM-based focal plane detectors
- Gas Jet or polarized T-shaped target
MAGIX Physics Program

- Electromagnetic Form Factors of the Nucleons
- Nucleon Polarizabilities
- Few Body Physics
- Nuclear Reactions with astrophysical Relevance
- Searches for Particles of the Dark Sector

©Klaus Hansen
The MAGIX Spectrometers

Simple Design: Quadrupole + Dipole

- 200 MeV maximum momentum
- 90 MeV momentum acceptance @ 200 MeV

Finite-element simulations

- $10^{-4}$ relative momentum resolution
- Assuming 50 μm resolution in the focal plane
The Focal Plane Detectors

2 Sensitive layers
- The first centered on the focal plane
- The second with a sizable lever arm to measure the angle
- 30 x 120 cm²

GEM Detectors
- 2D Strip readout
- 0.7% radiation length
- High rate capabilities
- Small TPC detector ???
- Aim for 50 μm resolution
Internal Gas Targets for MAGIX

Thin T-shaped foil

- Length (~ 30 cm)
- First prototype with mylar foil
- Can use polarized gases
- Estimated luminosity with polarized beam $O(>> 10^{32} \text{ cm}^{-2} \text{ s}^{-1})$

Gas Jet Target

- Supersonic gas/cluster jet
- Higher gas density ($10^{19}/\text{cm}^2$)
- O(mm) target length
- Estimated luminosity $O(10^{35} \text{ cm}^{-2} \text{ s}^{-1})$ @ $10^{19}/\text{cm}^2$
- Windowless!
- Ready in 2016!
Dark Sector Searches at MAGIX

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

Model 1: Dark Photon coupling to SM particles

→ parameter range motivated by Dark Photon relation to Dark Matter
**Model 2: Dark Photon coupling to Dark Matter**
- could still explain $(g-2)_\mu$ discrepancy
- exploit excellent momentum resolution of MAGIX (proton recoil!)
- Main background: Virtual Compton scattering

\[ e + p \rightarrow e' + p + X \]
\[ \downarrow \text{invisible} \]

\[ m_{\gamma'}^2 = (e + p - e' - p')^2 \]

Sensitivity at MAGIX currently calculated within a bachelor thesis (use of thin HVMAPS detectors for proton recoil under study)
Beam Dump Experiment (BDX) @ MESA

Electron Scattering on Beam Dump ➔ Collimated pair of Dark Matter particles!

This existing beam dump is going to be the P2 beam dump

10,000 hours @ 150 μA

10^{23} electrons on target (EOT)
**Background situation**

- FLUKA simulation of neutron background promising ($\sim 10^{11} \text{ EOT}$)
- MESA running below pion production threshold $\rightarrow$ no neutrinos!
Testing competitive parameter range

BDX@MESA, $10^{22}$ EOT, $E_e = 150$ MeV, $d = 3$ m, $m_\chi = 1$ MeV, $\alpha_D = 0.1$

G. Krnjaic + E. Izaguirre Perimeter Inst.
But what about BDX at MAMI?

Same intensity as MESA in extracted beam mode, but higher beam energy!!!

11 m underground!!!
Option 1: A1 Beam Dump

- Requires a dedicated building/well
- Could run parasitically to A1 data taking
- Maximum 1.6 GeV beam energy with $O(\text{few } 10^{21} \text{ EOT})$ per year depending on beam time
Option 2: A2 Beam Dump

- A2: Tagged photon facility
- Typically low beam intensities, but authorisation for 140μA beam should be trivial to get
- Space (many m²) with crane available after A2 beam dump (shaft)

- Very well shielded area (several m of concrete)
- $3 \times 10^{21}$ EOT with 1.6 GeV beam per 1000 hours (6 weeks) – MAMI running 7000 hours per year
- No parasitic running
BDX @ MAMI, Bunch-Structure

- Standard operation of MAMI with 2.45 GHz microwave frequency
  → bad for TOF purpose for BDX
- Recently single bunch tests carried out at MAMI
- Findings:
  - Bunch spacing can be varied almost arbitrarily
  - Drop of intensity
  - 12 ns bunch spacing @ 20 µA immediately achieved
  - 100 ns bunch spacing @ 3 µA possible
- These numbers are conservative estimates
  (A PhD student is working on this)
Conclusions
Conclusions

• Competitive results achieved at A1/MAMI

• MESA will be operational ~2020

Great opportunities for Dark Sector physics and beyond; Experiences from Dark Light / JLAB!

• Beam Dump Experiment at MESA and MAMI

- $10^{23}$ EOT parasitically to P2 data taking (0,155 GeV)
- $10^{22}$ EOT in 3000 h of beam time (1,6 GeV)
- Option to go for larger bunch spacing 12 ... 100 ns

Dedicated beam time for BDX measurement .... ?!