New Fixed-Target Experiments to Search for Dark Gauge Forces

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see: 0906.0580
New Gauge Forces

DAMA/LIBRA is suggestive of a small MeV mass scale and new gauge force

PAMELA/ATIC/FERMI is suggestive of a MeV-GeV mass scale and new gauge force

With SUSY, new weak-scale gauge forces are natural in any event
New Gauge Forces

A new gauge force nicely explains a variety of data

This might be true!

How do we find out?
New Gauge Forces

A minimal starting assumption:

$$\epsilon F^\mu_\nu D F^Y_\mu_\nu$$ operator and nothing lighter than $m_{A'}$
in the dark sector

[Holdom ‘86]

$A'$ decays back to electrons, muons (and pions)

Astrophysics constraints suggestive of minimality

Other decays (including invisible) can be probed as well

keep in mind that dark sector may be complicated

[Essig, PS, Toro; Batell, Pospelov, Ritz]
Outline

A program of fixed-target experiments that can search for MeV-GeV gauge forces

• Why fixed-target is best
• Why it’s hard
• Where it gets you
Collider vs. Fixed-Target

\[ \sigma \sim \frac{\alpha^2 \epsilon^2}{E^2} \]

\[ \sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \]

\[ 10^{11} e^- \times 10^{11} e^+ \text{ (in 5 ns)} \]

\[ 10^7 e^- \times 10^{19} Z \text{ (in 5 ns)} \]

O(few) \( ab^{-1} \) per decade

O(few) \( ab^{-1} \) per day
Unique Fixed-Target Kinematics

\[ \frac{d\sigma}{dx} \propto \frac{\alpha^3}{\pi} \frac{1}{m_e^2 \cdot x \cdot m_A^2 (1 - x)/x} \]

- \[ \theta_{\text{prod}} \sim \left( \frac{m_A}{E} \right)^{3/2} \] (narrow)
- \[ \theta_{\text{recoil}} \sim \left( \frac{m_A}{E} \right)^{1/2} \] (wide)
- Heavier product (here A') takes most of beam energy

Energy = E

Kinematics very different from massless photon bremsstrahlung
The Advantages of Fixed-Target

- Large luminosity advantage
- Larger production cross-sections (nuclear charge coherence)
- Compact detectors can be used to exploit unique kinematics
Fixed-Target Territory

\[ (g - 2)_e \quad (g - 2)_\mu \]

\[ \Upsilon(3S) \rightarrow (\mu^+ \mu^-) \gamma \]

 BABAR

\[ c\tau \approx 80 \mu m \]
\[ c\tau \approx 1 \text{ cm} \]

[Essig, PS, Toro; Batell, Pospelov, Ritz]

[Pospelov et al; Reece and Wang]

MegaWatt x Year lower limit for seeing >10 events

prompt decays

cm-m decays

m-10's km

[Essig, PS, Toro; Batell, Pospelov, Ritz]
Beam Dump Experiments

SLAC E137: 30 C at 20 GeV (200 m shield)

SLAC E141: mC of electrons at 9 GeV (12 cm W target)

FNAL E774: nC of electrons at 275 GeV (20 cm W target)
Past Beam Dump Limits

$\epsilon$

$10^{-2}$ $10^{-1}$ 1

$10^{-2}$ $10^{-3}$ $10^{-4}$ $10^{-5}$ $10^{-6}$ $10^{-7}$ $10^{-8}$ $10^{-9}$

$m_{A'}$ (GeV)

$\alpha_e$ $\alpha_\mu$ Y(3S) E774 E141 E137 SN
New Beam Dump Reach

Good Beams:
- FEL at JLab
- SLAC
- ELSA, Mainzer Mikrotron (MAMI), Max-lab
Displaced Vertex

thin target

tracking

calorimeter
Instrumental Limit to Sensitivity

[Thanks to Takashi Maruyama (SLAC)]

Clean signal but...
Large forward rate **fries** detector!

Rate (10 nA)

Depends on boost: need **multiple** geometries & energies

Max. current

Lower epsilon limit

signal kinematics

100 mrad (E/m~10)

300 mrad (E/m~3)
Bump Hunting

Max Signal to Background:

\[
\frac{\alpha}{\pi} \frac{\epsilon^2}{\text{mass resolution}} \frac{\text{mass}}{\text{mass}}
\]

Must exploit kinematics to achieve this!

\[
\epsilon_{\text{min}} \sim L^{-1/4}
\]

model-dependent
Summary: Discovery Approaches

\[ \gamma c \tau \sim m \]  Beam dump  Low-background

\[ \gamma c \tau \sim cm \]  Vertex  Clean signal, Limited by instrumental bkg

\[ \gamma c \tau \ll cm \]  Bump hunt  Fight background with high intensity, resolution

Same device, different analyses (x several geometries)
A Fixed-Target Search Program

1st generation reach of experiments: see 0906.0580

Existing facilities (JLab) and detection methods
Future Prospects

Clear physics program to look for new gauge force at existing labs (JLab & SLAC)

Tremendous discovery potential!

“Invisible” decay modes should be striking (recoil), especially with the “diffuse beam” design, so this is only the beginning...

Numerous alternative approaches not discussed (muon beams, neutrino detectors...etc)
Backup
Diffuse Beam Approach

Si strip tracking → thin W target → ecal/trigger

Reconstructed tracks and A' decay vertex
Two-Arm Spectrometer

Beam's eye:

0.1 X^0 W

tracking stations

cal/trigger

A

B

C