DARK PHOTONS FROM THE SUN
A NEW DARK MATTER SIGNAL FOR AMS

[work with Jordan Smolinsky and Philip Tanedo, 1602.01465]

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THE CONVENTIONAL DARK MATTER SIGNAL

- There is now overwhelming evidence for dark matter.
- A promising search method is indirect detection, particularly dark matter annihilating to positrons and detected by AMS:
  \[
  \text{DM} \rightarrow e^+ + e^-
  \]
- The signal is nearly isotropic, coming from the whole halo.
- Is there a smoking gun signal that makes better use of AMS’s remarkable angular resolution?

AMS Days at CERN, 2015
DARK SECTOR

• Dark matter $X$ may be part of a dark sector, with its own matter and forces.

• Consider a simple example, where the dark sector contains dark matter, but also a U(1) gauge interaction, “dark electromagnetism.”
SM-DARK SECTOR INTERACTIONS

• If the dark matter doesn’t interact with us, then it only has gravitational signals.

• However, generically, there will be a mixing between our U(1) gauge boson $A$ and the dark U(1) gauge boson $A_D$.

• This mixing will be generated by any matter field that has both standard model EM charge and dark EM charge.

• It is typically small, since it is induced by a loop.

DARK PHOTONS

• We can re-define fields to remove the mixing. The result is two physical particles: our SM photon $\gamma$, and a new particle, the dark photon $A'$. 

• The dark photon is like the SM photon, but
  – It can have a mass $m_{A'}$
  – Its coupling to dark sector particles is large
  – Its coupling to SM particles is suppressed by a small coupling $\varepsilon$
A NEW DARK MATTER SIGNAL

• In this dark matter model, dark matter collects in the Sun and then annihilates to dark photons ("dark sunshine").

• These can then travel out of the Sun and decay to $e^+e^-$.  

• A new DM signal for AMS: high energy positrons from the Sun.
SIGNAL CHARACTERISTICS

- We will consider parameters
  - Dark matter $m_X \sim 100$ GeV – 10 TeV
  - Dark photon $m_{A'} \sim$ MeV – GeV
  - Couplings $\varepsilon \sim 10^{-12} – 10^{-6}$

- The typical positron energy is $\sim 100$ GeV – 10 TeV

- The size of the DM population at the core of the Sun is $\sim 1^\circ$.

- AMS’s angular resolution: $\Delta \theta_{68} \sim \sqrt{5.8^2/(E \text{ in GeV}) + 0.23^2}$ from ECAL (and even better with tracker); negligible.

- The signal is essentially a point source of TeV positrons from the center of the Sun. No background looks like this!
MAGNETIC FIELDS

- In more detail, TeV positrons are bent in the magnetic fields of the Sun and Earth.

- The Sun’s magnetic field is not well understood. Conservatively, we can consider only dark photons that travel far enough before decaying.

- The Earth’s magnetic field is well understood. Assume we can deconvolute for this effect. (But note, without deconvoluting, the signal will not appear point-like.)
ISOTROPIC BACKGROUND AND EXPOSURE

• The background isotropic positron flux from AMS is

\[
\frac{d\Phi}{dE} \approx \frac{1.5 \times 10^{-9}}{\text{GeV cm}^2 \text{ sr s}} \left( \frac{E}{100 \text{ GeV}} \right)^{-2.8}
\]

We consider an energy and angle window that fixes \( N_{\text{background}} = 1 \) and maximizes signal.

• Last, of course, the Sun is not always in AMS’s field of view. In 924 days, the exposure for \( E > 50 \text{ GeV} \) was

\[
\xi_{\odot} \approx 1.6 \times 10^5 \text{ m}^2 \text{ s}
\]

The effective area is \( \sim 20 \text{ cm}^2 \), would be 80 times larger if AMS pointed at the Sun continuously.

Machate, Gast, Schael for the AMS Collaboration (2016)
RESULTS

• For 3 years of AMS data, AMS probes new regions of parameter space beyond existing constraints.

• Direct detection constraints are competitive, but model-dependent.

Smolinsky, Tanedo, 1701.03168
RESULTS

• Same as above, but for high exposure (80 times larger).

• All results can be greatly improved with knowledge of Sun’s magnetic field.
CONCLUSIONS

• If dark matter is generalized to a dark sector with its own forces, many new dark matter signals are possible.

• For AMS, an interesting one is “dark sunshine,” dark photons from the Sun, which decay to positrons and electrons.

• Exploits AMS’s fantastic angular resolution and event rates. Potentially a smoking gun signal with no astrophysical background.