Search for Dark Photon Decay Via $A' \to \ell^+\ell^-$ in SciBooNE and ANNIE

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FERMILAB-POSTER-23-241-STUDENT-T

Introduction to Dark Photons

Dark photons (A') are a theorized type of new vector boson which, through kinetic mixing with the Standard Model (SM) $U(1)$ hypercharge group, acquires a small couplings to SM fermions. Dark photons interact through the vector portal

$$\mathcal{L} \supset \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} - \frac{\varepsilon}{2} F^{\mu\nu} F'_{\mu\nu} + \frac{m_{A'}^2}{2} A'_\mu A'^\mu,$$

where A' has a mass $m_{A'}$, field strength $F'_{\mu\nu}$, and kinetic mixing strength ε.

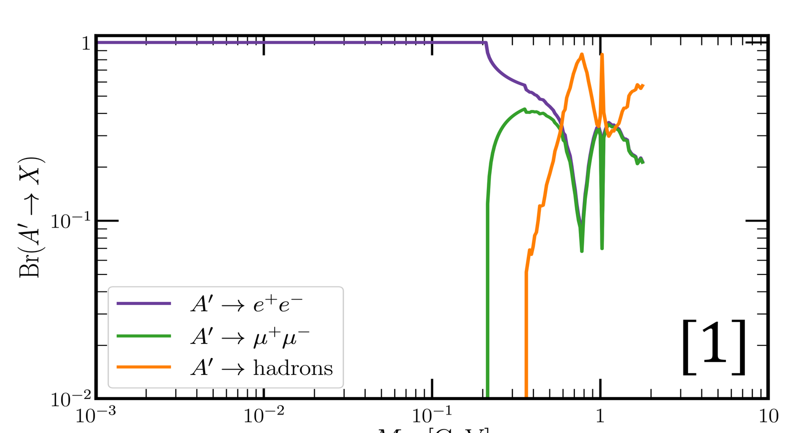
Dark Photon Decay

In this study, we focus on visible A' decays, specifically $A' \to \ell^+\ell^-$. We require that, if other dark matter χ exists, A' will decay into only SM particles, such that $m_{A'} < 2m_\chi$. We can calculate A' decay width for lepton pair decay

$$\Gamma(A' \to \ell^+\ell^-) = \frac{1}{3} \alpha \varepsilon^2 m_{A'} \sqrt{1 - \frac{3m_\ell^2}{m_{A'}^2}} \left(1 + \frac{2m_\ell^2}{m_{A'^2}}\right),$$

and the total width as

$$\Gamma = \sum^{leptons} \Gamma(A' \to \ell^+\ell^-) + \sum^{hadrons} \Gamma(A' \to hadrons).$$



[1]

Then, we can calculate the amount of A' that decay between within a distance from d_i to d_f as

$$N(t) = N_0 \left(e^{-\frac{t_i \Gamma}{\hbar}} - e^{-\frac{t_f \Gamma}{\hbar}}\right) = N_0 \left(e^{\frac{-\Gamma d_f}{c\hbar\sqrt{\gamma^2-1}}} - e^{\frac{-\Gamma d_i}{c\hbar\sqrt{\gamma^2-1}}}\right).$$

Conclusions and Future Work

While SciBooNE's expected sensitivity to $A' \to \ell^+\ell^-$ from $\pi^0 \to \gamma A'$ does not extend past existing constraints, there are many more modes of production and decay which need to be factored into our study. We expect that adding $\eta \to \gamma A'$ and $pp \to ppA'$ will significantly increase the parameter space able to be tested by SciBooNE and ANNIE. Additionally, we neglected to include any hadronic A' decays such as $A' \to \pi^+\pi^-, A' \to K^+K^-, A' \to \pi^+\pi^-\pi^0$, etc. [2].

Another consideration is availability of statistics. While SciBooNE is limited to 2.52E20 POT, ANNIE is a currently existing experiment, and thus can record significantly more data.

Regardless of the expected sensitivity of these studies, they require no additional detector budget. Neutrino experiments in general, due to their primary observable being photons, have the ability to expand well outside of their proposed scientific goals.

References

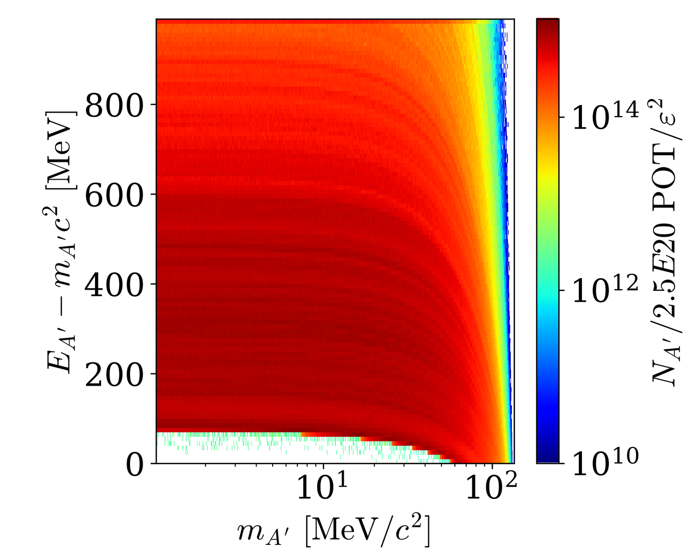
[1] 10.1007/jhep02(2020)174
[2] 10.1007/jhep07(2015)045
[3] 10.1007/jhep06(2018)004
[4] 10.1007/jhep11(2022)124
[5] arXiv:1707.08222 (2017)
[6] 10.1088/17426596/120/5/052043
[7] 10.1103/physrevd.79.072002

Dark Photon Production In the Booster Neutrino Beam

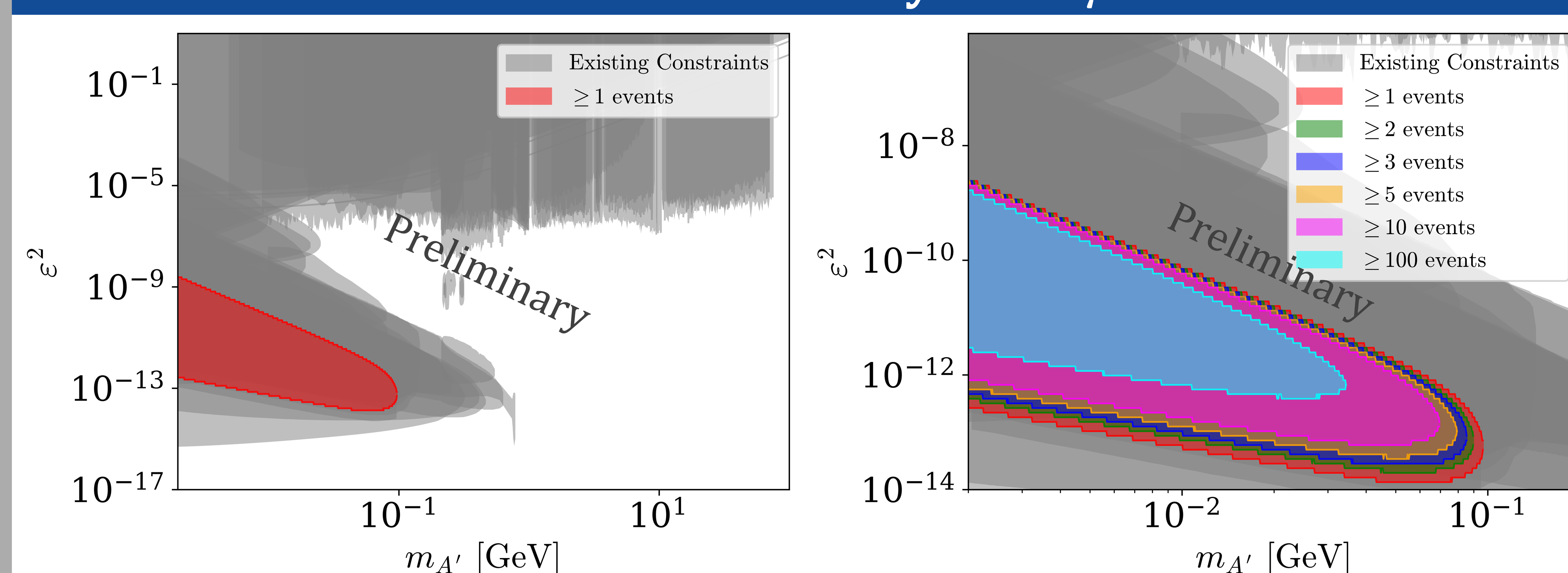
The Booster Neutrino Beam (BNB) [7] at Fermilab uses 8.89 GeV/c momentum protons incident on a beryllium target to create $\pi^\pm$ (and $K^\pm$) which subsequently decay into $\nu/\bar{\nu}$. Dark photons can be produced from any interaction that produces a final state photon. The most common of these in the BNB is $\pi^0 \to \gamma A'$.

BNB simulations only record decays which produce a neutrino. Thus, they contain no information about π^0 or η. However, with the assumption that $\langle p_{\pi^\pm} \rangle \approx \langle p_{\pi^0} \rangle$, we can predict the number of A' produced in the BNB using the meson (m) branching ratio (Br)

$$\mathrm{Br}(m \to \gamma A') = \mathrm{Br}(m \to \gamma\gamma) \times 2\varepsilon^2 \left(1 - \frac{m_{A'}^2}{m_m^2}\right)^3.$$

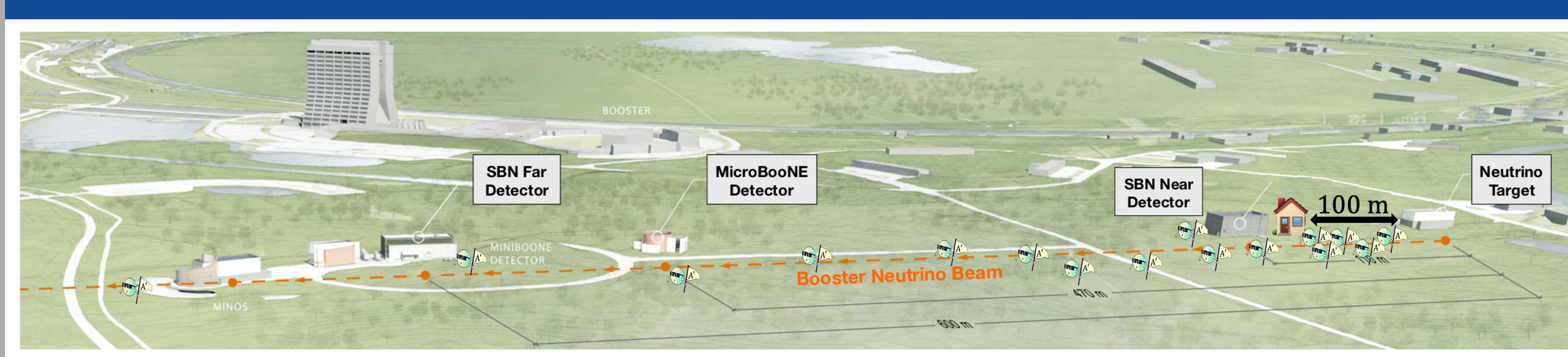


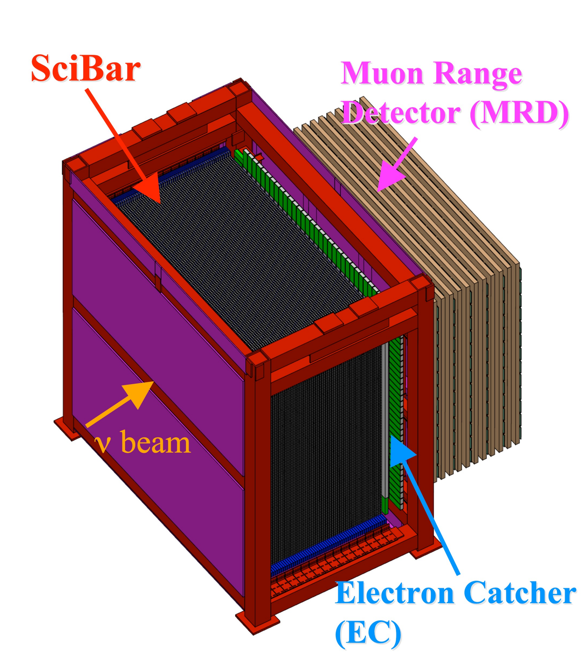
Expected Sensitivity of SciBooNE's $2.52E20$ POT to $A' \to \ell^+\ell^-$ from only $\pi^0 \to \gamma A'$



Plots made with DarkCast [3,4]

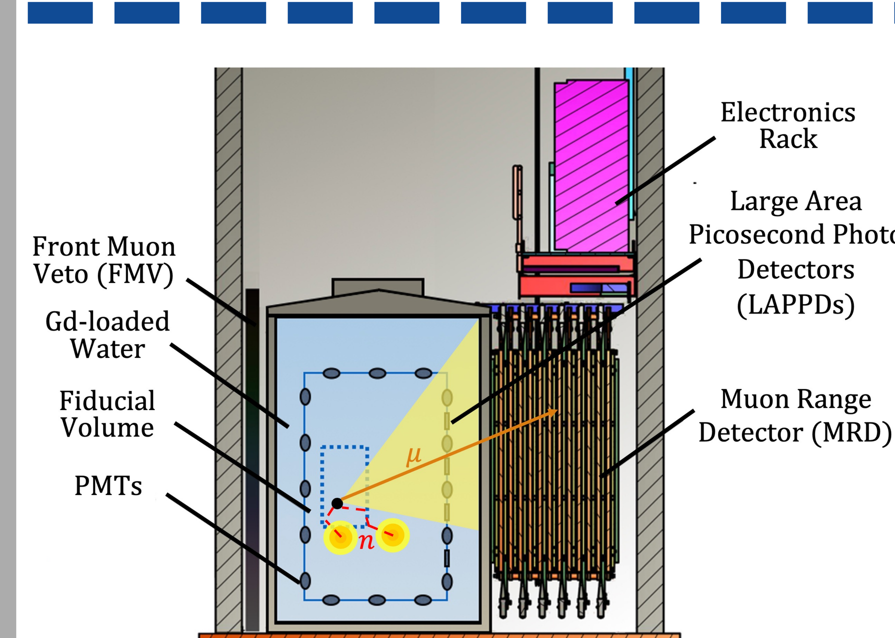
SciBooNE and ANNIE on the Booster Neutrino Beam





SciBooNE (Scintillator Booster Neutrino Experiment) [6]

- Ran from Jun 07 to Aug 08
- $2.52E20$ POT $= (1.53\bar{\nu} + 0.99\nu)E20$ POT
- Use segmented plastic scintillators
  - SciBar: $3\times3\times1.7$ m^3, 14,336 bars, read out by multi-anode PMT
  - MRD: alternating layers of scintillator and iron (12 each), 362 total panels each with PMT
- Allows for simple event reconstruction and background tagging



ANNIE (Accelerator Neutrino Neutron Interaction Experiment) [5]

- Currently taking calibration data
- Uses 132 PMT and 5 LAPPDs
- Standard fiducial volume of 3 m^3 which is limited to increase neutron capture efficiency can be greatly increased for this study
- Approximately the same MRD as SciBooNE