A Dark Seesaw at Low Energy Experiments

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Based on 2007.11813
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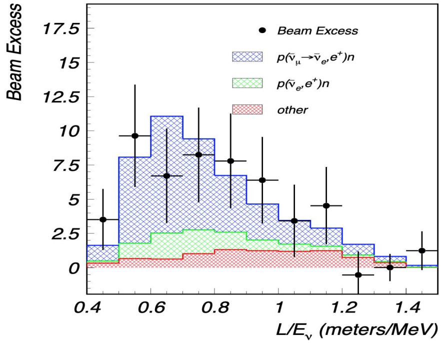
Short baseline anomalies

Where do the short baseline anomalies point us?

LSND

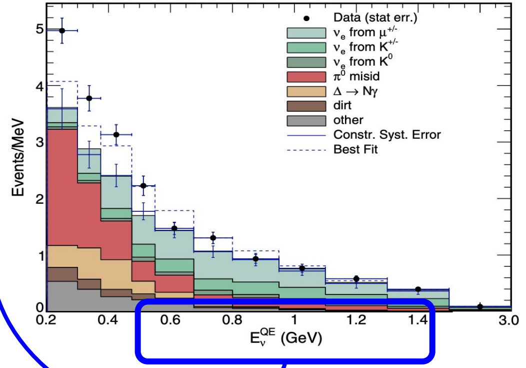
10.1103/PhysRevD.64.112007



A **3.8 sigma** excess of 87.9 ± 22.4 ± 6 events

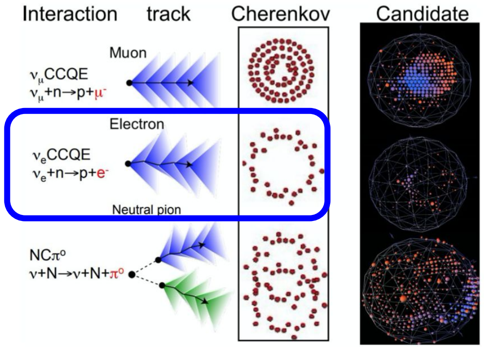
MiniBooNE

10.1103/PhysRevLett.121.2 1801

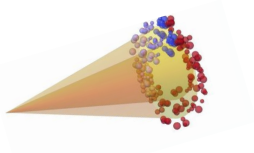


LSND EXCESS REGION

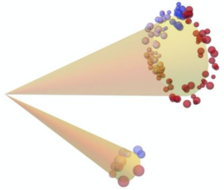
A **4.8 sigma** excess of 560.6 ± 119.6 (77.4 ± 28.5) events in nu (anti-nu) mode



Possible alternatives to standard electron or photon hypotheses are:



Overlapping e+e-



Asymmetric pair of e+e-

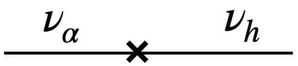
Portals to a neutral dark sector

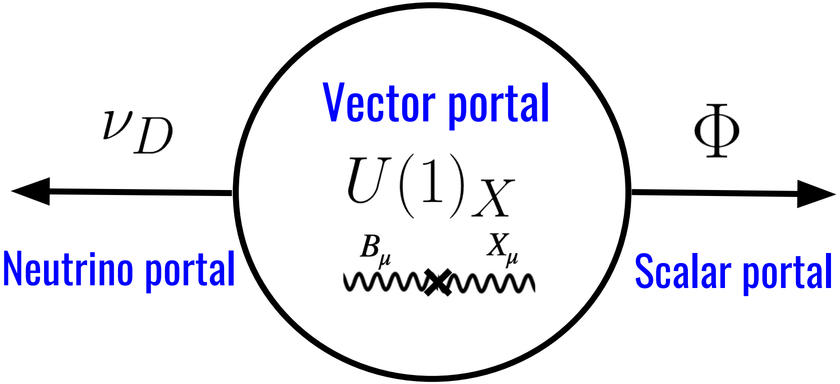
How do we build a model that can give us the right signature?

Fermions charged under dark force

$$\mathcal{L} \supset -y_D \overline{N} \Phi \nu_D^c$$
$$\mathcal{L} \supset -y_N \overline{L} \tilde{H} N$$

Additional sterile neutrino allows mass mixing with SM neutrinos



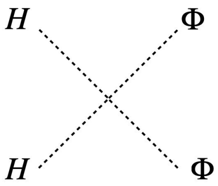


Standard three portal connections to SM arise naturally

Need scalar to break U(1) and give mass to dark photon

$$\mathcal{L} \supset -\lambda_{\Phi H} |\Phi|^2 |H|^2$$

No reason to not have mixing with SM Higgs



The Dark Seesaw Model

Particle content

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
$\hat{\nu}_N$	$\mathbf{1}$	$\mathbf{1}$	0	0
$\hat{\nu}_{D_L}$	$\mathbf{1}$	$\mathbf{1}$	0	Q_X
$\hat{\nu}_{D_R}$	$\mathbf{1}$	$\mathbf{1}$	0	Q_X
Φ	$\mathbf{1}$	$\mathbf{1}$	0	Q_X

Three steriles N + pair of LH and RH dark neutrinos

Neutrino masses

$$\mathcal{L}_{\nu-\text{mass}} = \frac{1}{2}\overline{\hat{\nu}_f^c}\begin{pmatrix} 0 & M_D & 0 & 0 \\ M_D^T & M_N & \Lambda_L & \Lambda_R \\ 0 & \Lambda_L^T & 0 & M_X \\ 0 & \Lambda_R^T & M_X^T & 0 \end{pmatrix}\hat{\nu}_f + \text{ h.c.}$$

Inverse seesaw type mass mechanism

Phenomenology

States of interest: ν_4, ν_5, ν_6

BP for this talk:

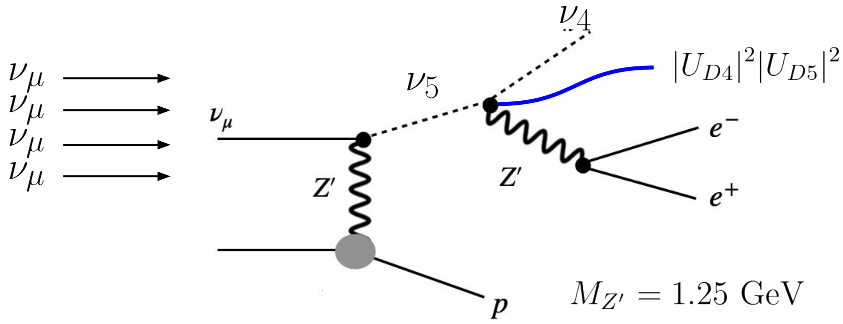
α_D	m_3 /eV	m_4 /MeV	m_5 /MeV	m_6 /MeV	$c\tau^0$/cm N_4	$c\tau^0$/cm N_5	$c\tau^0$/cm N_6
0.32	0.05	74	146	220	1.1×10^7	2.2	0.14

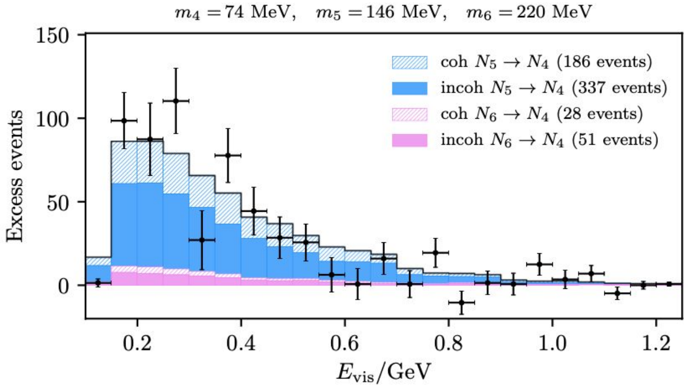
Three heavy neutrinos at the **O(100) MeV** scale

Two short-lived **O(mm~cm) decay lengths**

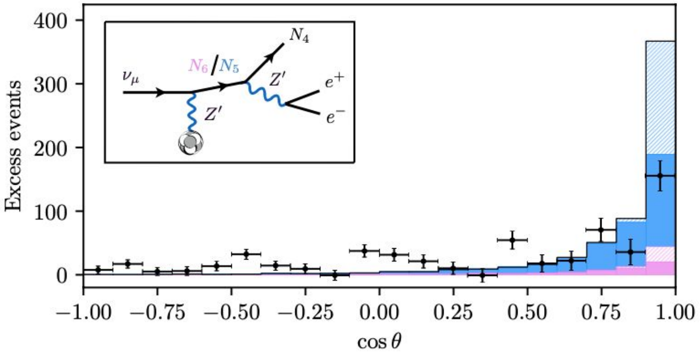
MiniBooNE

Incoming muon neutrinos upscatter incoherently (or coherently) off of carbon and hydrogen nuclei (or protons)…





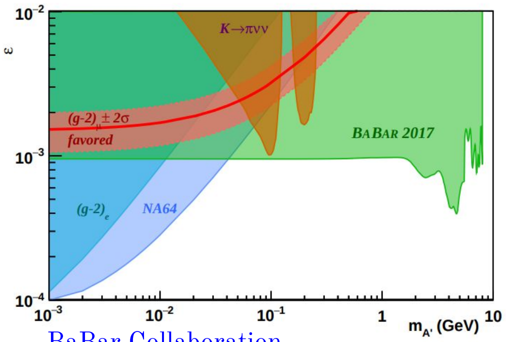
…producing a pair of boosted e+e- and possibly an invisible proton in the final state



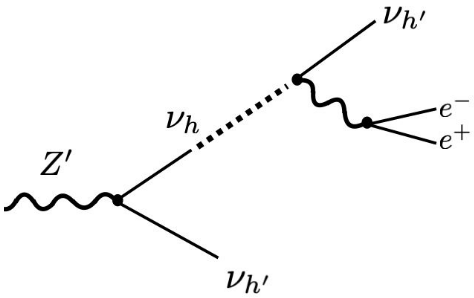
Dark photon and $(g-2)_\mu$

Minimal dark photon explanations of the muon $(g-2)_\mu$ all but ruled out

Strongest bound on our model comes from BaBar's search for an invisibly decaying dark photon in $e^+e^- \to \gamma Z'$

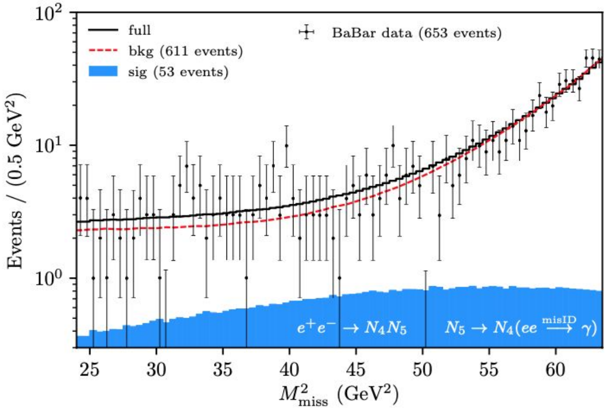


BaBar Collaboration
10.1103/PhysRevLett.119.131804



For our 1.25 GeV dark photon, require an **invisible branching ratio of below 0.22%** for an explanation of the muon $(g-2)_\mu$

In fact, BaBar's monophoton data set appears to have an excess compatible with a semi-visibly decaying dark photon

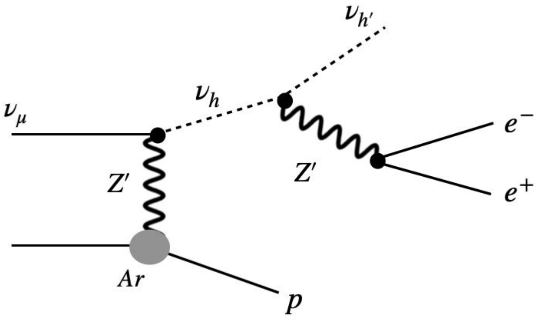


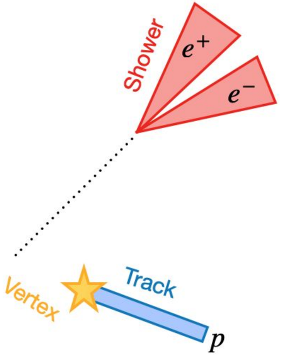
2.5σ preference for a dark neutrino signal

Searches for Dark Neutrinos

How can we search for our model at experiment?

@ MicroBooNE (work in progress)

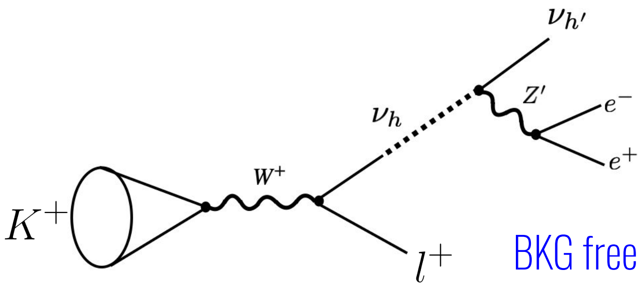




Signal: Visible proton track + EM shower
Or single shower

Possibility of distinguishing from single photon/electron MiniBooNE hypotheses with calorimetric information as well as shower-vertex distances

@ NA62 Kaon decays to heavy neutrinos and leptons



BKG free process!

Sensitive to BOTH heavy neutrino masses

$$(p_K - p_l)^2 = m_h^2 \quad (p_K - p_l - p_{ee})^2 = m_{h'}^2$$

$$p_{ee}^2 = (p_{e^+} + p_{e^-})^2 \leq (m_h - m_{h'})^2$$

Summary

- ★ There is a need to fully explore the range of possible light dark sectors
- ★ Dark neutrino models are able to offer an alternative explanation for MiniBooNE excess
- ★ Simultaneously able to address a number of anomalous results: $(g-2)_\mu$, PS-191, E816, etc.
- ★ Provides us with a multitude of possible signatures to be searched for at e.g. MicroBooNE, NA62, IceCube etc.

Thank you!