A LIGHT DARK NEUTRINO SECTOR

Radiative masses & ν BSM portals

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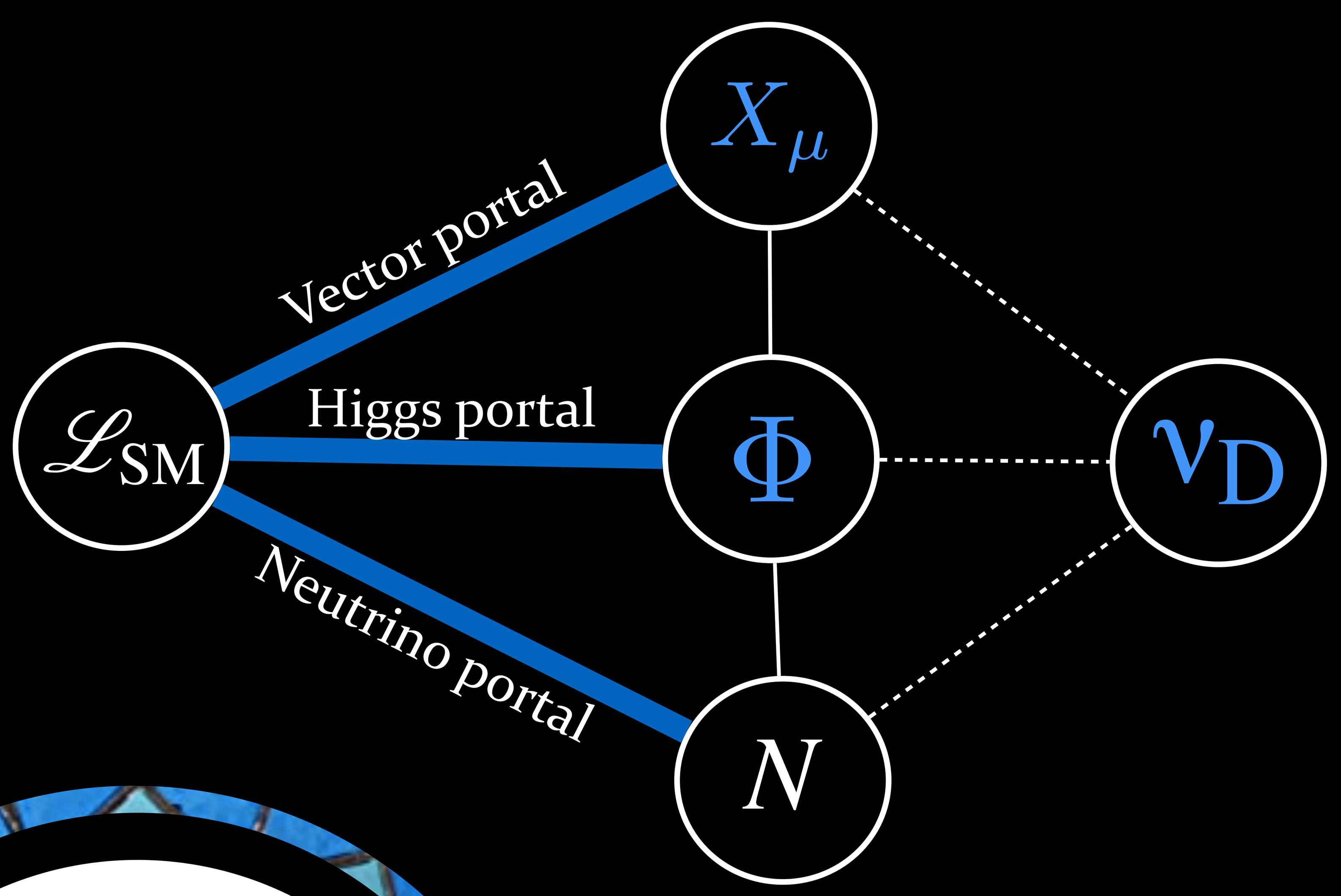
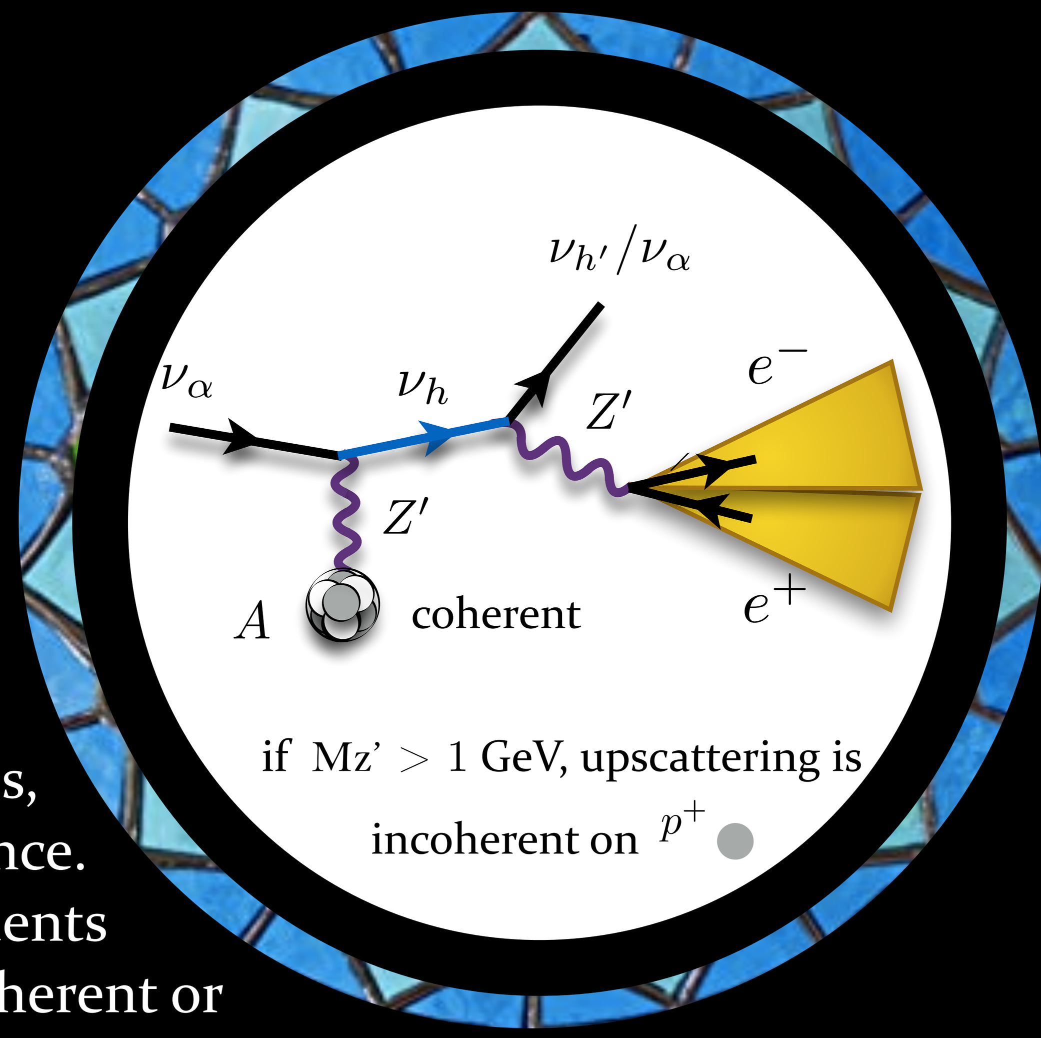
Three portal connection to the SM



UPSCATTERING

Active neutrinos can upscatter into heavy neutrinos, which then decay in cm distance. Typical signatures are NC tridents or charged pion pairs from coherent or incoherent scattering.



MINIBOONE

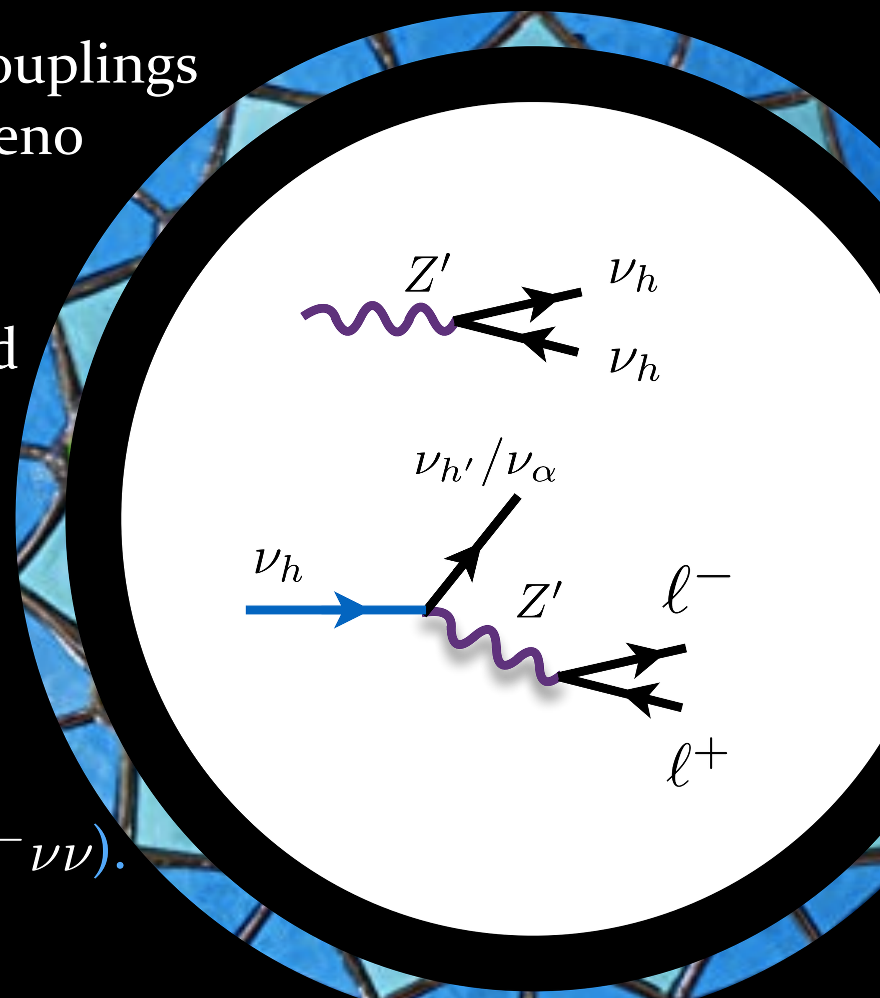
The **MiniBooNE** excess of low energy electron-like events is explained with upscattering followed by decay into electrons. Require Mz' = 1 GeV to reproduce angular distribution. Unique interplay of neutrino and vector portals.

ν DARK PORTALS

Scalar	Vector	Neutrino
$\lambda_{\Phi H} H^\dagger H \lvert\Phi\rvert^2$	$\frac{\sin\chi}{2} B_{\mu\nu} X^{\mu\nu}$	$y_\nu \left(\overline{L}\cdot\tilde{H}\right) N^c$

The interplay of 2 or more portals couplings coexisting leads to very different pheno from each case taken separately.

Evades most dark photon, scalar and heavy neutrino searches. New exp. vetoes required (3-body decays).



Important implications for:

- muon (g-2) via kinetic mixing,
- neutrino scattering experiments,
- rare meson decays ($K^+ \to \mu^+ e^+ e^- \nu\nu$).

	$SU(2)_L$	$U(1)_Y$	$U(1)'$
N	**1**	0	0
ν_D	**1**	0	Q
Φ	**1**	0	Q

Neutrino portal DM

χ_L χ_R

	$U(1)'$	$\mathcal{Z}_2$
χ_L	0	-1
χ_R	Q	-1

DARK MATTER

Anomaly cancellation requires extra field content. One option is to add a pair of chiral fields and charge only the RH field under the U(1)' symmetry. If these possess a $\mathcal{Z}_2$ symmetry not shared by the SM, they provide a Dark Matter candidate with a phenomenology strongly connected to the neutrino sector.

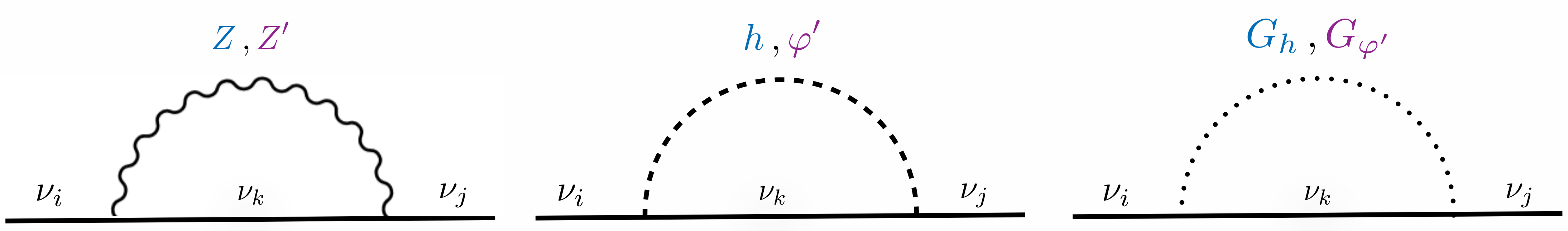
Radiative neutrino masses from dark neutrinos

The one active generation neutrino mass matrix reads:

$$\mathscr{L}_{\rm mass} \supset \frac{1}{2}\begin{pmatrix}\overline{\nu_\alpha} & \overline{N} & \overline{\nu_D}\end{pmatrix}\begin{pmatrix}0 & m_D & 0\\ m_D & \mu' & \Lambda\\ 0 & \Lambda & 0\end{pmatrix}\begin{pmatrix}\nu_\alpha^c\\ N^c\\ \nu_D^c\end{pmatrix} \longrightarrow$$

Massless light neutrinos at tree-level!

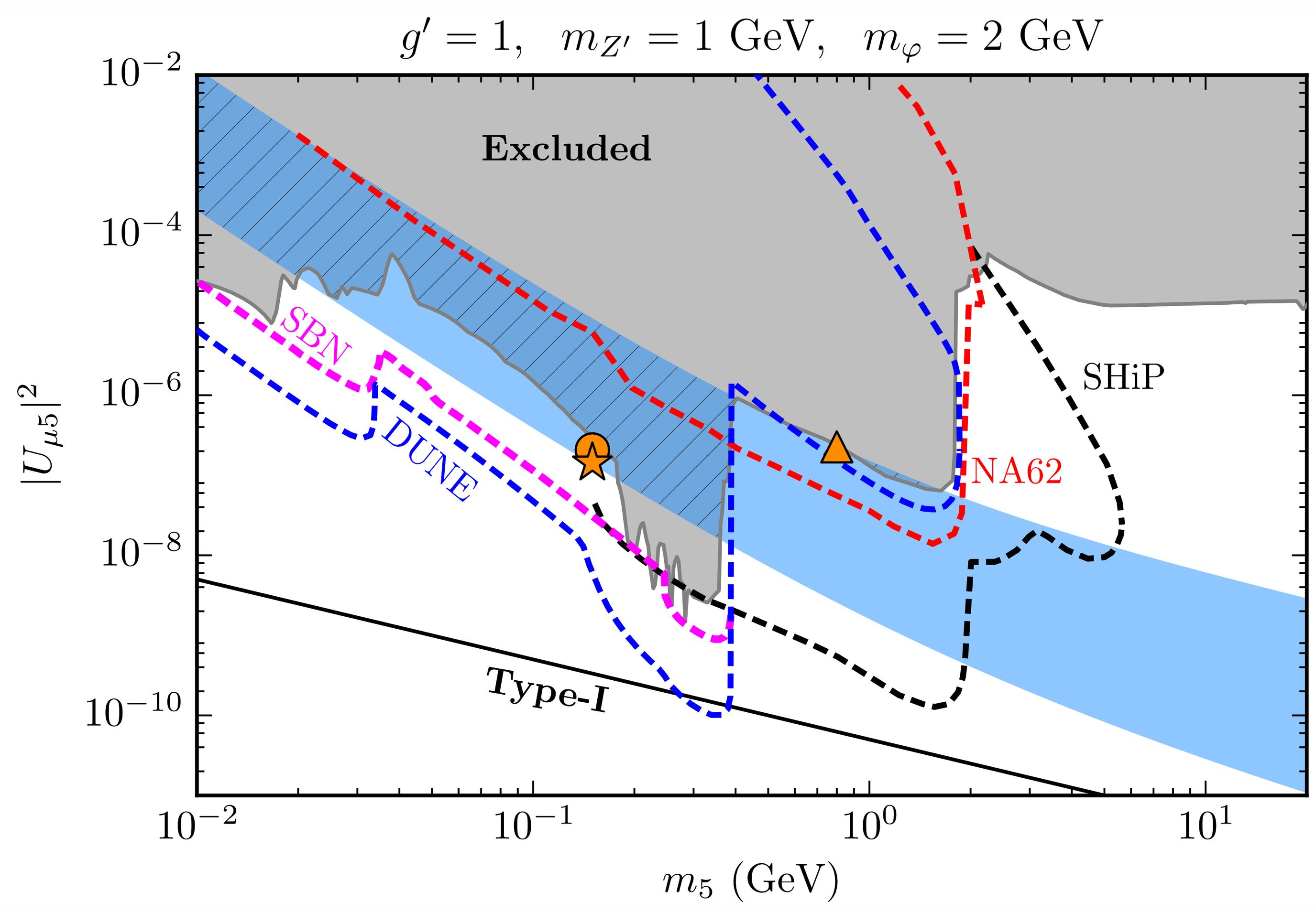
At one-loop level, non-zero masses are generated (δm_L and $\delta\mu$):



With 3 generations, the one-loop light neutrino mass matrix is given by:

$$m_{ij} = \frac{1}{4\pi^2}\sum_{k=4}^{5}\left[C_{ik}C_{jk}\frac{m_k^3}{m_Z^2}F(m_k^2, m_Z^2, m_h^2) + D_{ik}D_{jk}\frac{m_k^3}{m_{Z'}^2}F(m_k^2, m_{Z'}^2, m_{\varphi'}^2)\right],$$

where the SM couplings are $C_{ik} \equiv \frac{g}{4c_W}\sum_{\alpha=e}^{\tau} U_{\alpha i}^* U_{\alpha k}$ and the BSM $D_{ik} \equiv \frac{g'}{2} U_{Di}^* U_{Dk}$.



The active-heavy neutrino mixing as a function of the ν_5 mass. The blue band shows where the light neutrino masses are achieved by varying R.

$$R = \frac{m_4}{m_5} = -\frac{U_{\alpha 5}^2}{U_{\alpha 4}^2}$$

R = 1% — ESS-like
R = 99% — ISS-like

[1] P. Ballett, **MH,** S. Pascoli. (2019), Dark Neutrinos and a Three Portal Connection to the Standard Model, 1903.07589.
[2] P. Ballett, **MH,** S. Pascoli. (2019), Neutrino Masses from a Dark Neutrino Sector below the Electroweak Scale, 1903.07590.
[3] E. Bertuzzo et al. (2018), Dark Neutrino Portal to Explain MiniBooNE excess, 1807.09877.
[4] P. Ballett et al. (2018), U(1)' mediated decays of heavy sterile neutrinos in MiniBooNE, 1808.02915.

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