

Opportunities and signatures of NON-MINIMAL HEAVY NEUTRAL LEPTONS

**NF03 kick-off meeting
day 1**

**Neutrino Frontier
BSM topical group**

Matheus Hostert

*University of Minnesota,
William I. Fine Institute
&
Perimeter Institute*



UNIVERSITY OF MINNESOTA



PERIMETER
INSTITUTE

Heavy Neutral Leptons

the wild card of BSM phenomenologists

Neutrino masses

Type-I seesaw, low-scale variants, and more exotic.

Baryon asymmetry of the Universe

Leptogenesis, nu-assisted EW baryogenesis.

Dark matter

Warm DM or portal to dark sector.

Experimental anomalies

Short-baselines, Hubble, XENON1T, + others.



matter particles

Singlet fermions will, in general, mix with SM neutrinos

LHN

Majorana or Dirac mass scale of N are, in principle, arbitrary.

No conclusive evidence for minimal sterile ν so far.*

Have we missed anything?

** SBL anomalies may be pointing to **something** interesting, but very unlikely to look anything like usual 3+1 models.*

No conclusive evidence for minimal sterile ν so far.

Have we missed anything?

Minimality is a great principle,
but what if the complexity (\neq contrivance/fine-tuning)
of new physics is hiding right under our noses?

Beyond Minimality

HNLs as a bridge to exotic sectors

Approach I

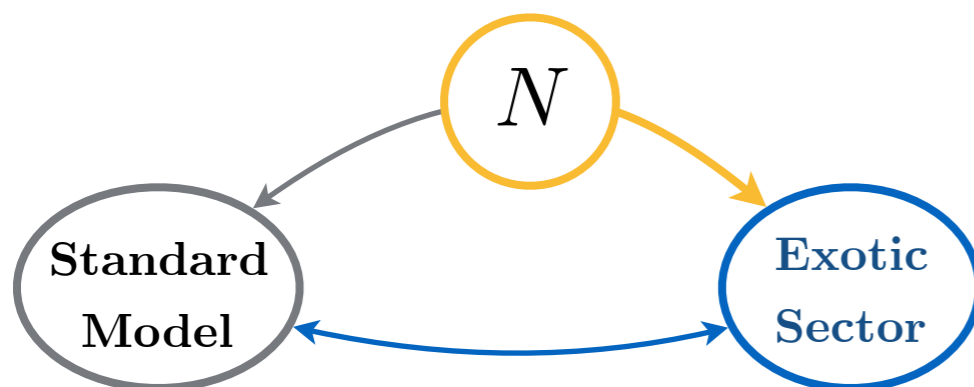
Multiple mass scales and new symmetries in the neutral lepton mass matrix.

nuMSM, inverse/linear/extended seesaws, ...

Approach II

Neutral leptons as part of/portal to some exotic sector in nature

new gauge symmetries,
scalar sectors,
effective operators,
dark sectors,



Opportunities and signatures of non-minimal Heavy Neutral Leptons

Contact Information:

Carlos A. Argüelles (Harvard University) [carguelles@fas.harvard.edu]

Matheus Hostert (University of Minnesota) [mhostert@umn.edu]

Pedro A. N. Machado (Fermilab) [pmachado@fnal.gov]

Silvia Pascoli (Durham University) [silvia.pascoli@durham.ac.uk]

Author List

Asmaa Abada¹, Kevork N. Abazajian², Asli Abdullahi³, Sanjib Kumar Agarwalla⁴, J. A. Aguilar⁵, Wolfgang Altmannshofer⁶, Carlos A. Argüelles⁷, A. B. Balantekin⁸, Gabriela Barenboim⁹, Brian Batell¹⁰, John F. Beacom¹¹, Joshua Berger¹², Nicolás Bernal¹³, Jeffrey M. Berryman¹⁴, Summer Blot¹⁵, Patrick D. Bolton¹⁶, Vedran Brdar¹⁷, Mauricio Bustamante¹⁸, Rodolfo Capdevilla¹⁹, Sabya Sachi Chatterjee²⁰, Sandhya Choubey²¹, James M. Cline²², Pilar Coloma²³, Janet M. Conrad²⁴, J. B. Dent²⁵, Peter B. Denton²⁶, P. S. Bhupal Dev²⁷, Tyce DeYoung²⁸, Andrea Donini²⁹, Marco Drewes³⁰, Maíra Dutra³¹, Bhaskar Dutta³², Ivan Esteban³³, Malcolm Fairbairn³⁴, Kareem R.H.A.M. Farrag³⁵, Yasaman Farzan³⁶, Enrique Fernández-Martínez³⁷, Oliver Fischer³⁸, Leander Fischer³⁹, Chee Sheng Fong⁴⁰, Nicolò Foppiani⁴¹, Alexander Friedland⁴², Shao-Feng Ge⁴³, Julia Gehrlein⁴⁴, Carlo Giunti⁴⁵, Manuel González-López⁴⁶, Stefania Gori⁴⁷, André de Gouvêa⁴⁸, Lukas Graf⁴⁹, Julia Harz⁵⁰, Julian Heeck⁵¹, Josu Hernández-García⁵², Pilar Hernandez⁵³, Matheus Hostert⁵⁴, Patrick Huber⁵⁵, Alejandro Ibarra⁵⁶, Sudip Jana⁵⁷, Georgia Karagiorgi⁵⁸, Teppei Katori⁵⁹, Kevin J. Kelly⁶⁰, Joachim Kopp⁶¹, Gordan Krnjaic⁶², Jeffrey Lazar⁶³, Jiajun Liao⁶⁴, Zhen Liu⁶⁵, Jacobo Lopez-Pavon⁶⁶, William C. Louis⁶⁷, Lucía Duarte⁶⁸, Michele Lucente⁶⁹, Pedro A. N. Machado⁷⁰, Xabier Marcano⁷¹, Danny Marfatia⁷², Gustavo Marques-Tavares⁷³, Davide Meloni⁷⁴, Davide Meloni⁷⁵, Manimala Mitra⁷⁶, I. Mocioiu⁷⁷, Kristian Moffat⁷⁸, Rabindra N. Mohapatra⁷⁹, Marjon H. Moulai⁸⁰, V. Muñoz⁸¹, Newton Nath⁸², Viviana Niro⁸³, Antonio Palazzo⁸⁴, Christopher John Parkinson⁸⁵, Silvia Pascoli⁸⁶, Yuber F. Perez-Gonzalez⁸⁷, S.T. Petcov⁸⁸, Maxim Pospelov⁸⁹, Matteo Puel⁹⁰, Farinaldo S. Queiroz⁹¹, Adam Ritz⁹², Nuria Rius⁹³, Albert De Roeck⁹⁴, Valentina De Romeri⁹⁵, S. Rosauero-Alcaraz⁹⁶, Mark Ross-Lonergan⁹⁷, Ibrahim Safa⁹⁸, Jordi Salvado⁹⁹, Manibrata Sen¹⁰⁰, Michael H. Shaevitz¹⁰¹, Bibhushan Shakya¹⁰², Ian M. Shoemaker¹⁰³, Rahul Srivastava¹⁰⁴, Mariam Tórtola¹⁰⁵, Z. Tabrizi¹⁰⁶, Alberto Tonero¹⁰⁷, Yun-Tse Tsai¹⁰⁸, Yu-Dai Tsai¹⁰⁹, J. W. F. Valle¹¹⁰, Carlos E. M. Wagner¹¹¹, Cédric Weiland¹¹², and Xun-Jie Xu¹¹³

Cross listed frontiers NF1-6, 9, 10, TF8 &10, RF 4 & 6, EF9.

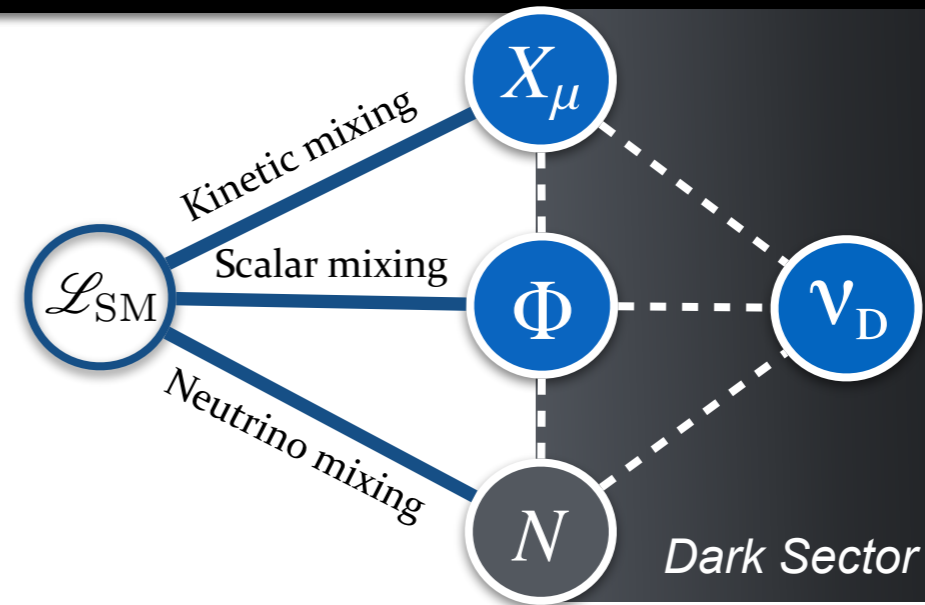
[View Lol]

Building a Dark Neutrino Sector

A. Abdullahi, MH, S. Pascoli, 2007.11813

Building a simple dynamical dark sector:

	SU(2) _L	U(1) _Y	U(1) _X
N	$\mathbf{1}$	0	0
ν_{DL}	$\mathbf{1}$	0	Q
ν_{DR}	$\mathbf{1}$	0	Q
Φ	$\mathbf{1}$	0	Q



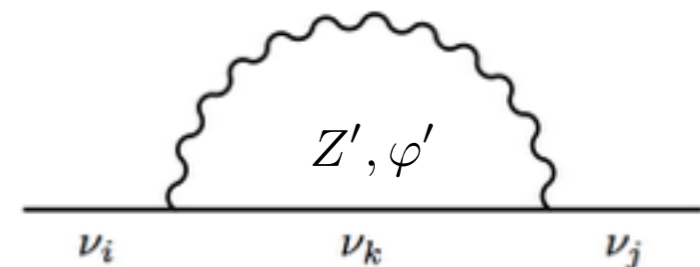
New vector-like fermions charged under a dark U(1)' symmetry, broken at the GeV scale by $\langle \Phi \rangle$.

A “dark” variation of the extended seesaw

$$\frac{1}{2} \overline{\hat{\nu}_f^c} \begin{pmatrix} 0 & M_D & 0 & 0 \\ M_D^T & M_N & \Lambda_L & \Lambda_R \\ 0 & \Lambda_L^T & 0 & M_X \\ 0 & \Lambda_R^T & M_X^T & 0 \end{pmatrix} \hat{\nu}_f$$

$$\hat{\nu}_f \equiv (\hat{\nu}_\alpha^c \quad \hat{\nu}_N^c \quad \hat{\nu}_{DL}^c \quad \hat{\nu}_{DR}^c)^T$$

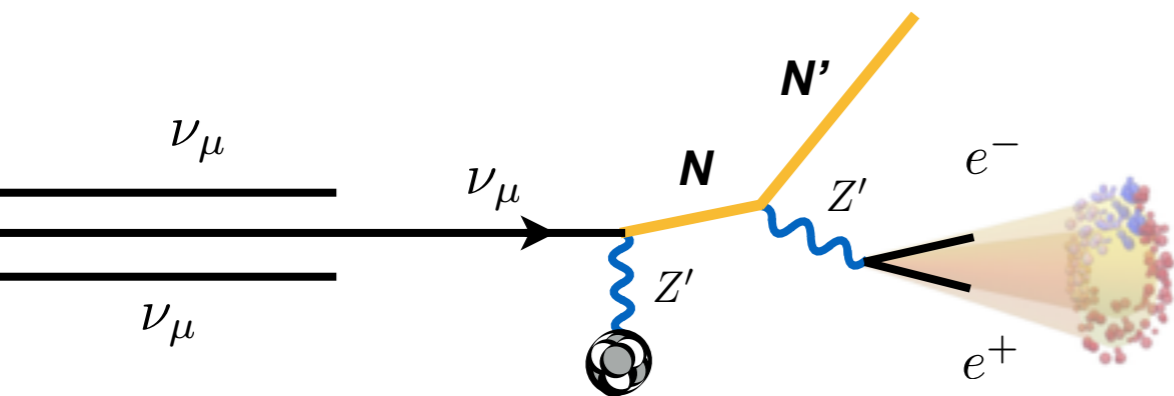
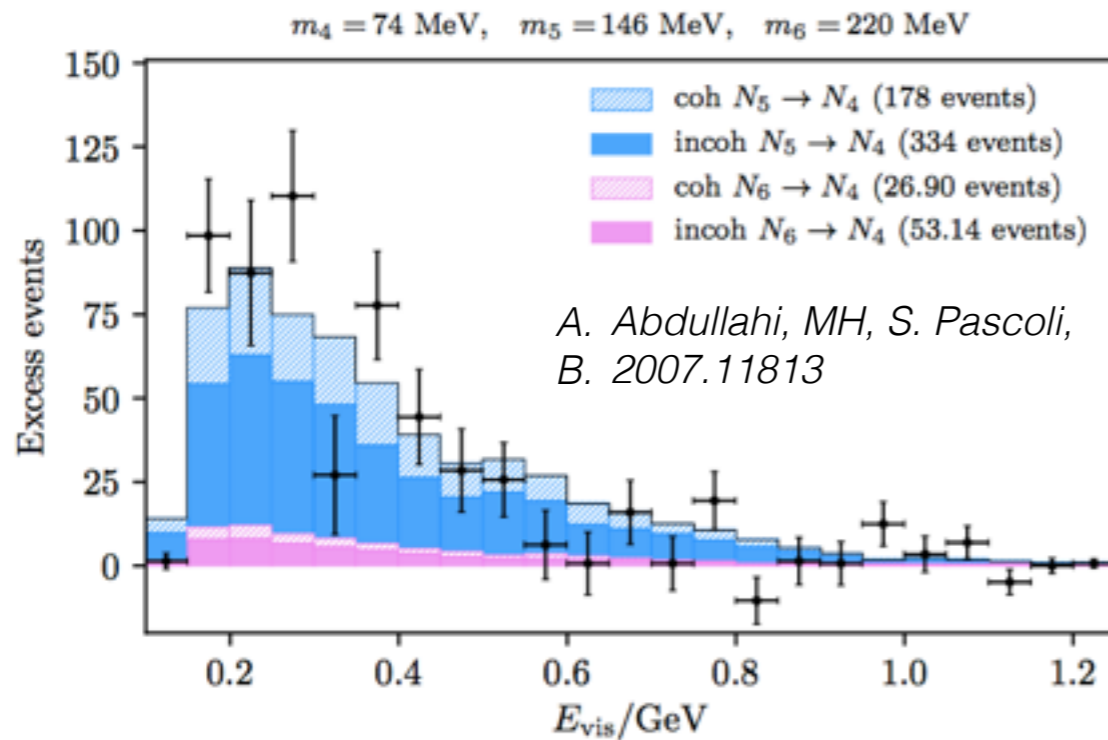
Neutrino masses at tree-level a-la ISS w/ substantial **radiative corrections** from dark mediators:



Explaining the MiniBooNE Excess

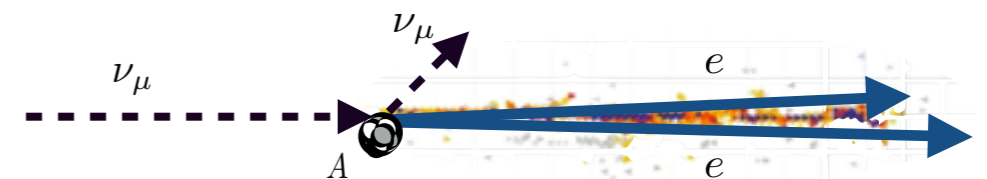
E. Bertuzzo et al, PRL121.241801, P. Ballett et al, PRD 99.071701, + others

Neutrinos up-scatter into HNLs, which rapidly decay into e^+e^- .



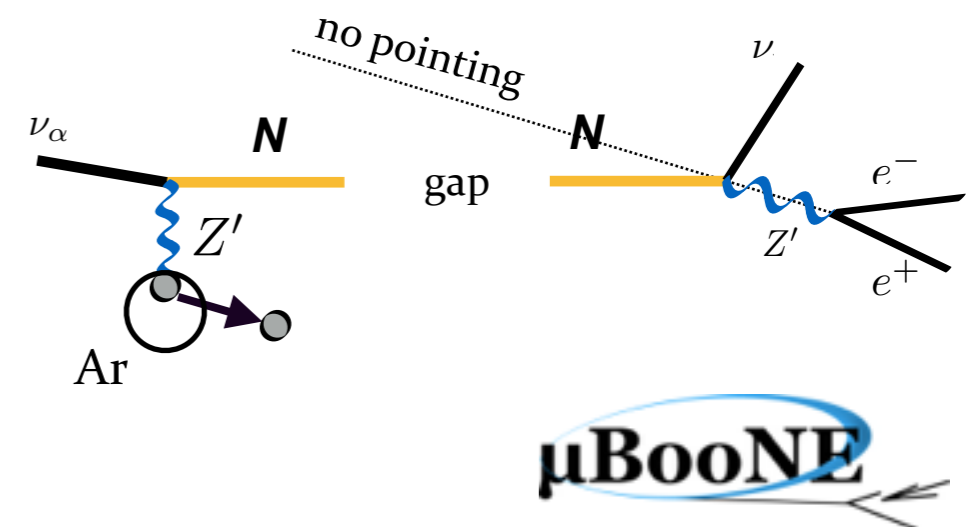
Direct Predictions

Pseudo single photons at ν detectors:



C. Argüelles, MH, Y. Tsai, PRL123.261801

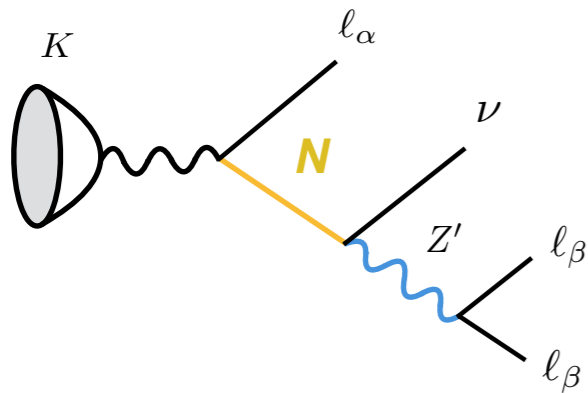
With better PID of LAr detectors, search for trident-like (e^+e^-) events.



Dark Neutrino Predictions

Semi-visible mediators and fast HNL decays

Rare leptonic kaon decays

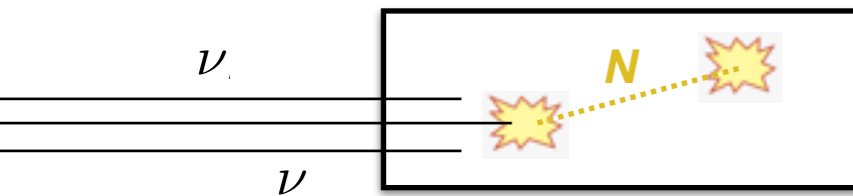


At **NA62**, would expect $\sim 3k$ events with existing data.

Inv. mass bumps in $m_{Z'}$ and m_N

$$|U_{\mu 4}|^2 < \mathcal{O}(10^{-10})$$

“Double bang” events*

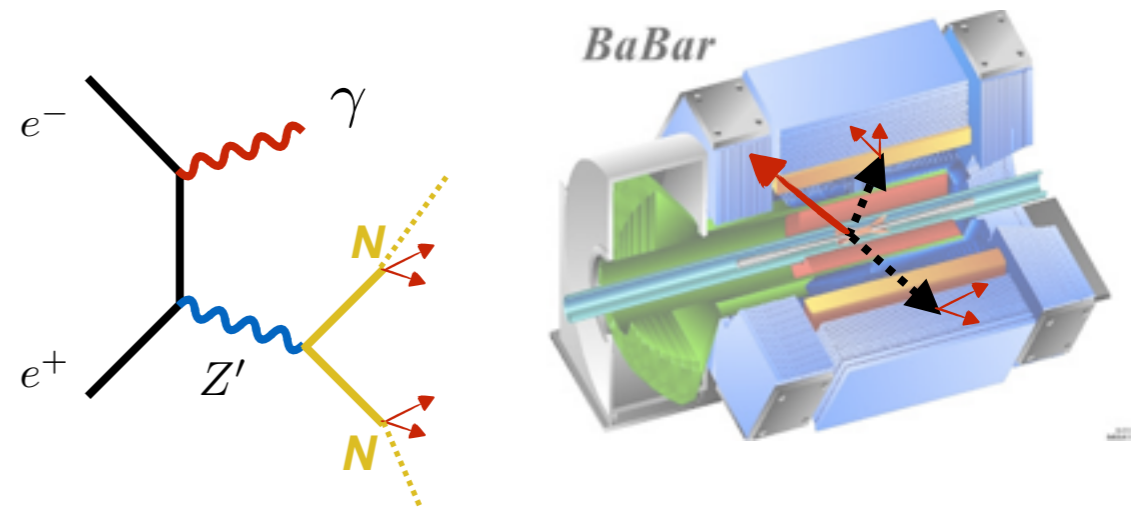


1000s of events/year at **IceCube**

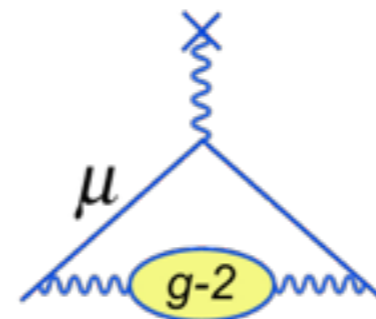
P. Coloma et al, PRL119.201804

*Several double NC events observed at CCFR, not explained to this date, are compatible with our model.

Semi-visible dark photon



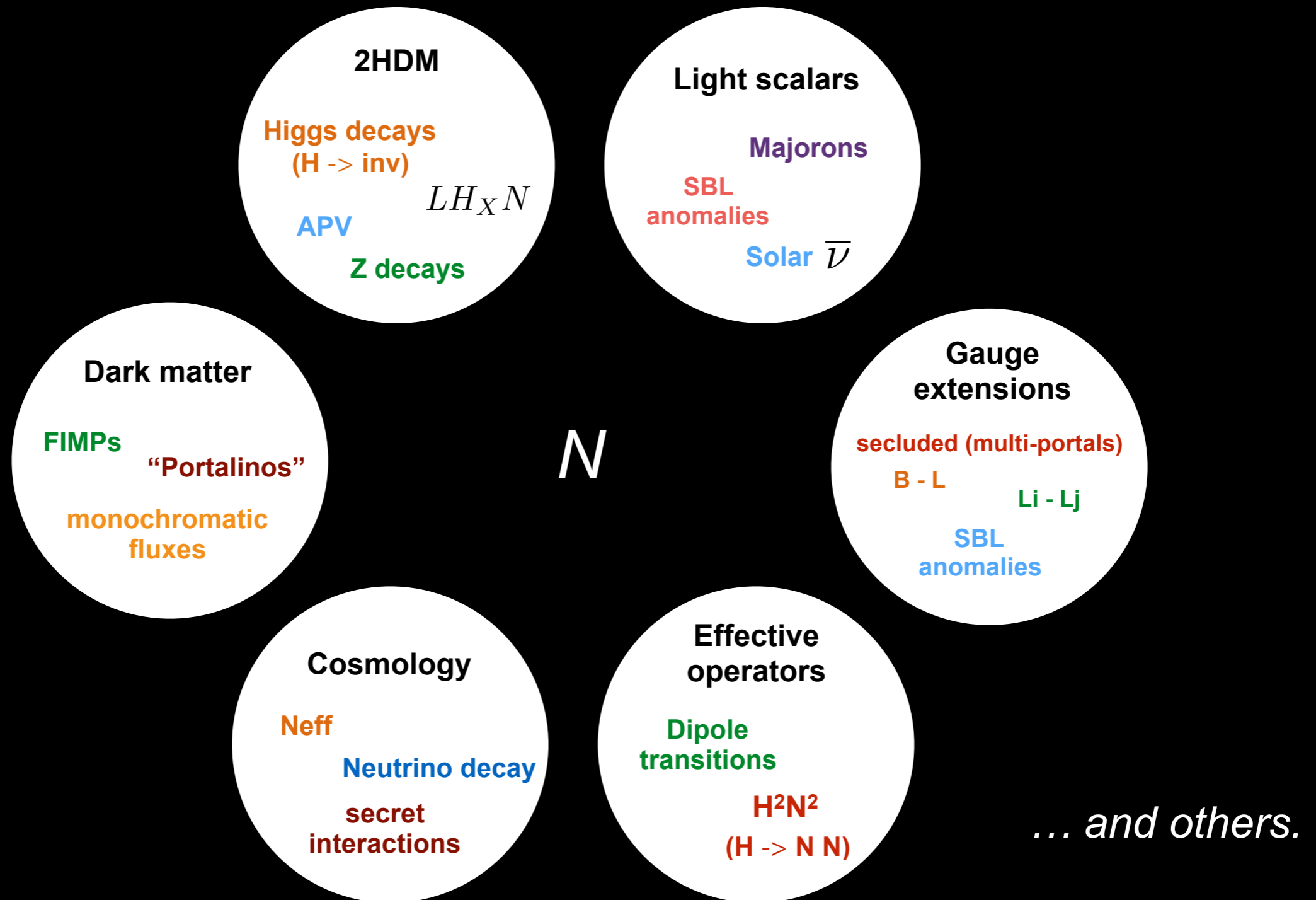
Invisible dark photon bounds relaxed.



Explanation of the **muon (g-2)** anomaly via a dark photon now viable?

Predicts a huge rate of s-channel $e^+e^- \rightarrow NN$ production @ **BaBar** and **Belle-II** ($\mathcal{O}(10^4)$ events).

An opportunity to increase our experimental reach to models with more complex dynamics but still conceptually minimal.



A diverse and vibrant community spanning a wide range of energy scales and expertise.

DENNIS the MENACE



LOTS OF THINGS ARE INVISIBLE, BUT WE DON'T KNOW HOW MANY BECAUSE WE CAN'T SEE THEM.