Probing New Physics with Neutrino Scattering

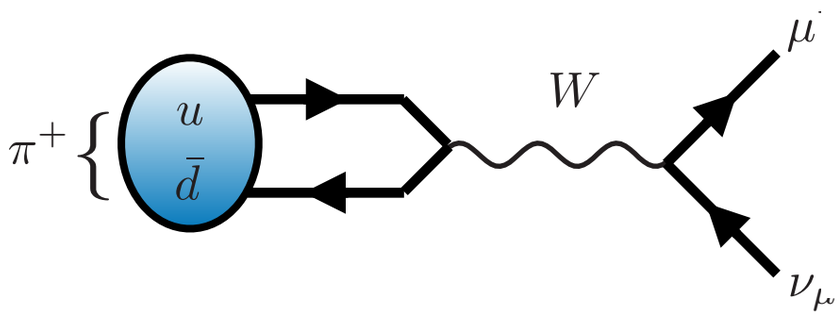
Ian M. Shoemaker

Center for Neutrino Physics Research Day

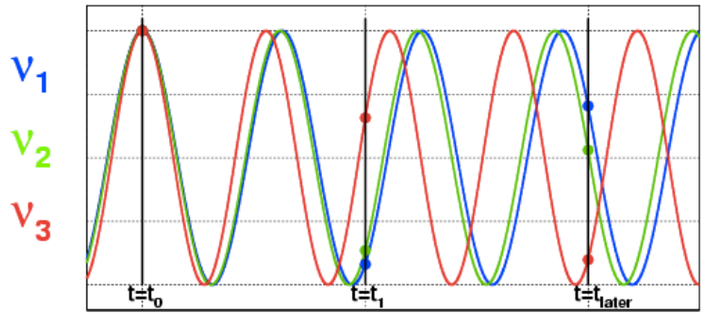
May 10th, 2019

Neutrino Flavor Oscillates

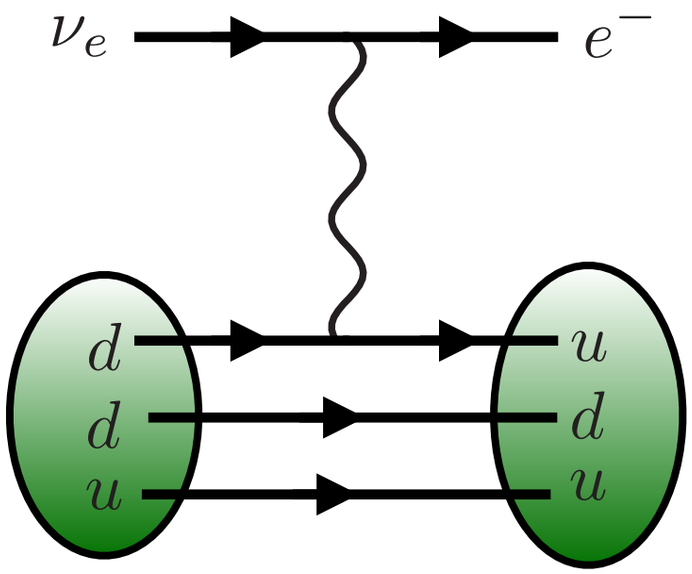
Produce them



Oscillate them

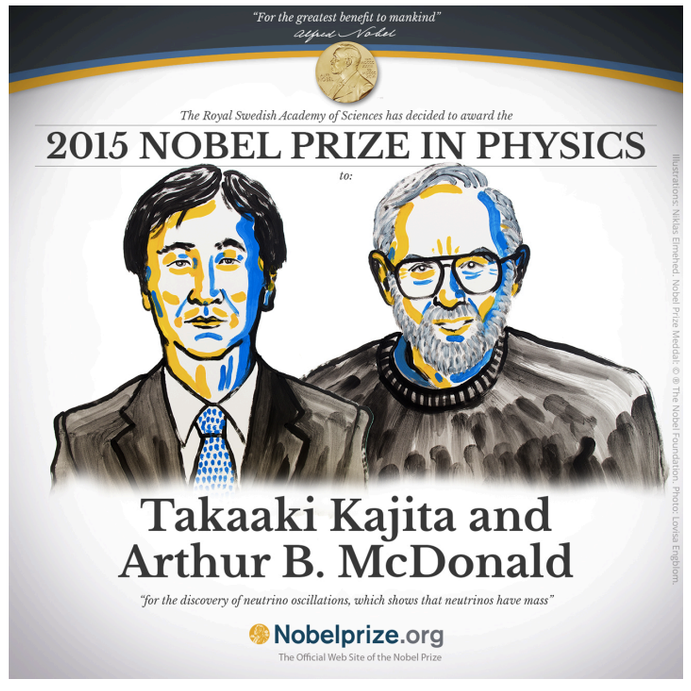


Detect them

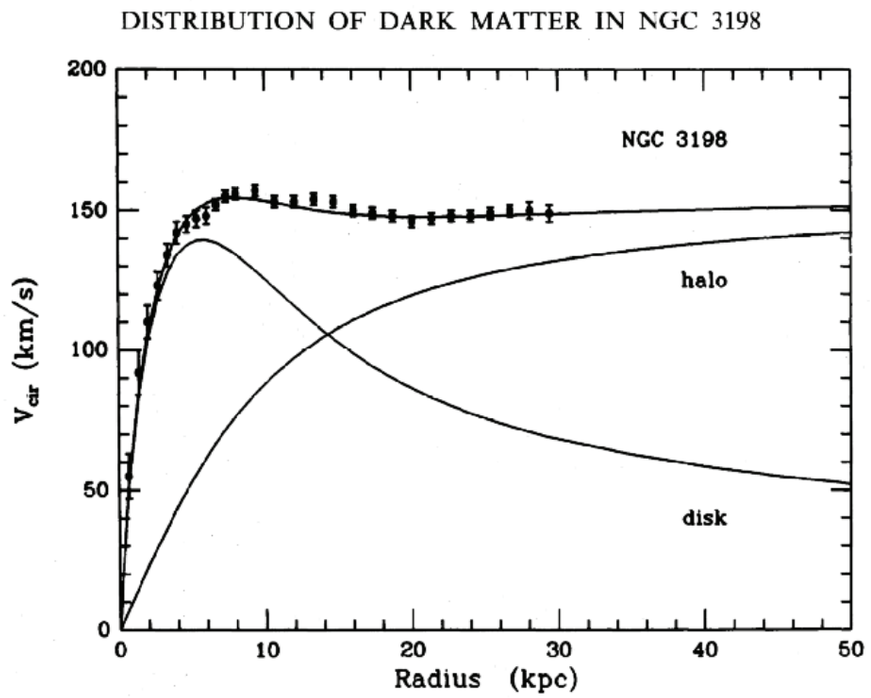


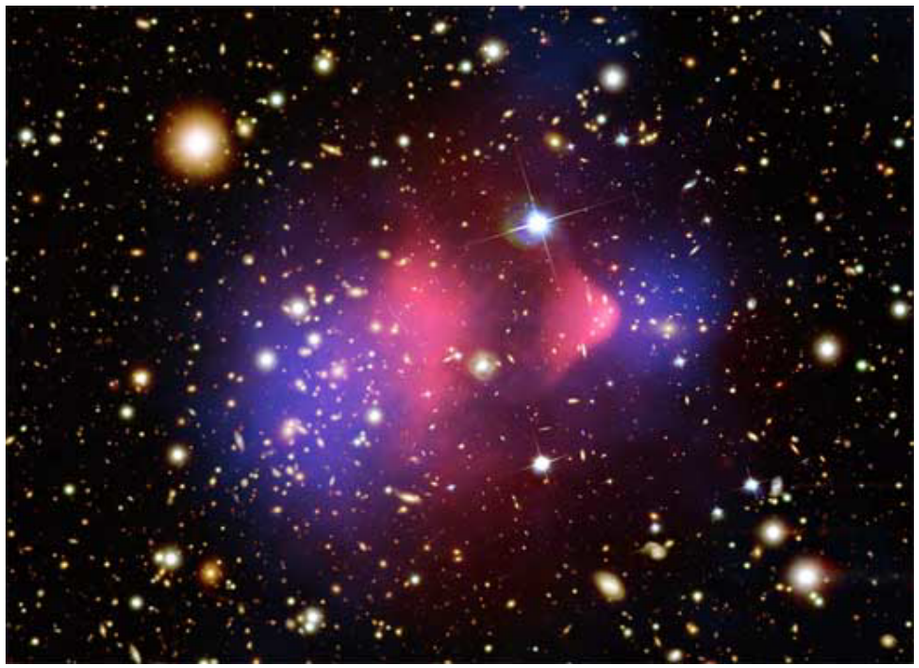
weak int. eigenstate		energy eigenstate
$\lvert\nu_\alpha\rangle$	$\neq$	$\lvert\nu_i\rangle$

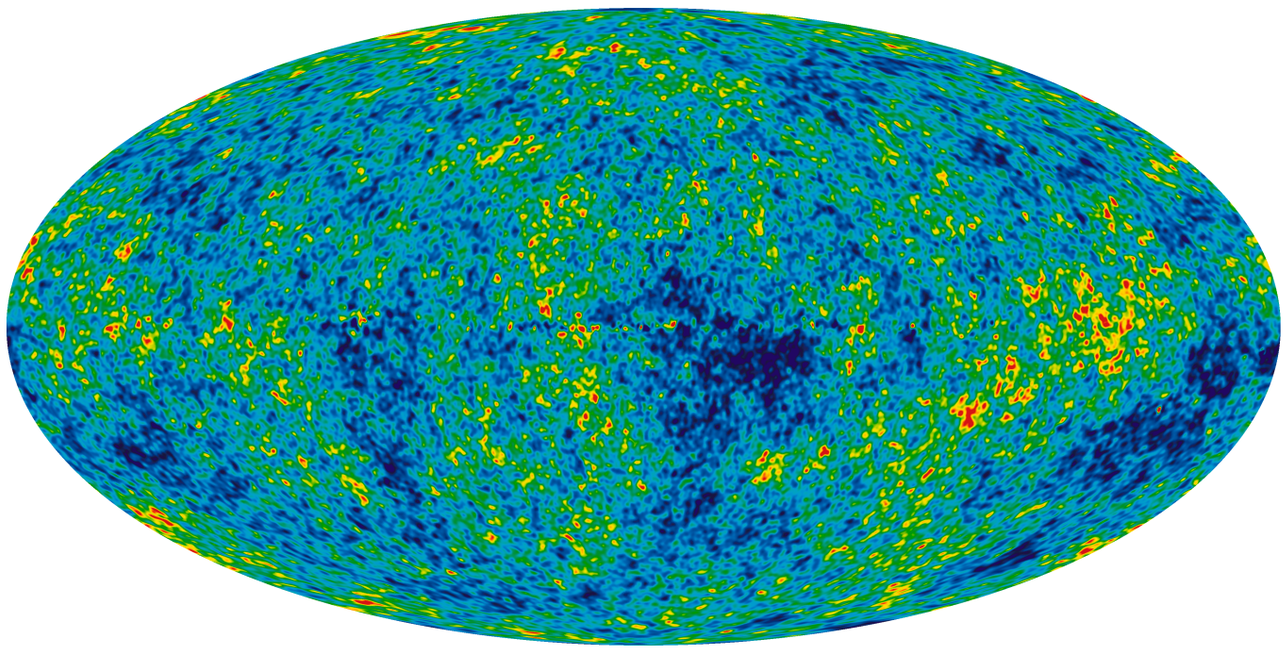
Neutrino masses are nonzero.

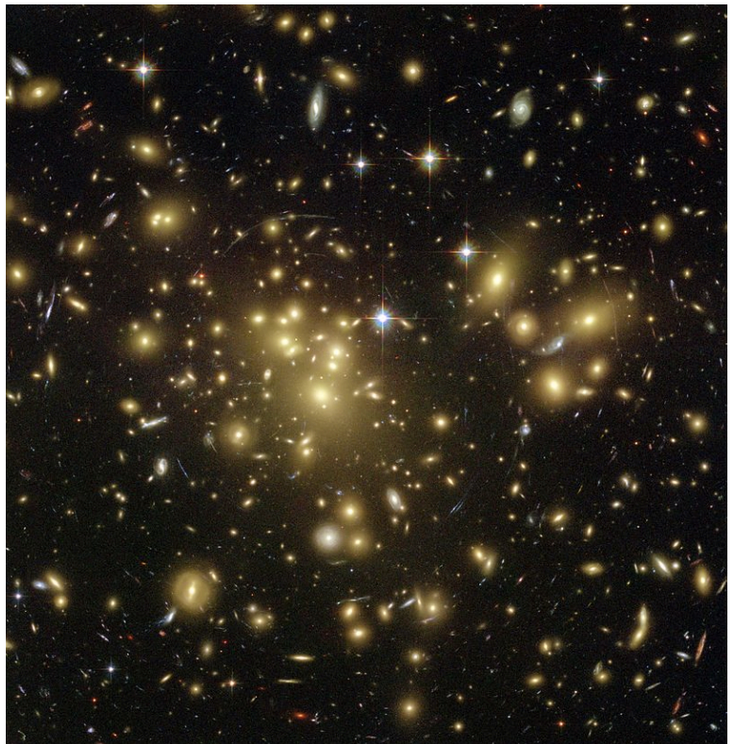


Most of the Universe's Matter is Invisible

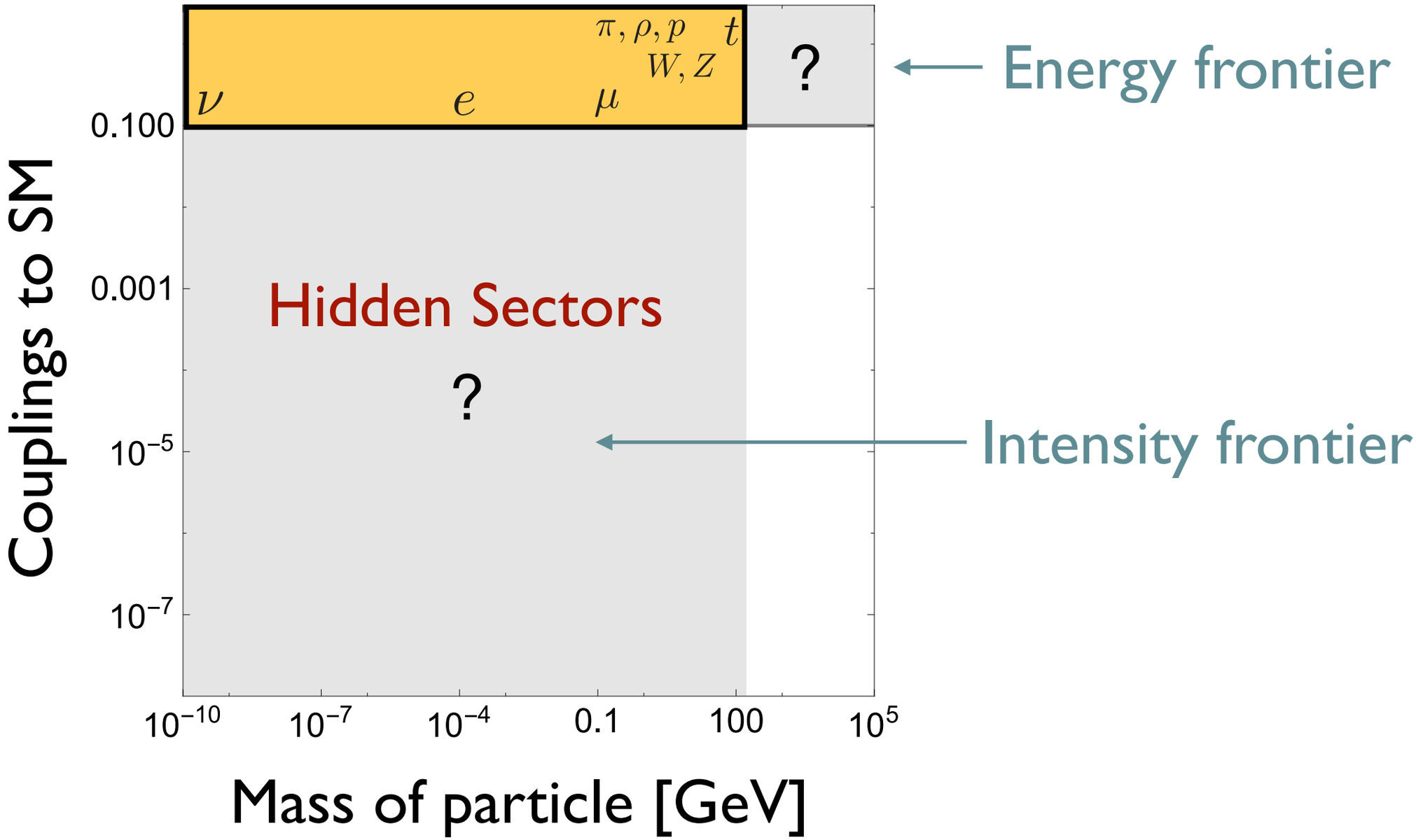






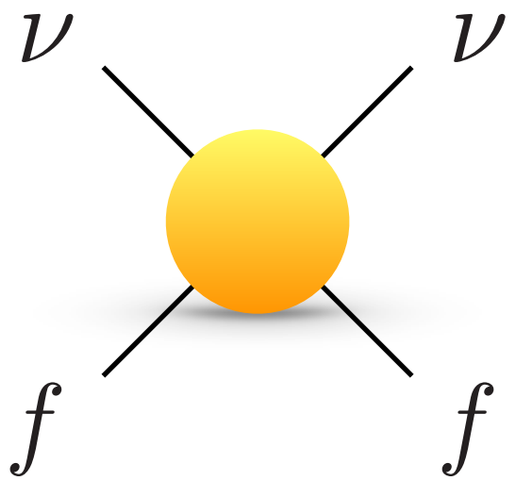


Where is the new physics?



Need a multi-pronged effort to find new physics.

BSM via Neutrino Scattering



Part 1:

Neutrino Scattering @ zero momentum transfer

⇒ **Modified Oscillations in medium.**

MSW Effect

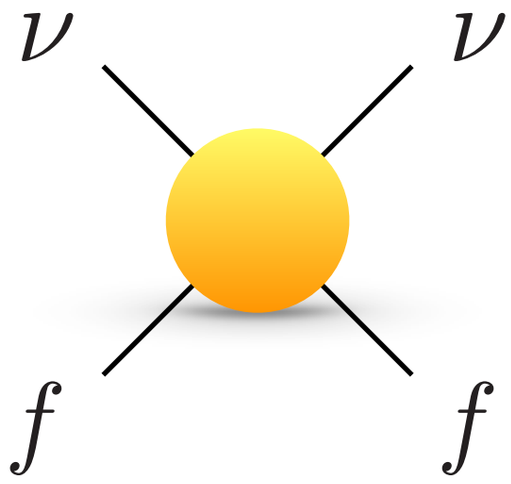
DM Direct Detection

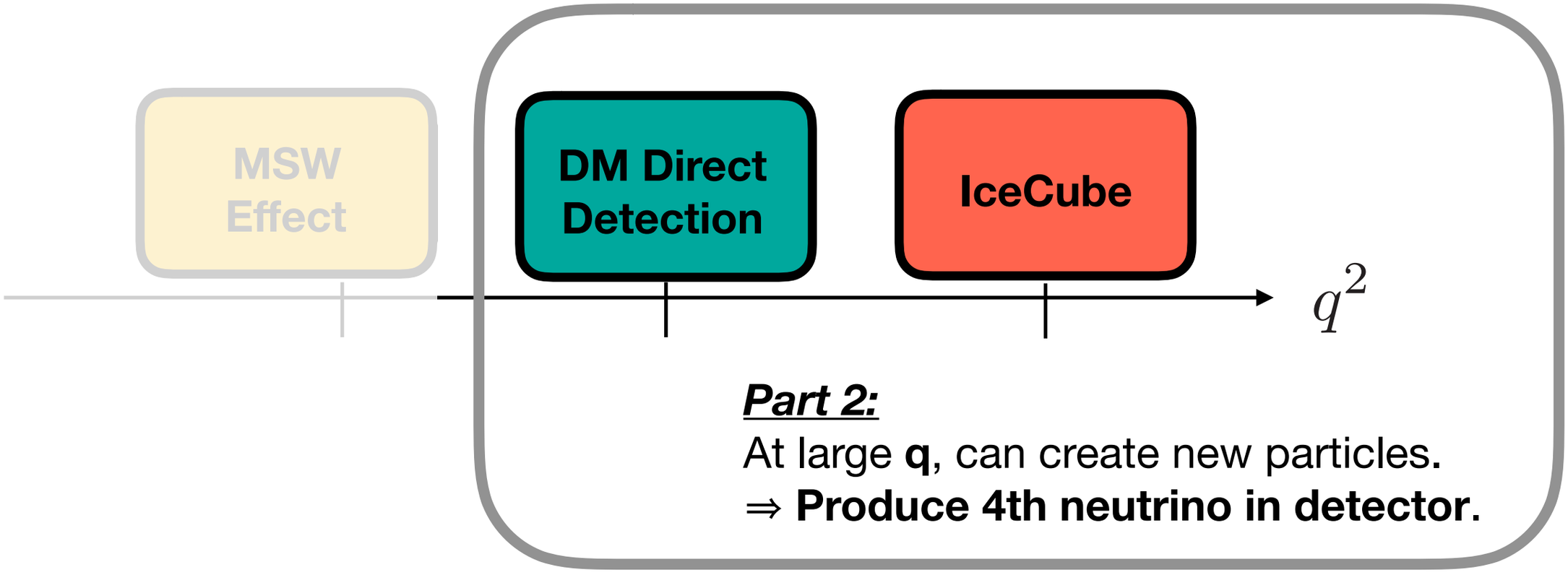
IceCube

q^2

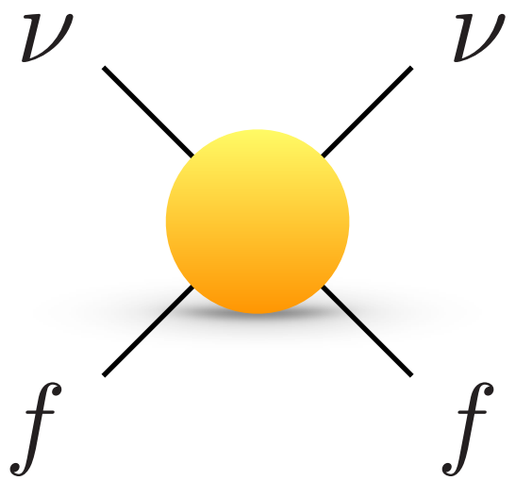
$q^2 = 0$

BSM via Neutrino Scattering





BSM via Neutrino Scattering



Part 1:

Neutrino Scattering @ zero momentum transfer

⇒ **Modified Oscillations in medium.**

MSW Effect

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q^2

$q^2 = 0$

Matter Oscillations

PHYSICAL REVIEW D VOLUME 17, NUMBER 9 1 MAY 1978

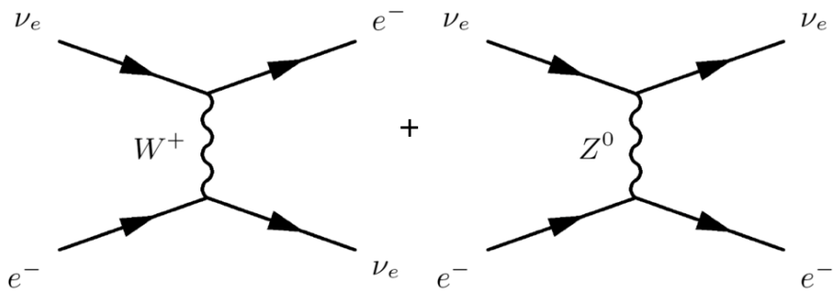
Neutrino oscillations in matter

L. Wolfenstein
Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213
(Received 6 October 1977; revised manuscript received 5 December 1977)

The effect of coherent forward scattering must be taken into account when considering the oscillations of neutrinos traveling through matter. In particular, for the case of massless neutrinos for which vacuum oscillations cannot occur, oscillations can occur in matter if the neutral current has an off-diagonal piece connecting different neutrino types. Applications discussed are solar neutrinos and a proposed experiment involving transmission of neutrinos through 1000 km of rock.

[ALSO: S.P. Mikheev, A.Yu. Smirnov, Sov.J. Nucl. Phys. 42:913-917, 1985; Nuovo Cim. C9:17-26, 1986]

coherent forward scattering

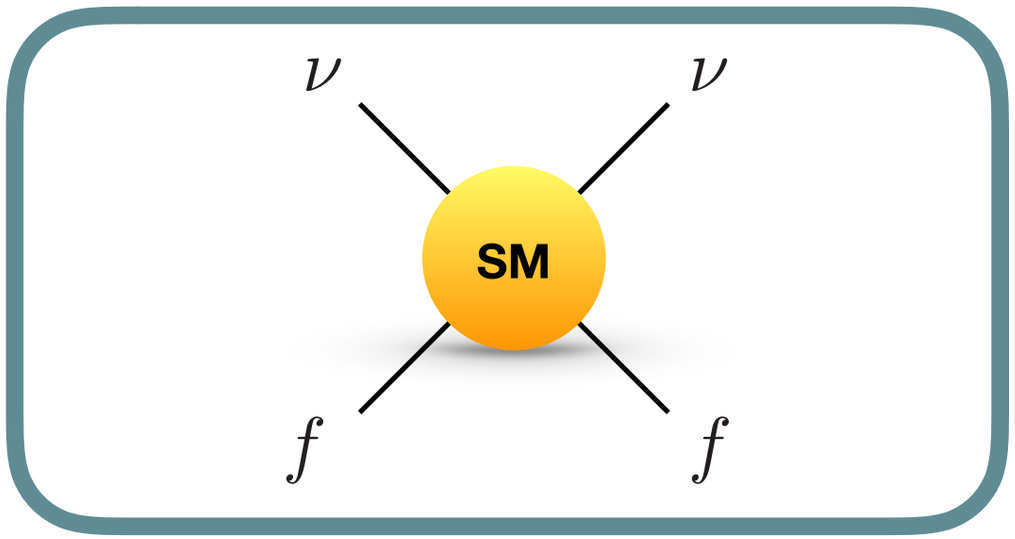


Charged current contribution from W:

$$V_{CC} \sim n_e \times G_F$$

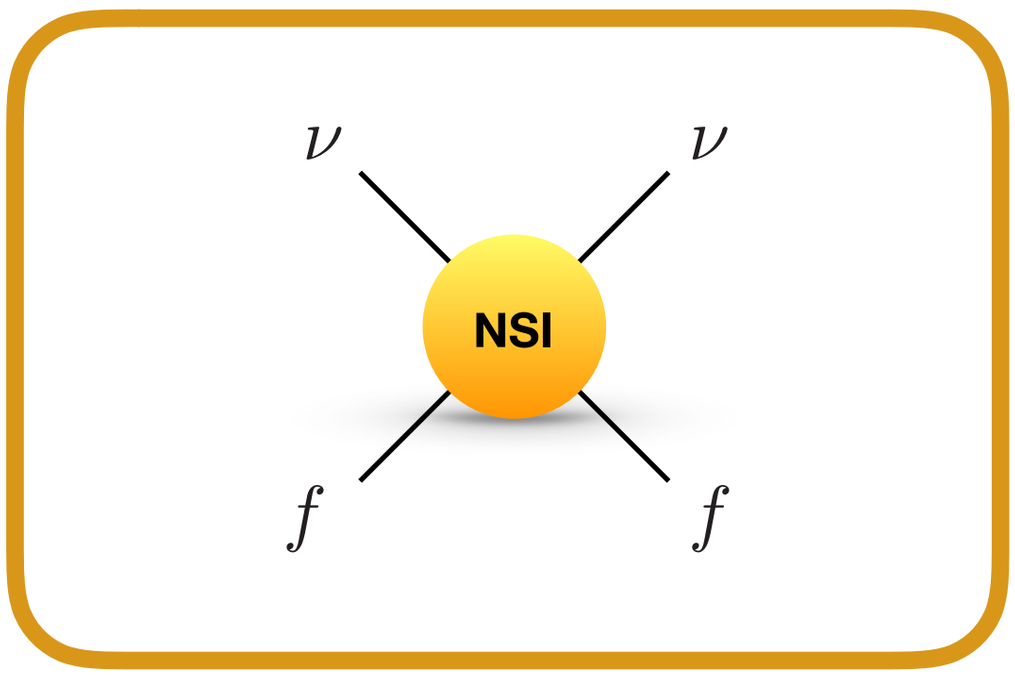
Generalized Matter Potential

SM int. + matter



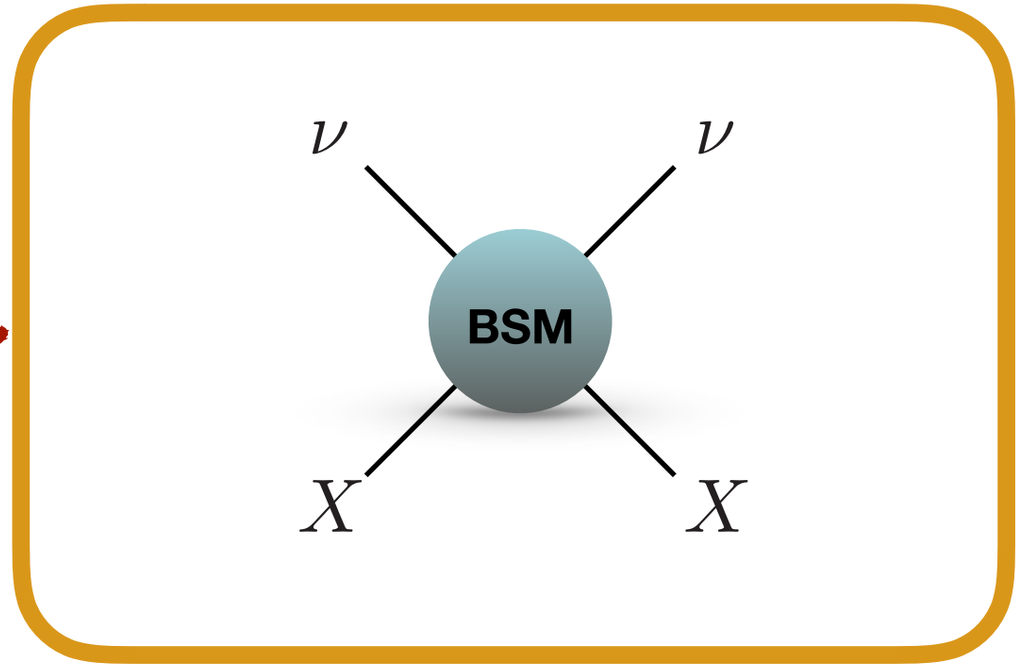
$\sim G_F n_f$

new int. + matter



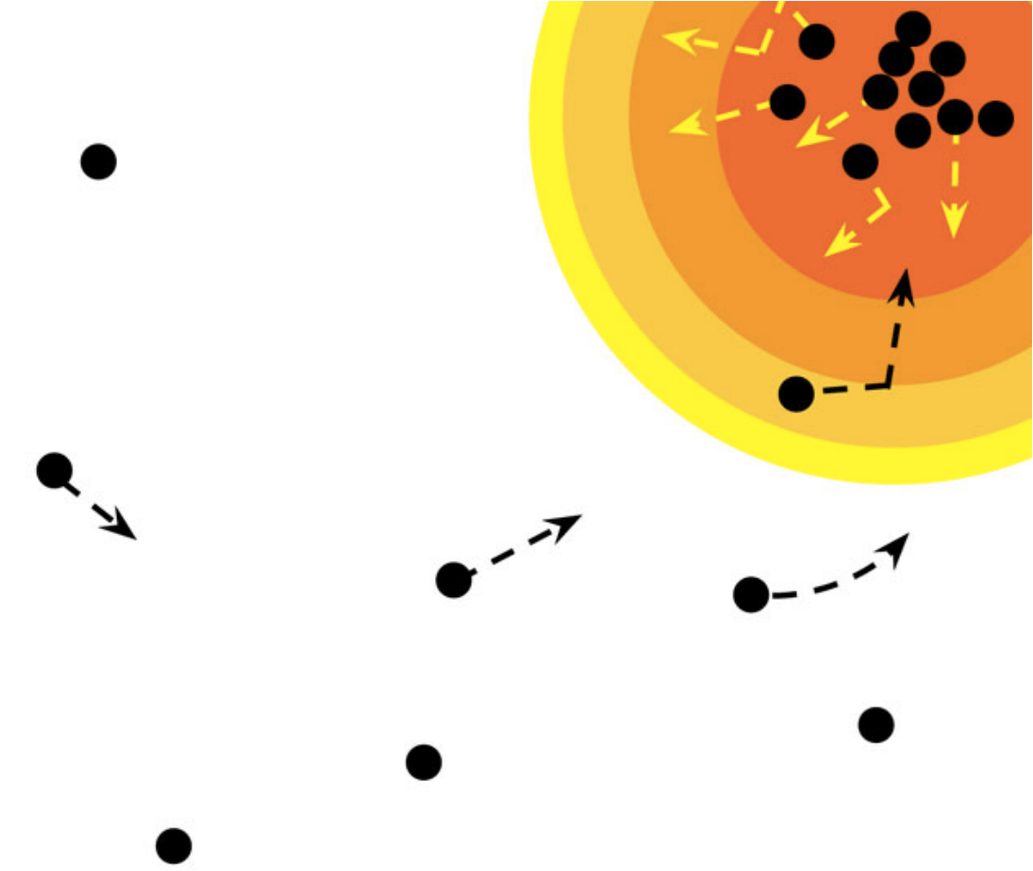
$\sim \varepsilon G_F n_f$

new int. + DM



$\sim G'_F n_X$

DM in the Sun



- Standard WIMPs accumulate, start annihilating. Searches for high-E neutrinos from solar core.

- If mildly asymmetric, can set new limit on ADM from solar annihilation [IMS, Murase 2016].

- If DM is strongly asymmetric, it simply accumulates (i.e. annihilation is negligible) => Large abundance of DM in the Sun but how do we search for it?

    - => Can look for a modified matter potential for solar neutrinos.

Francesco Capozzi, IMS, Luca Vecchi, JCAP 1707 (2017) no.07, 021

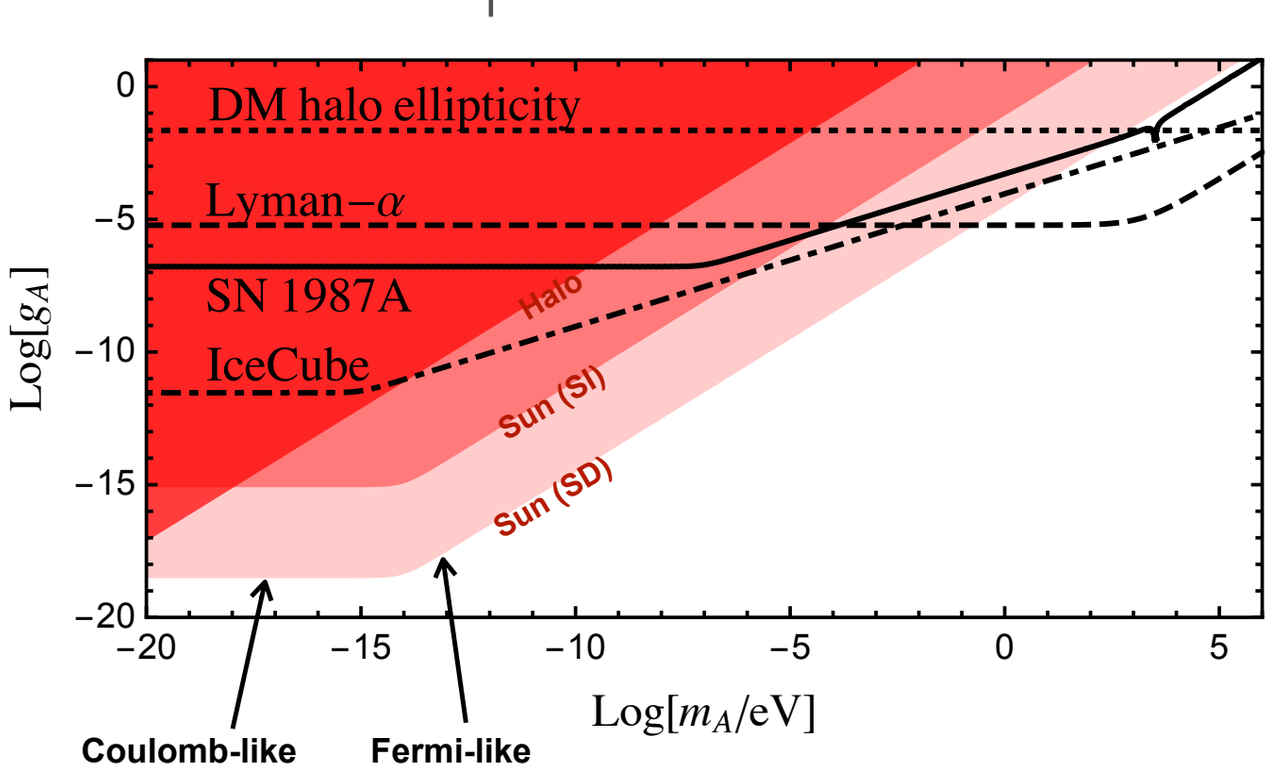
Related work: P.F. de Salas, R.A. Lineros, M. Tórtola [1601.05798], A. Berlin [1608.01307]

Probing DM-Neutrino Interactions

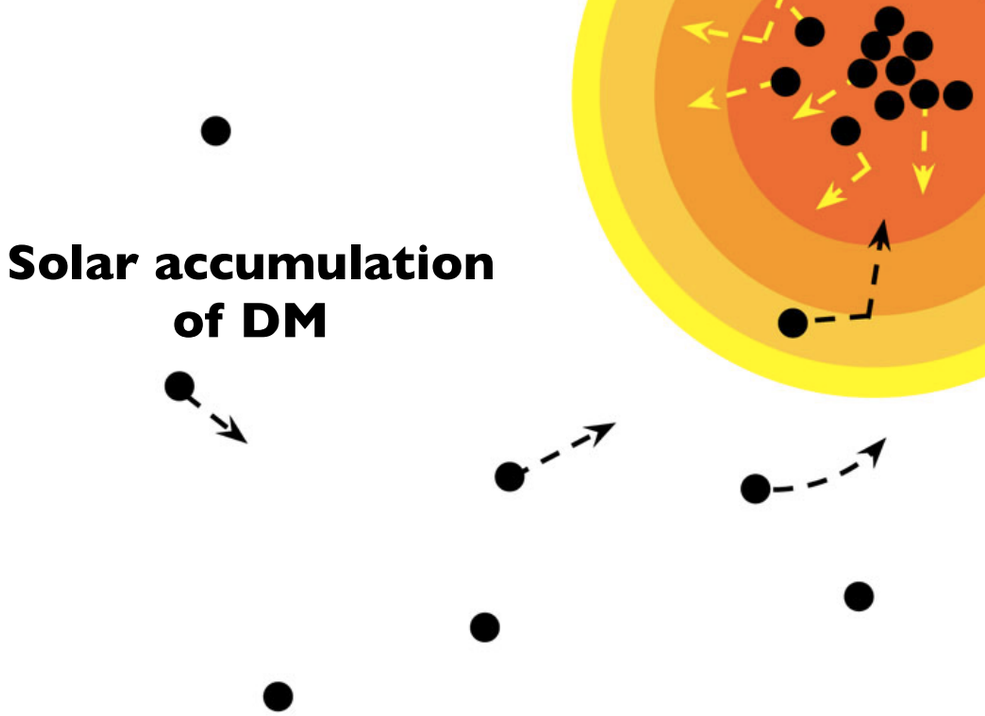
Francesco Capozzi, IMS, Luca Vecchi,
JCAP 1707 (2017) no.07, 021;
JCAP 1807 (2018) no.07, 004

$$\mathcal{L} \supset g\bar{X}\gamma_\mu X A^\mu + g\bar{\nu}\gamma_\mu \nu A^\mu$$

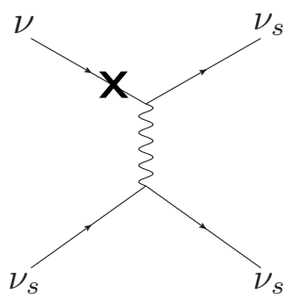
DM impact on oscillations



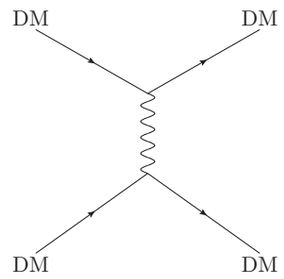
<u>Upshot</u>: Large DM parameter space only accessible via neutrino oscillations.



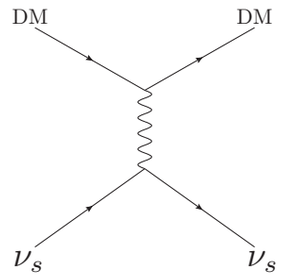
IceCube/ SN1987A



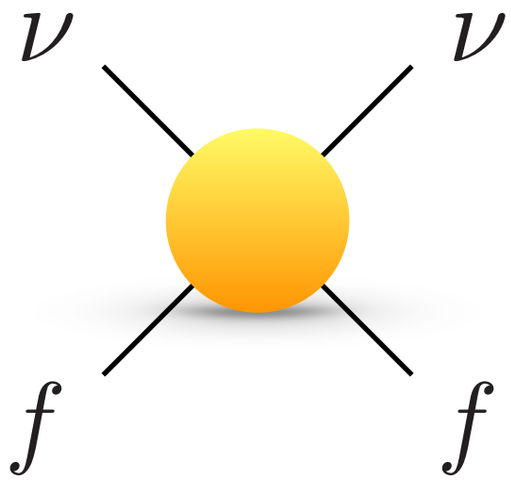
DM Self-Interactions

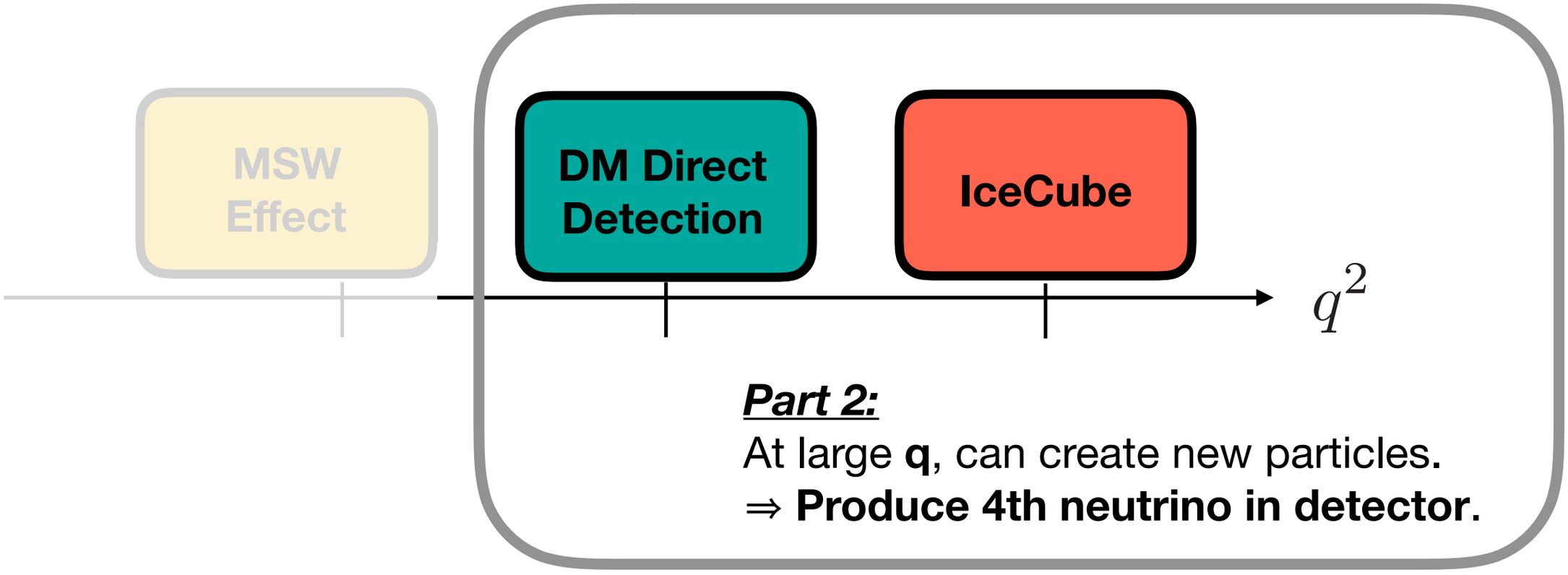


Lyman-alpha



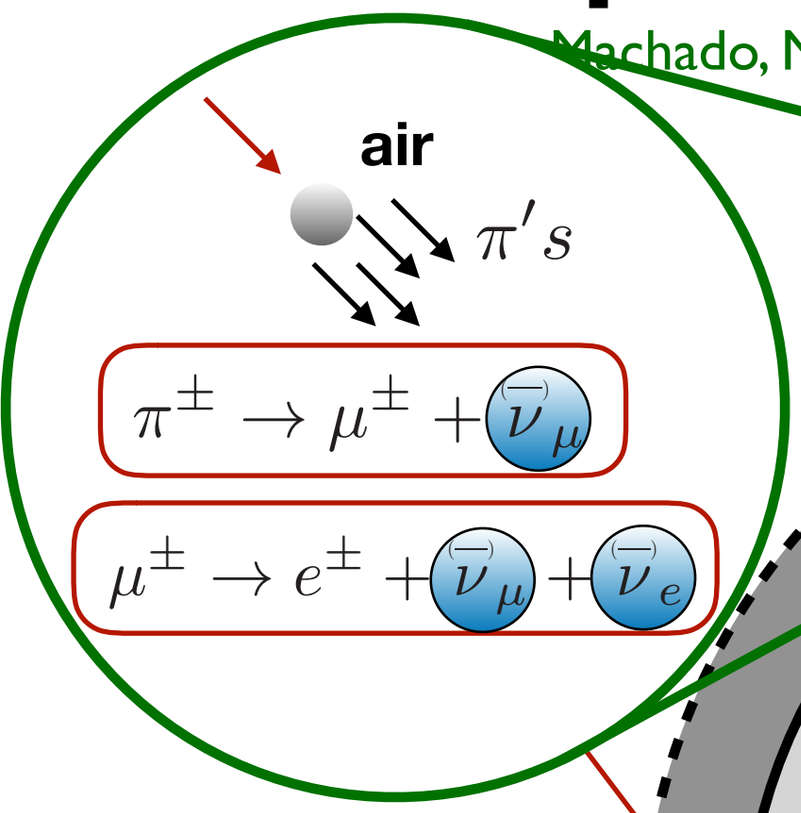
BSM via Neutrino Scattering

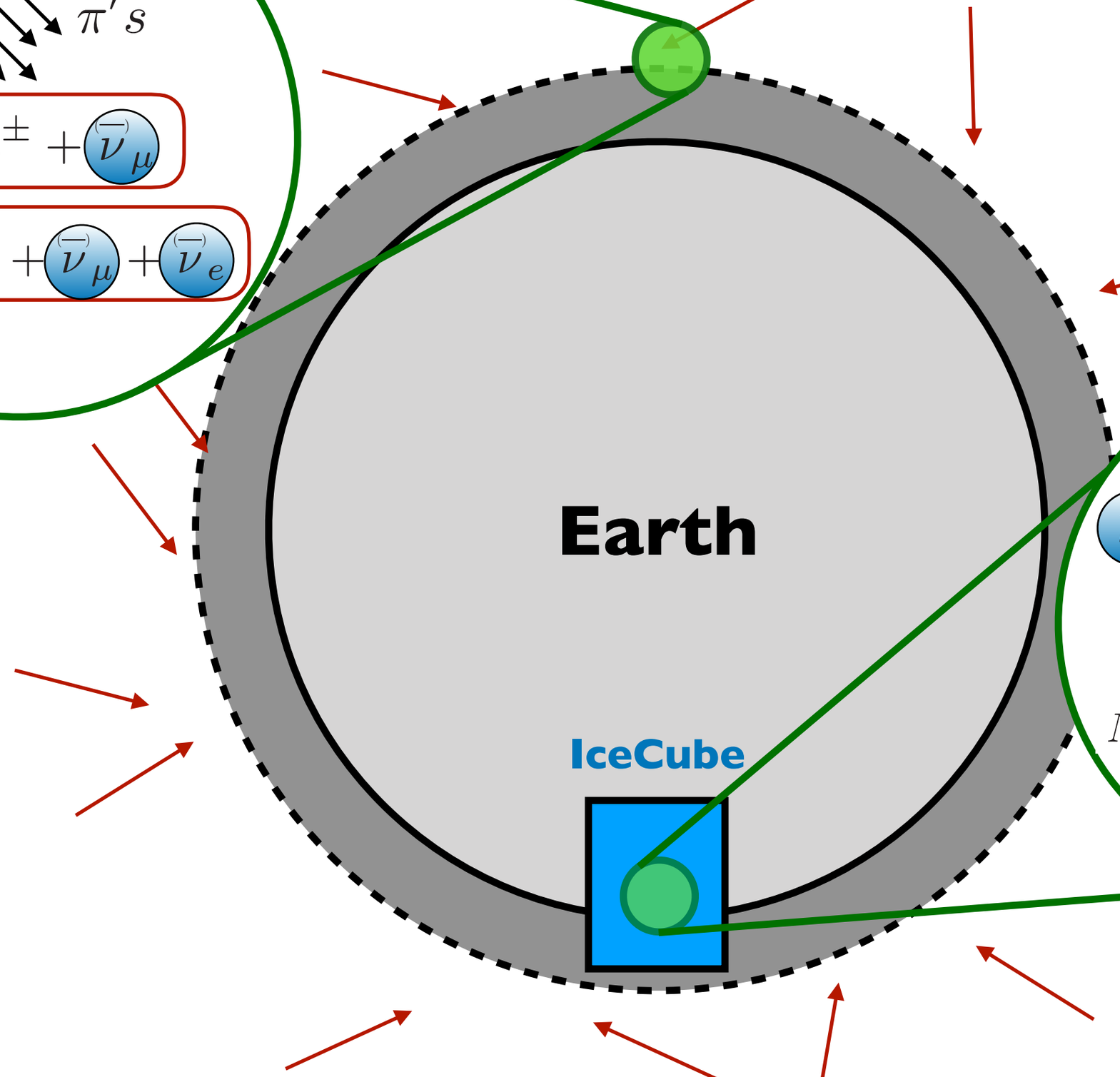




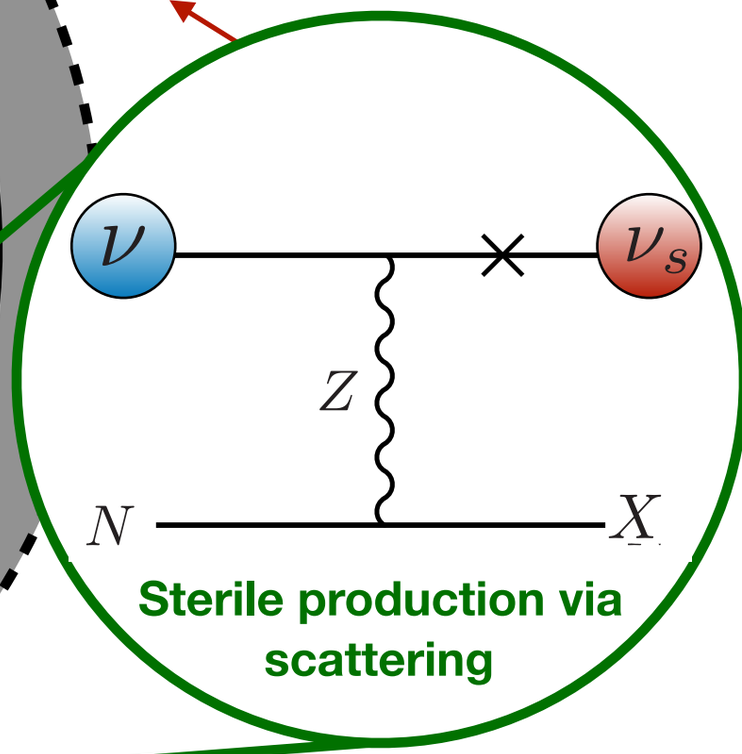
Atmospheric Neutrinos as a BSM probe

Machado, Martinez-Soler, Shoemaker 2017, Phys. Rev. Lett. **119**, 201804



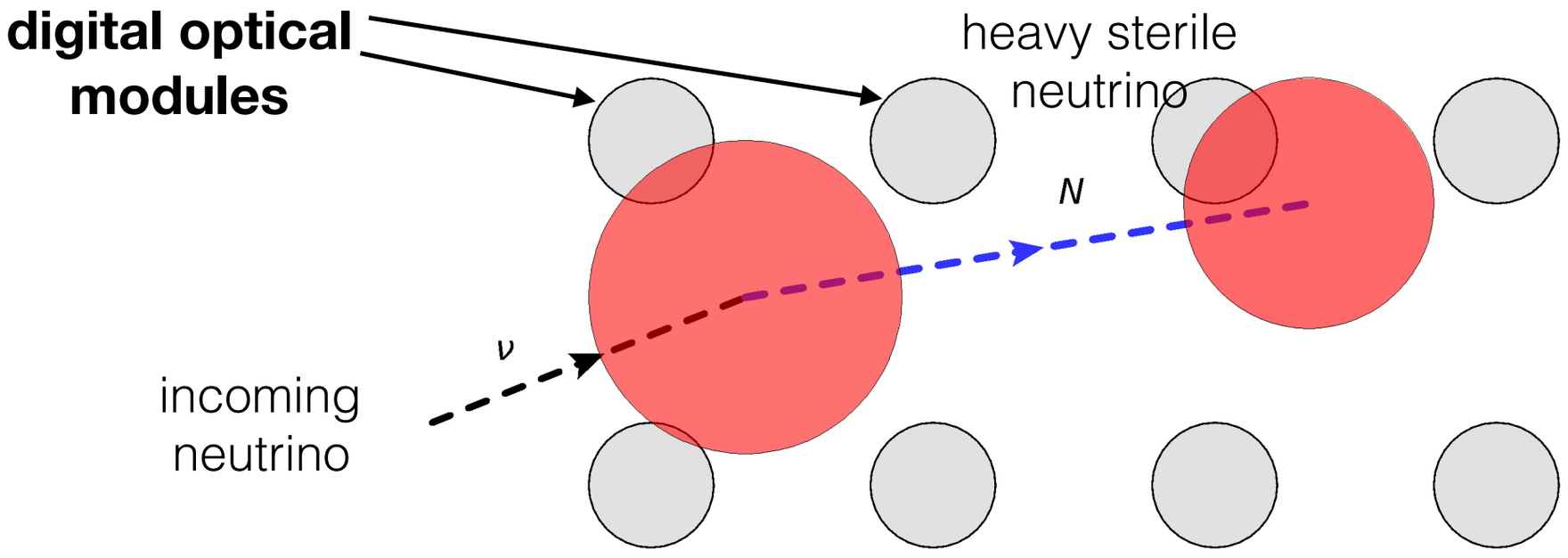


cosmic rays



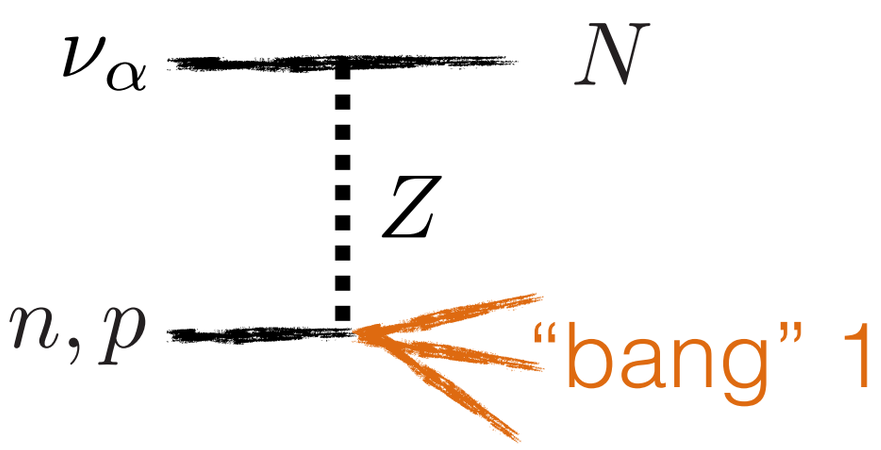
“Double-bangs” from Sterile Neutrinos

Coloma, Machado, Martinez-Soler, Shoemaker 2017, Phys. Rev. Lett. **119**, 201804



Low background!

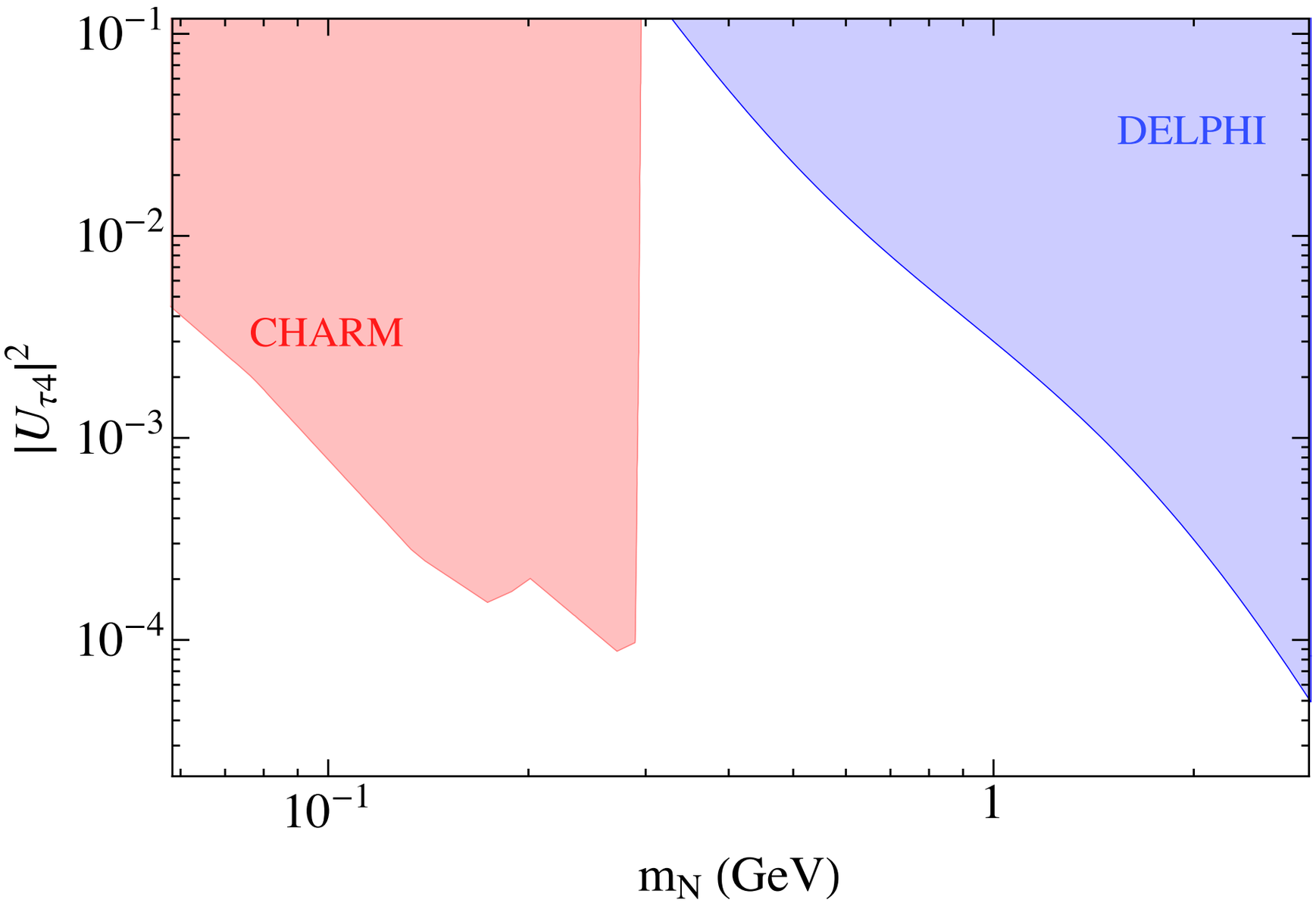
Step 1: produce N



Step 2: N decays

No extra radiation between steps 1 and 2.

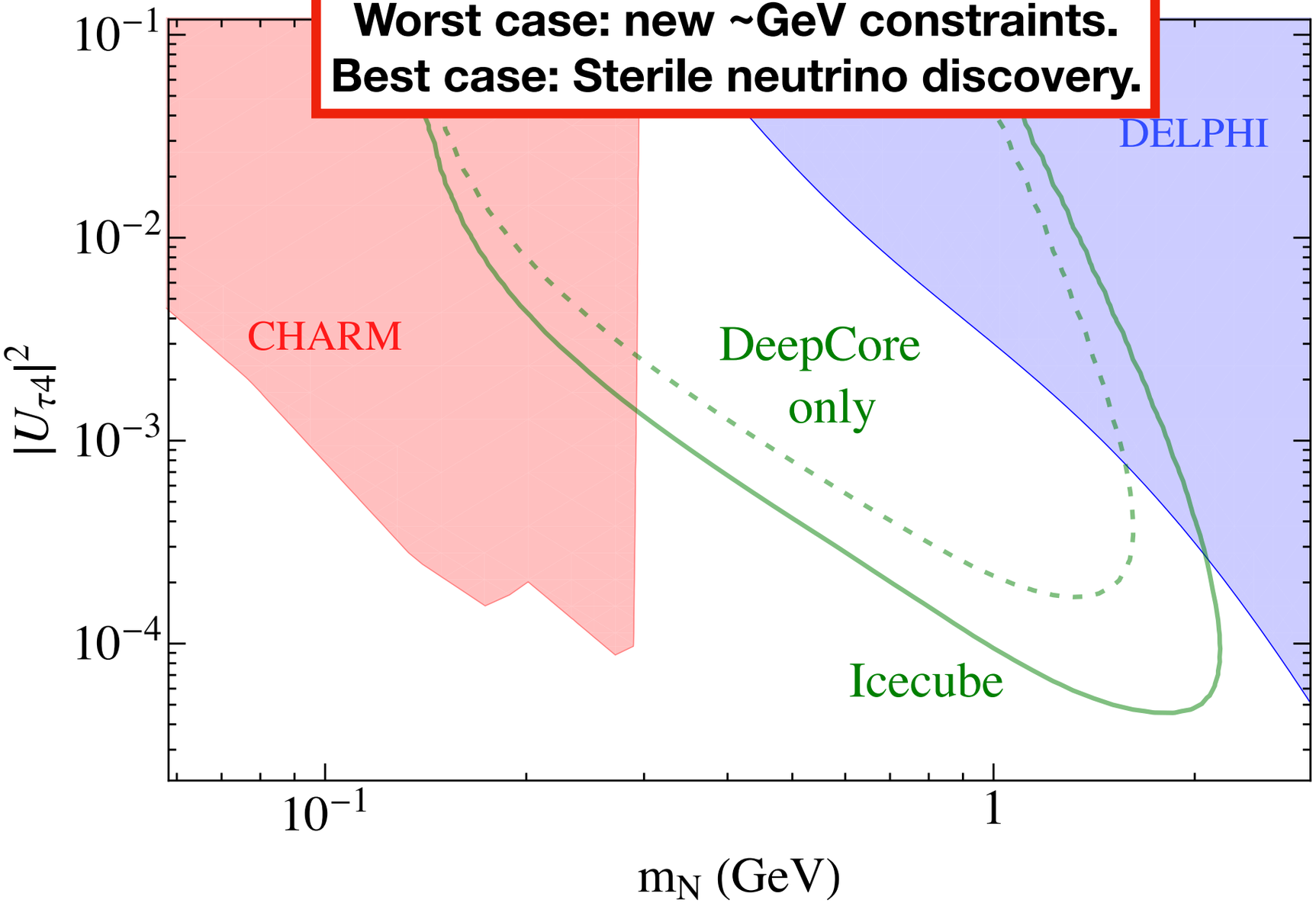
Heavy Neutrinos from the Atmosphere



Coloma, Machado, Martinez-Soler, Shoemaker 2017, Phys. Rev. Lett. **119**, 201804

Heavy Neutrinos from the Atmosphere

Assumes only existing data.
Worst case: new ~GeV constraints.
Best case: Sterile neutrino discovery.

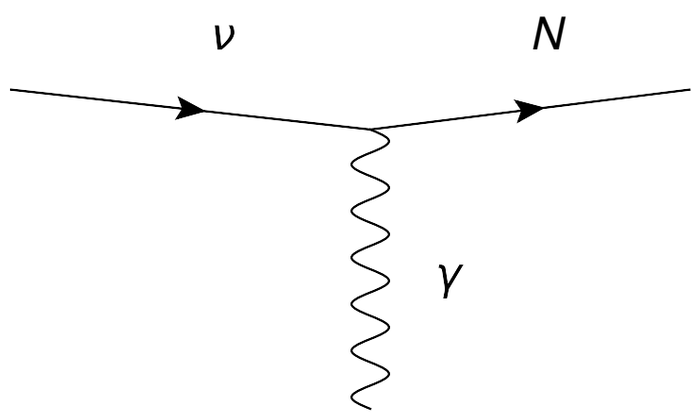


Coloma, Machado, Martinez-Soler, Shoemaker 2017, Phys. Rev. Lett. **119**, 201804

Potential EM Properties of Sterile Neutrinos

-Don't know dominant Sterile Neutrino -SM "portal"
-Could be higher-dim. operator.

$$\mathcal{L} \supset -\mu_\nu \bar{N}_4 \sigma_{\mu\nu} P_L \nu_\alpha F^{\mu\nu}$$



Potential EM Properties of Sterile Neutrinos

-Don't know dominant Sterile Neutrino -SM "portal"
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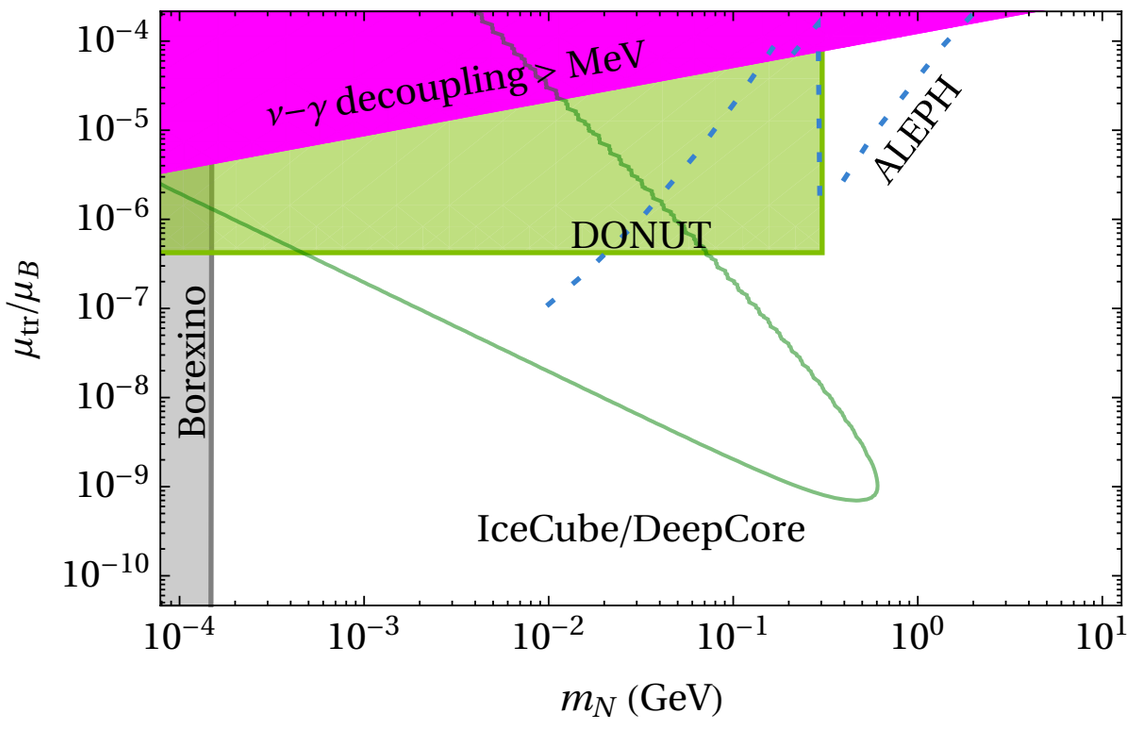
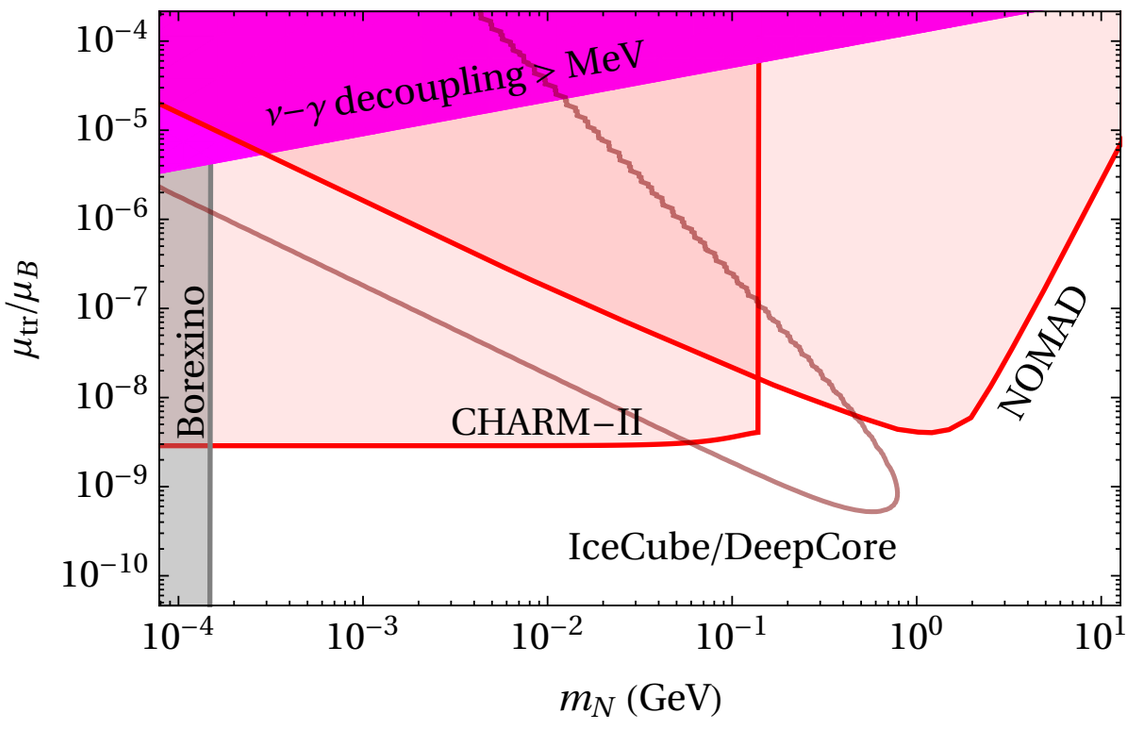
$\nu_\tau - N$ transition



$\nu_\mu - N$ transition



Coloma, Machado, Martinez-Soler, Shoemaker 2017, Phys. Rev. Lett. **119**, 201804

An important lesson:

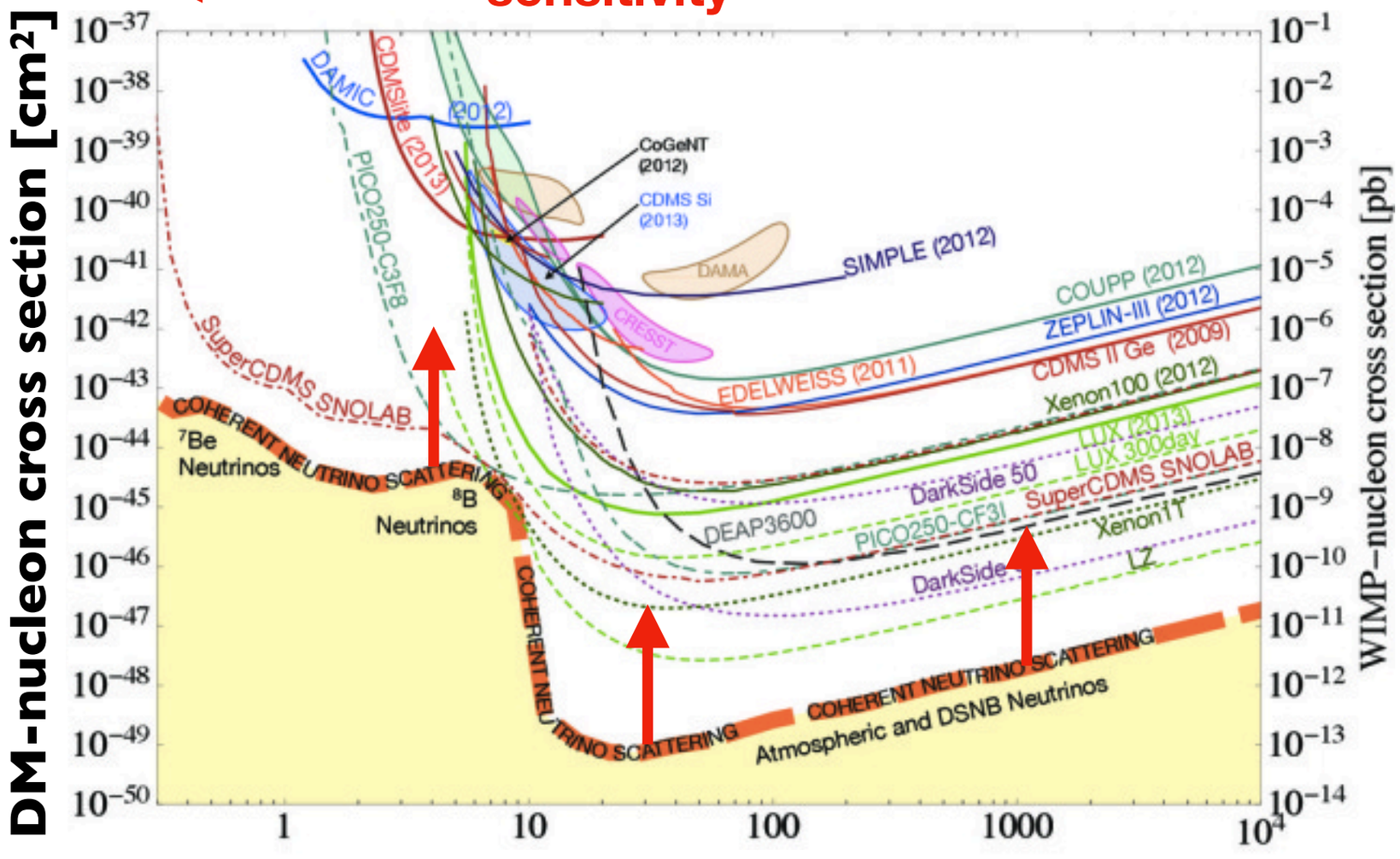
no need to re-invent the wheel!

Future of DM Direct Detection

smaller energy sensitivity

bigger experiments

BSM raises floor



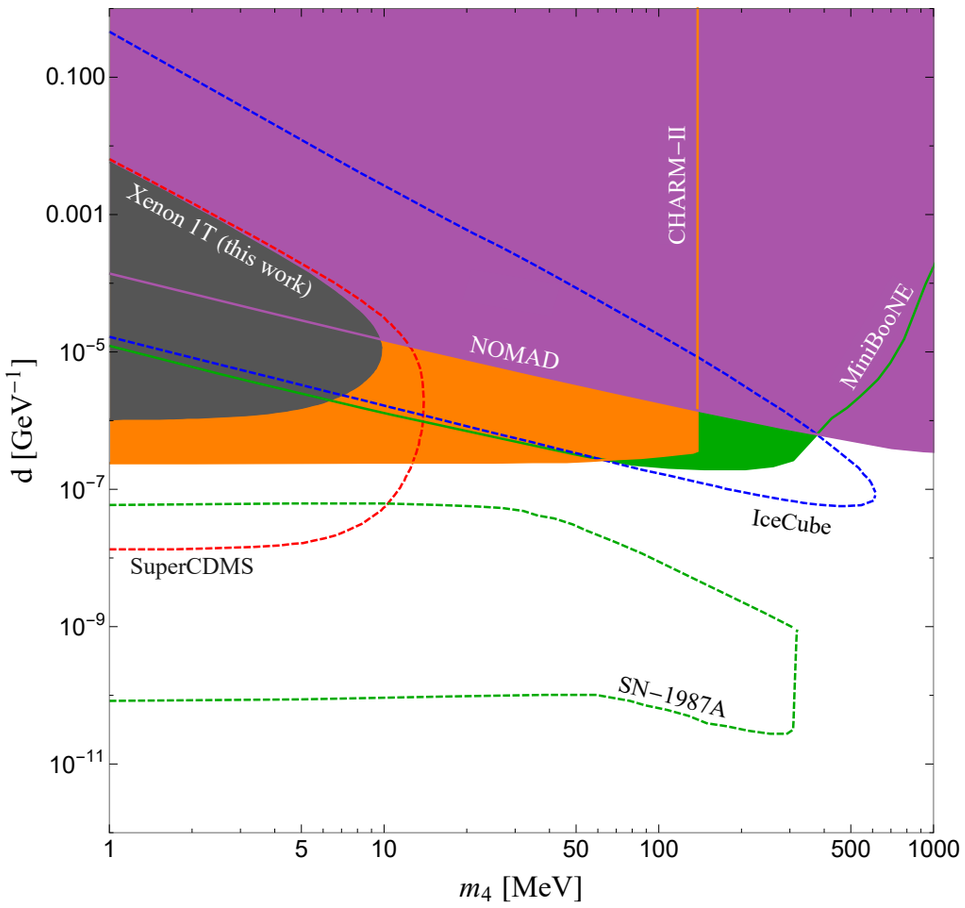
Eventually run into a “neutrino floor.” Bad for DM, but good for neutrinos!

Direct Detection Experiments at the Neutrino Dipole Portal Frontier

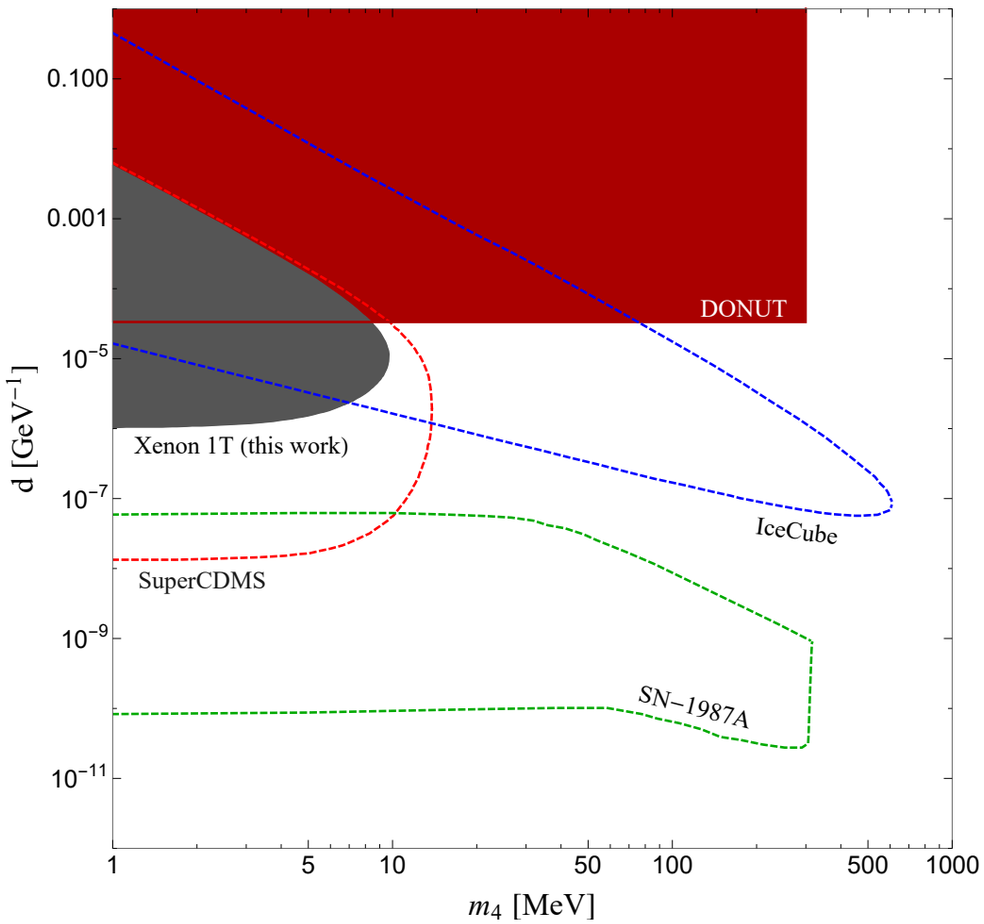
IMS, Wyenberg (Phys.Rev. D 2019)

$$\mathscr{L}_{\rm NDP} \supset d\,(\bar{\nu}_L \sigma_{\mu\nu} F^{\mu\nu} N)$$

mu-flavored



tau-flavored



- **Current XENON1T data improves bounds more than order of magnitude at low masses in tau case.**

- **Future data can close gap down to the SN1987A limit (Magill, Plestid, Pospelov, Tsai, [1803.03262]) for both muon/tau.**

Conclusions

- Two key indications that the real world has ingredients beyond the SM: DM and neutrino masses.

- Neutrino Scattering is very rich, offers many avenues for testing BSM ideas.

  - **<u>May imply connections between DM and neutrinos:</u>**
    - New Matter effects to investigate with future oscillation data.

  - **<u>Can make sterile neutrinos in collisions today:</u>**
    - IceCube "double-bang" events at anomalously low energies.
    - DM Direct Detection expts. can probe non-minimal portals to Sterile Neutrinos.

Thanks!