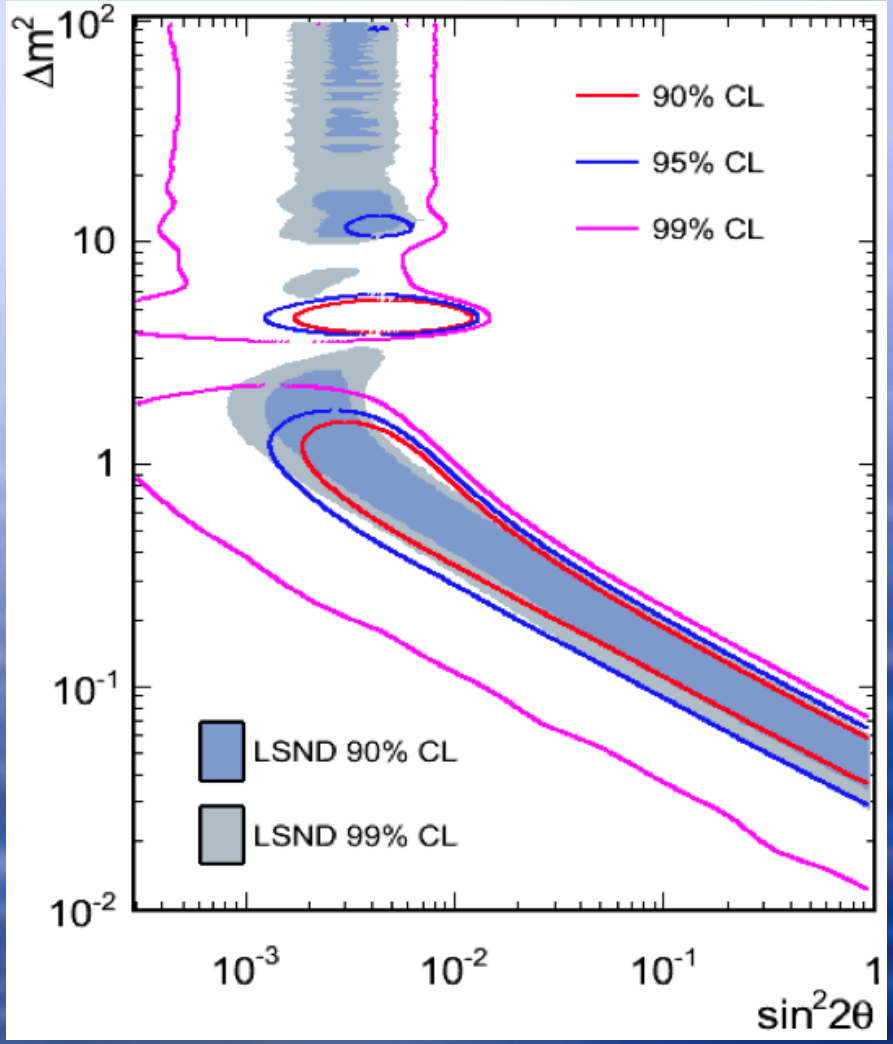
Tensions Subgroup Report



Boris Kayser, Fermilab

March 21, 2012

The Subgroup

Steve Brice
André de Gouvêa
Patrick Huber
Boris Kayser (facilitator)
Geoff Mills
Richard Van de Water
Sam Zeller

The Mission

Summarize the tensions with the 3 – ν paradigm

(André de Gouvêa, Patrick Huber, Boris Kayser)

Assess the expected/possible impact of ongoing or near-term approved experiments

(Richard Van de Water, Sam Zeller)

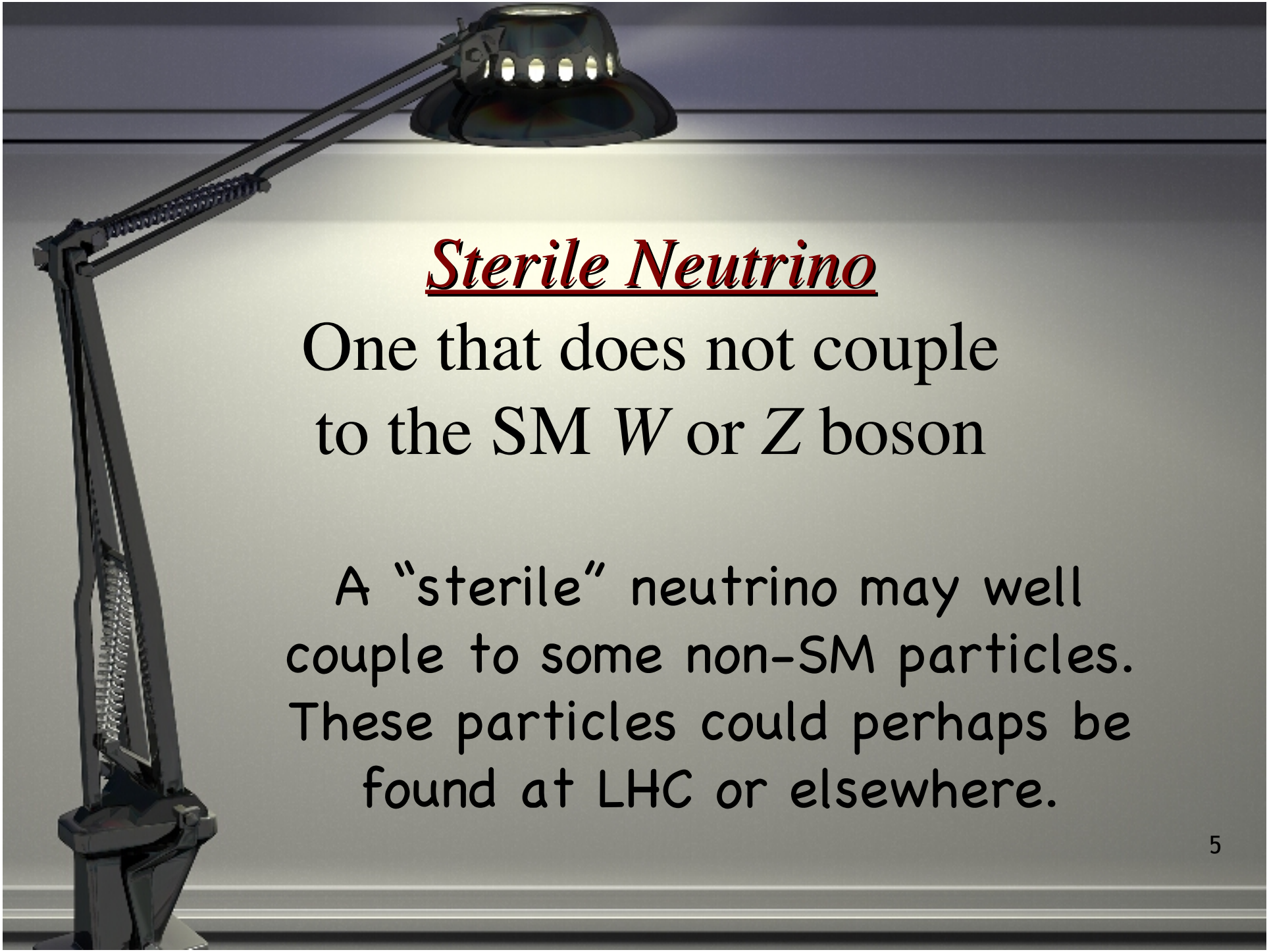
Determine the requirements for a longer-term ***definitive*** collection of experiments

(Steve Brice, Geoff Mills)

The Hints Of

Sterile Neutrinos

(André de Gouvêa, Patrick Huber, Boris Kayser)



Sterile Neutrino

One that does not couple to the SM *W* or *Z* boson

A "sterile" neutrino may well couple to some non-SM particles. These particles could perhaps be found at LHC or elsewhere.

Terrestrial $\nu_{sterile}$ Hints

LSND

MiniBooNE

Reactor Experiments with
Detectors at (10 – 100) m

^{51}Cr and ^{37}Ar Sources
Used to Test Solar Neutrino Detectors

Jon Link's talk

Cosmological $\nu_{sterile}$ Hints

Big Bang Nucleosysthesis (BBN) and CMB anisotropies count the effective number of relativistic degrees of freedom, $N_{\rm eff}$, at early times.

Light sterile neutrinos mixed with the active ones as required by the terrestrial anomalies would very likely have thermalized in the early universe.

Then $N_{\rm eff}$ grows by 1 for each sterile species.

The evidence suggests that perhaps $N_{\rm eff} > 3$.

N_{eff} From BBN

Model	Data	N_{eff}	Ref.
$\eta+N_{eff}$	$\eta_{CMB}+Y_p+D/H$	$3.8^{(+0.8)}_{(-0.7)}$	[10]
	$\eta_{CMB}+Y_p+D/H$	$< (4.05)$	[11]
	Y_p+D/H	3.85 ± 0.26	[13]
	Y_p+D/H	3.82 ± 0.35	[13]
	Y_p+D/H	3.13 ± 0.21	[13]
$\eta+N_{eff}, (\Delta N_{eff} \equiv N_{eff} - 3.046 \geq 0)$	$\eta_{CMB}+D/H$	3.8 ± 0.6	[12]
	$\eta_{CMB}+Y_p$	$3.90^{+0.21}_{-0.58}$	[12]
	Y_p+D/H	$3.91^{+0.22}_{-0.55}$	[12]

$N_{\rm eff}$ From CMB

Model	Data	$N_{\rm eff}$	Ref.
$N_{\rm eff}$	W-5+BAO+SN+H_0	$4.13^{+0.87(+1.76)}_{-0.85(-1.63)}$	[26]
	W-5+LRG+H_0	$4.16^{+0.76(+1.60)}_{-0.77(-1.43)}$	[26]
	W-5+CMB+BAO+XLF+$f_{\rm gas}$+H_0	$3.4^{+0.6}_{-0.5}$	[29]
	W-5+LRG+maxBCG+H_0	$3.77^{+0.67(+1.37)}_{-0.67(-1.24)}$	[26]
	W-7+BAO+H_0	$4.34^{+0.86}_{-0.88}$	[18]
	W-7+LRG+H_0	$4.25^{+0.76}_{-0.80}$	[18]
	W-7+ACT	5.3 ± 1.3	[23]
	W-7+ACT+BAO+H_0	4.56 ± 0.75	[23]
	W-7+SPT	3.85 ± 0.62	[24]
	W-7+SPT+BAO+H_0	3.85 ± 0.42	[24]
	W-7+ACT+SPT+LRG+H_0	$4.08^{(+0.71)}_{(-0.68)}$	[30]
	W-7+ACT+SPT+BAO+H_0	3.89 ± 0.41	[31]
$N_{\rm eff}$+f_ν	W-7+CMB+BAO+H_0	$4.47^{(+1.82)}_{(-1.74)}$	[32]
	W-7+CMB+LRG+H_0	$4.87^{(+1.86)}_{(-1.75)}$	[32]
$N_{\rm eff}$+Ω_k	W-7+BAO+H_0	4.61 ± 0.96	[31]
	W-7+ACT+SPT+BAO+H_0	4.03 ± 0.45	[32]
$N_{\rm eff}$+Ω_k+f_ν	W-7+ACT+SPT+BAO+H_0	4.00 ± 0.43	[31]
$N_{\rm eff}$+f_ν+w	W-7+CMB+BAO+H_0	$3.68^{(+1.90)}_{(-1.84)}$	[32]
	W-7+CMB+LRG+H_0	$4.87^{(+2.02)}_{(-2.02)}$	[32]
$N_{\rm eff}$+Ω_k+f_ν+w	W-7+CMB+BAO+SN+H_0	$4.2^{+1.10(+2.00)}_{-0.61(-1.14)}$	[33]
	W-7+CMB+LRG+SN+H_0	$4.3^{+1.40(+2.30)}_{-0.54(-1.09)}$	[33]

More precise information will come from the Planck satellite.

$\sum_i m(\nu_i)$ In the Early Universe

Large Scale Structure in the universe and the CMB suggest that —

$$\sum_i m(\nu_i) < (0.17 - 1.0)\ \text{eV}$$

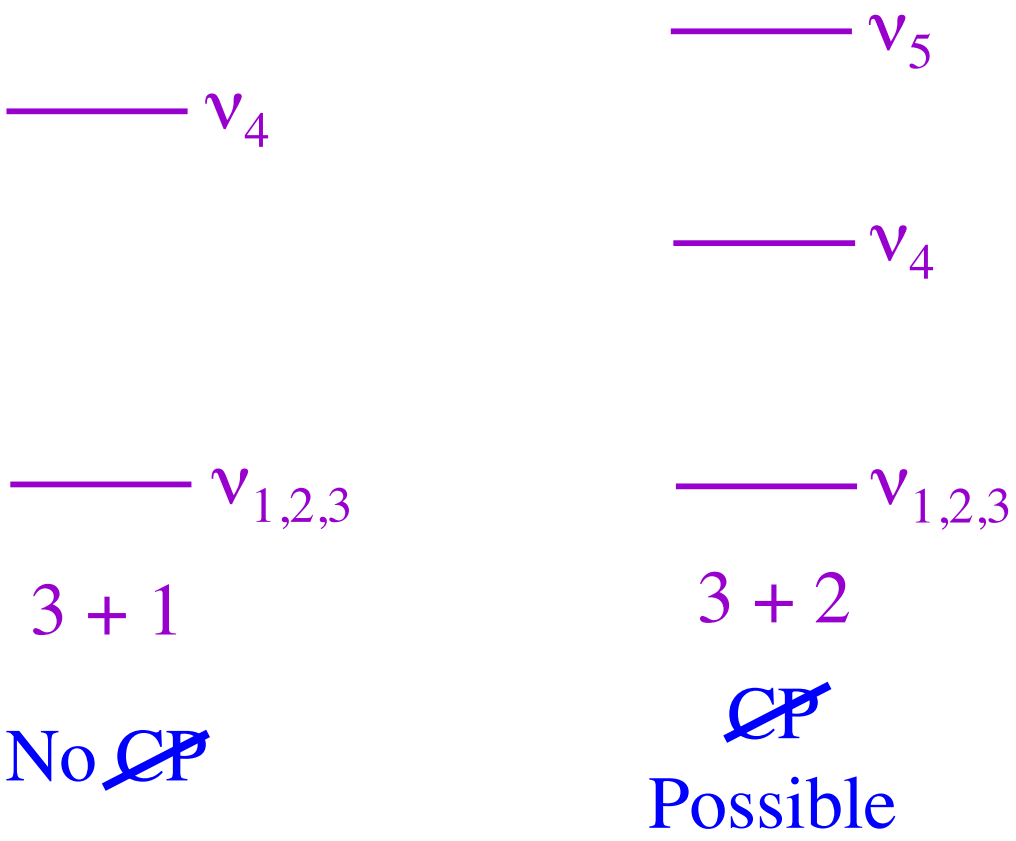
(Seljak, Slosar, McDonald
Hannestad; Pastor)

Possible tension with terrestrial experiments if $\Delta m^2 > 1\ \text{eV}^2$.

However, in cosmology, there are parameter degeneracies.

Global Fits To Short-Baseline Terrestrial Data

The Spectra That Are Tried



Short-Baseline experiments
have an L/E too small to see
the splitting between ν_1, ν_2, and ν_3.

The Bottom Line

3 + 1 spectra do not provide a good fit to all the data.

They do not violate CP.

They cannot accommodate the CP-violating simultaneous presence of a $\bar{\nu}$ signal in LSND and MiniBooNE, and the absence of a ν signal in MiniBooNE.

(Karagiorgi; Kopp, Maltoni, and Schwetz)

3 + 2 spectra can violate CP, so they do better, but there is still tension between appearance data and disappearance data.

Other phenomenological models are being tried ….

Reaction of This Subgroup to the Hints of Sterile Neutrinos

Individually or taken together,
the hints are certainly not convincing.

But —

**They are interesting enough
to call for further,
hopefully definitive,
investigation.**

Getting Information on Anticipated Inputs From Approved Experiments

(Richard Van de Water, Sam Zeller)

List of expected measurements from on-going and near-term approved experiments

appearance:

2012-2013	2013-2014	2014-2017
MiniBooNE $\overline{\nu}_e$ appearance (expect x2 more data) MiniBooNE combined ν_e, $\overline{\nu}_e$ 3+N appearance fit	ICARUS ν_e appearance T2K ND280 near detector	MicroBooNE ν_e appearance

disappearance:

MiniBooNE/SciBooNE joint $\overline{\nu}_\mu$ disappearance	IceCube ν_μ and $\overline{\nu}_\mu$ disappearance	MicroBooNE ν_μ disappearance MINOS+ high Δm^2 ν_μ disappearance

other input:

continued reactor flux calculations	radioactive source measurements (Borexino, Daya Bay, KamLAND, SNO+) mass limit from Planck data	

time →

- have identified contacts for each of these and solicited input …

Status of Getting Information on Anticipated Inputs from Approved Experiments
R. Van de Water, G.P. Zeller

- **MiniBooNE**
  contact: Zarko Pavlovic (VdW, GPZ)
  status: updated anti-ν_e and joint SB/MB anti-ν_μ disappearance results expected this summer

- **ICARUS**
  contact: trying to find a contact
  status: TBD

- **T2K near detector**
  contact: Hiro Tanaka, Morgan Wascko
  status: there have been "un-official" studies done on this, but this has not been a focus
  Hiro will be at FNAL at end of March, not sure what we will be able to get here

- **MicroBooNE**
  contact: Georgia Karagiorigi and Roxanne Guenette
  status: they will give an update on their sensitivity calculations at the March 21st meeting

- **Ice Cube**
  contact: Warren Huelsnitz
  status: will give a status/timeline for the atmospheric ν_μ and anti-ν_μ disappearance analysis

Status of Getting Information on Anticipated Inputs from Approved Experiments

R. Van de Water, G.P. Zeller

- **MINOS+**

  contact: Geoff Mills

  status: will give a status/timeline for the high Δm^2 ν_μ disappearance analysis

- **Planck mass limit**

  contact: Marco Bersanelli (gave Planck colloquium at FNAL on 03/07/12)

  status: first cosmology results expected in Jan 2013, second data release from full mission in Feb 2014

- **radioactive sources at reactor experiments**

  contact: Karsten Heeger

  status: have a 1-page write-up from Karsten for Daya Bay, additional input expected at March 21 meeting

- **continued reactor flux calculations**

  contact: Patrick Huber

  status: will give outline and future developments in the reactor flux calculations

Requirements for a *Definitive* Collection of Experiments

(Steve Brice and Geoff Mills)

Determining the requirements for a ***definitive*** *collection of experiments is likely to be a centrally important part of our study.*

Reflection on what these requirements should be is at an early stage.

Consideration is not limited to experiments at accelerators, but we would like to determine —

What role Fermilab can play.

General Requirements for Future Experiments

Ability to provide convincing measurement

- High statistical significance ($\approx 5\sigma$)
  - Be realistic – shoot for more like 10σ at proposal stage if making a major departure from previous methodology
- Control of systematic error ($\approx$ statistical error)
  - Have redundant ways to demonstrate systematic error is controlled
- Proof of oscillatory effect (beyond reasonable doubt)
  - e.g., seeing an effect in L as well as in E

Full coverage of Δm^2 range: From 0.1 eV^2 on up …

Clean separation of electrons and photons

It is desirable to study a ***variety*** of processes:

Appearance —

$$\nu_\mu \rightarrow \nu_e \quad \text{and} \quad \bar{\nu}_\mu \rightarrow \bar{\nu}_e$$

Disappearance —

$$\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$$

Example: $P\left(\bar{\nu}_\mu \rightarrow \text{Not } \bar{\nu}_\mu\right) < P\left(\bar{\nu}_\mu \rightarrow \bar{\nu}_e\right)$

would ***disprove*** an oscillation interpretation of the data.

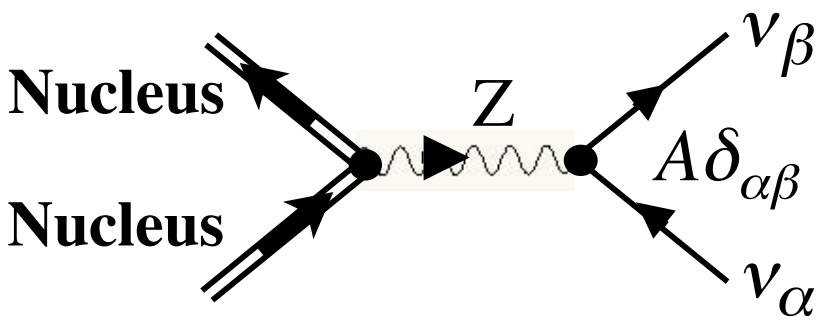
It would be desirable to probe the existence of additional neutrinos in several quite different ways.

Just to ***illustrate*** (no judgment implied!):

Most probes that are foreseen would look for oscillation with $\Delta m^2 > \Delta m^2_{\text{atmospheric}}$ and $\Delta m^2_{\text{solar}}$.

But there is a way, in principle, to look for the specifically ***sterile*** nature of sterile neutrinos…

Coherent Neutral-Current Scattering



This process has the same rate for any incoming ***active*** neutrino, ν_e, ν_μ, or ν_τ.

But the Z does not couple to $\nu_{sterile}$.

If $\nu_{active} \rightarrow \nu_{sterile}$, the coherent scattering event rate will oscillate with it.

Summary

The tensions with the $3-\nu$ paradigm call for investigation.

The possible impacts of approved experiments will soon be assessed.

Determining the requirements for definitive experiments has begun.