

Neutrino Oscillation Parameters in
a
Six-Channel **Reduced Rank** See-Saw
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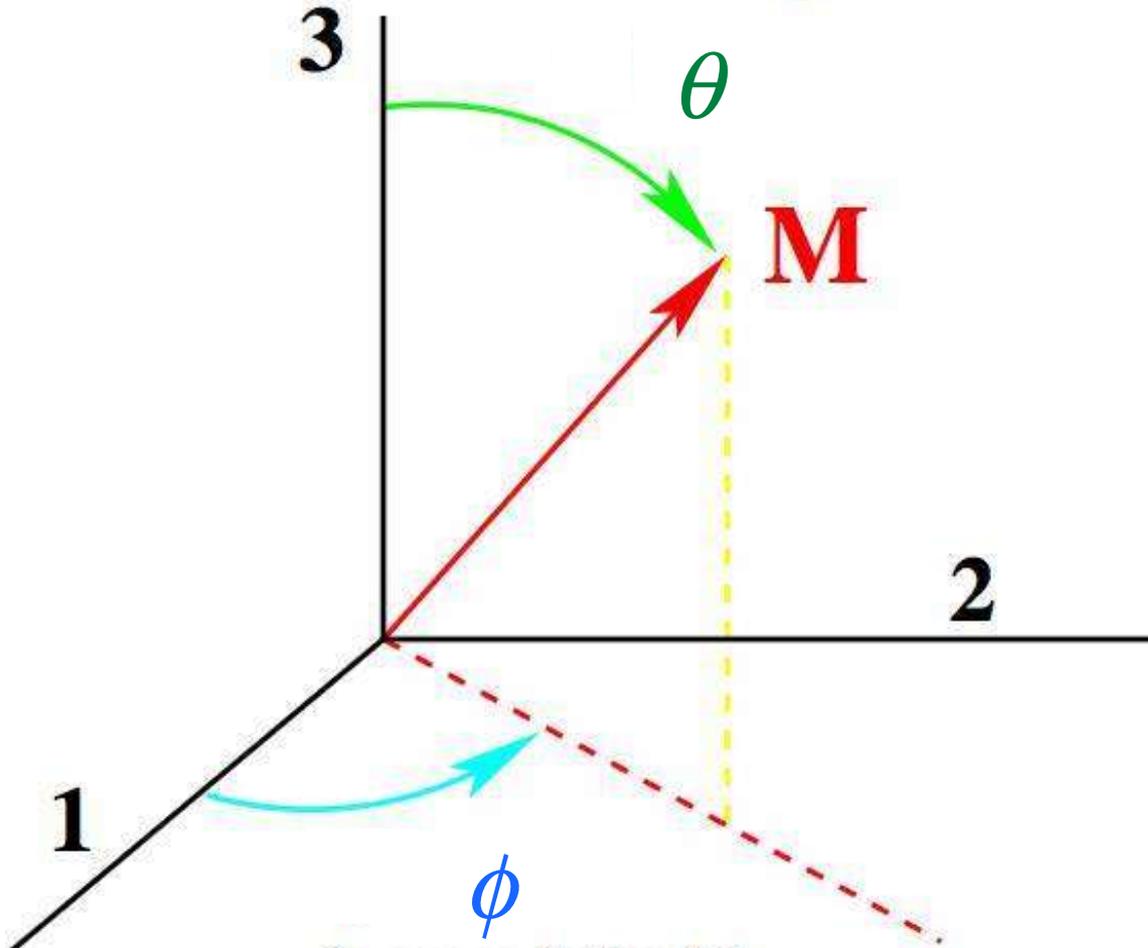
Based on “**3+2 neutrinos in a see-saw variation**”,
G.J. Stephenson, Jr., T. Goldman, B.H.J. McKellar
and M. Garbutt, to appear in *IJMPA*
[[hep-ph/0404015](#)]

3 Flavor, Rank 1 Sterile Mass Matrix

Diagonal Dirac mass matrix defines “sterile flavors”

0	0	0	m_1	0	0	V_{af}
0	0	0	0	m_2	0	V_{ag}
0	0	0	0	0	m_3	V_{ah}
m_1	0	0	0	0	0	V_{sf}
0	m_2	0	0	0	0	V_{sg}
0	0	m_3	0	0	M	V_{sh}

Direction of Single Massive Sterile Eigenstate



in space defined by
Dirac mass eigenstates

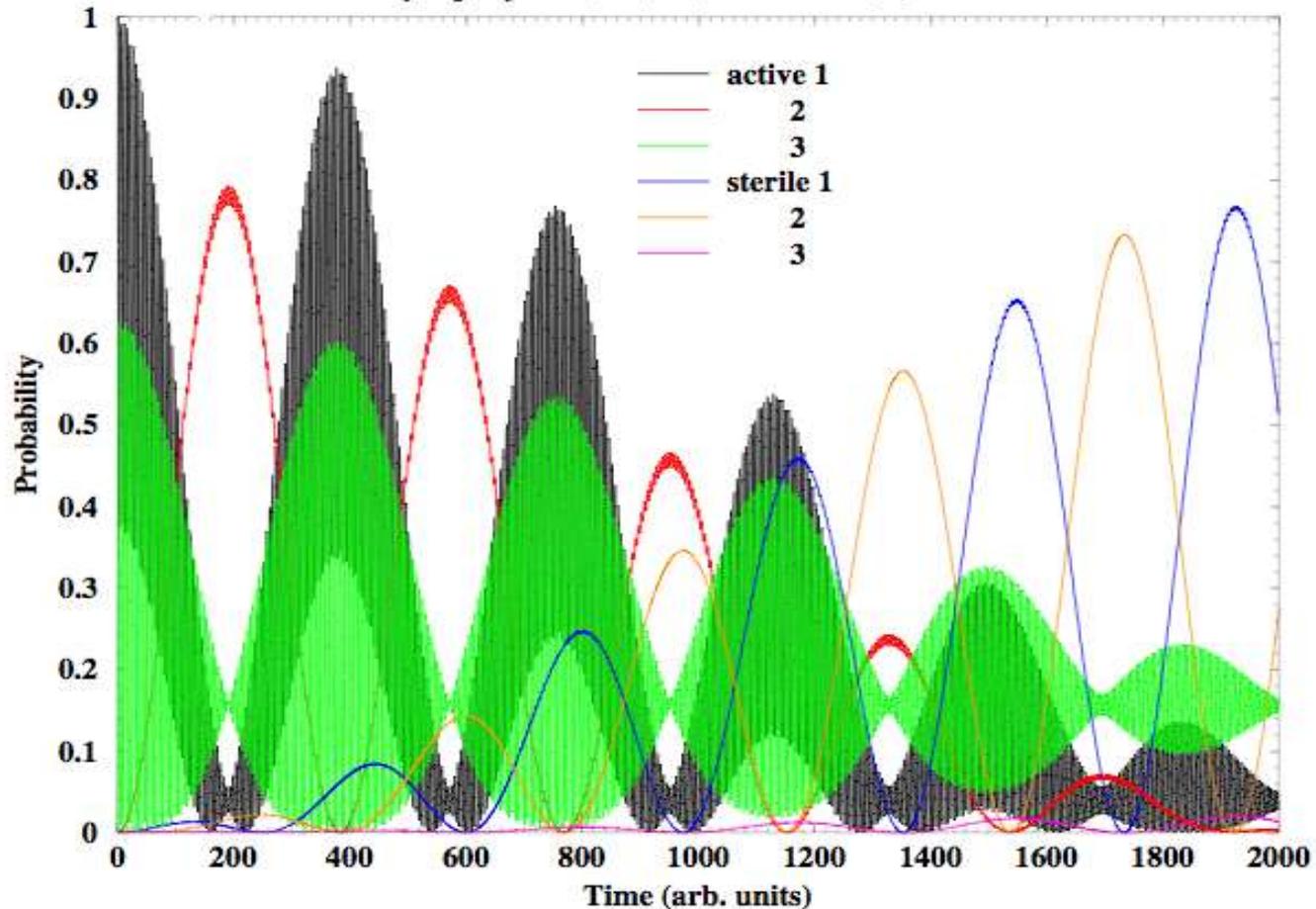
$$M \longrightarrow M^*$$

$\cos^2 \phi \sin^2 \theta$	$\cos \phi \sin \phi \sin^2 \theta$	$\cos \phi \sin \theta \cos \theta$
$\cos \phi \sin \phi \sin^2 \theta$	$\sin^2 \phi \sin^2 \theta$	$\sin \phi \sin \theta \cos \theta$
$\cos \phi \sin \theta \cos \theta$	$\sin \phi \sin \theta \cos \theta$	$\cos^2 \theta$

Small angles ϕ , θ for
 misalignment of sterile and active flavors
 nonetheless induce large mixing!

Oscillation Probabilities vs. Time

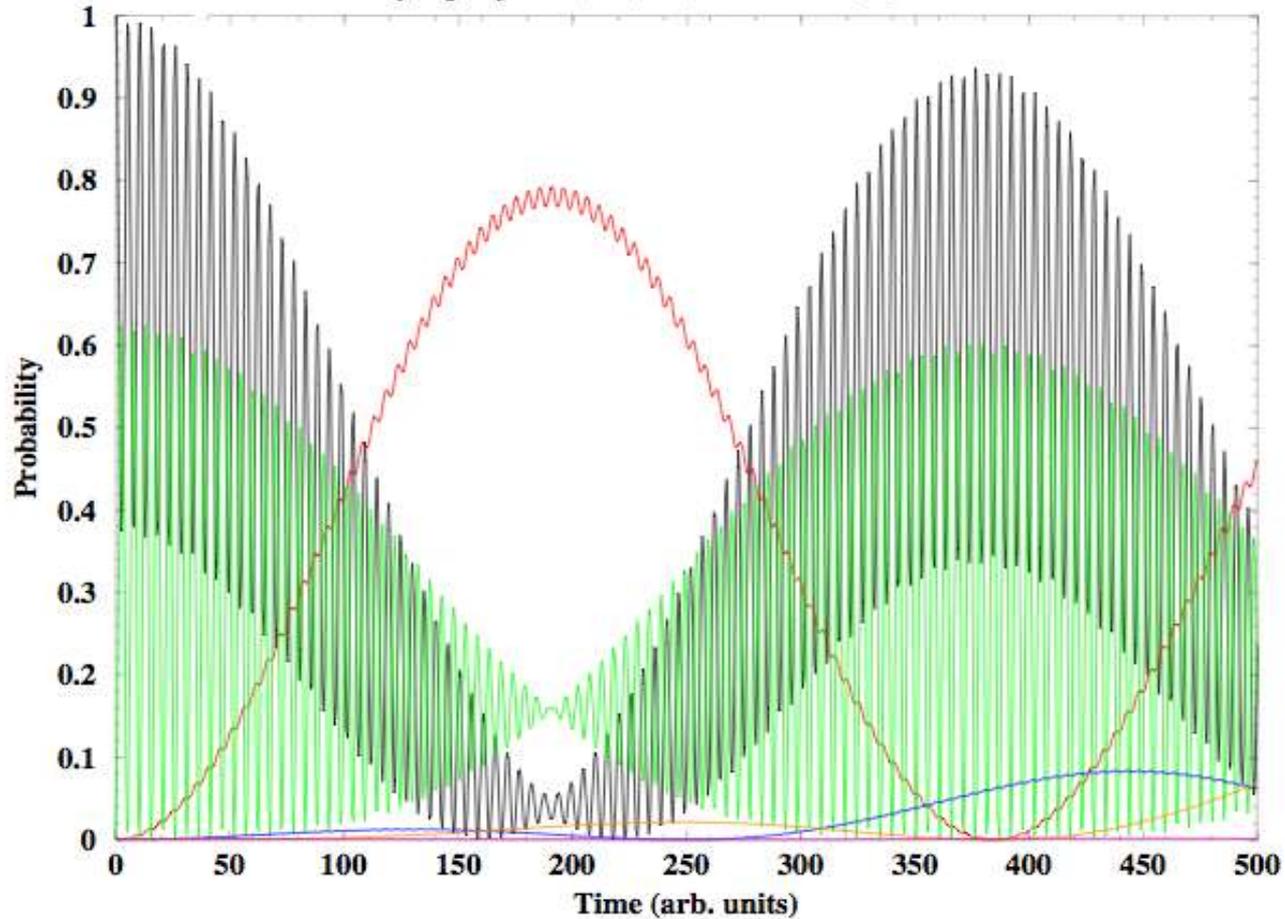
$m_1, m_2, m_3 = 1.0, 1.1, 3.0$; $\theta=9.324078^\circ$, $\phi=2.25^\circ$



Large mixing amplitudes to all channels on multiple scales

Oscillation Probabilities vs. Time

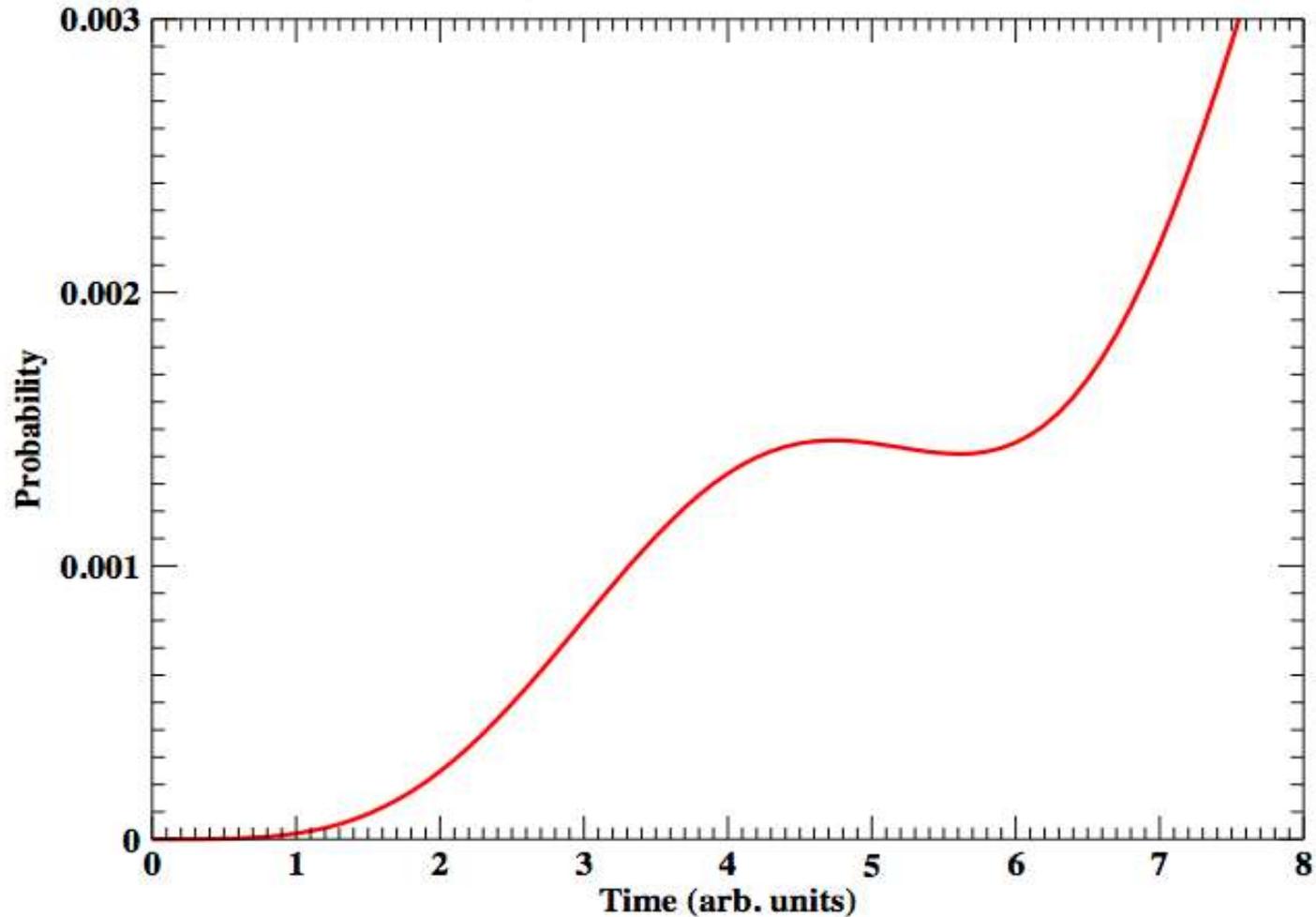
$m_1, m_2, m_3 = 1.0, 1.1, 3.0$; $\theta=9.324078^\circ$, $\phi=2.25^\circ$



Variation near source

Oscillation Appearance Probability vs. Time

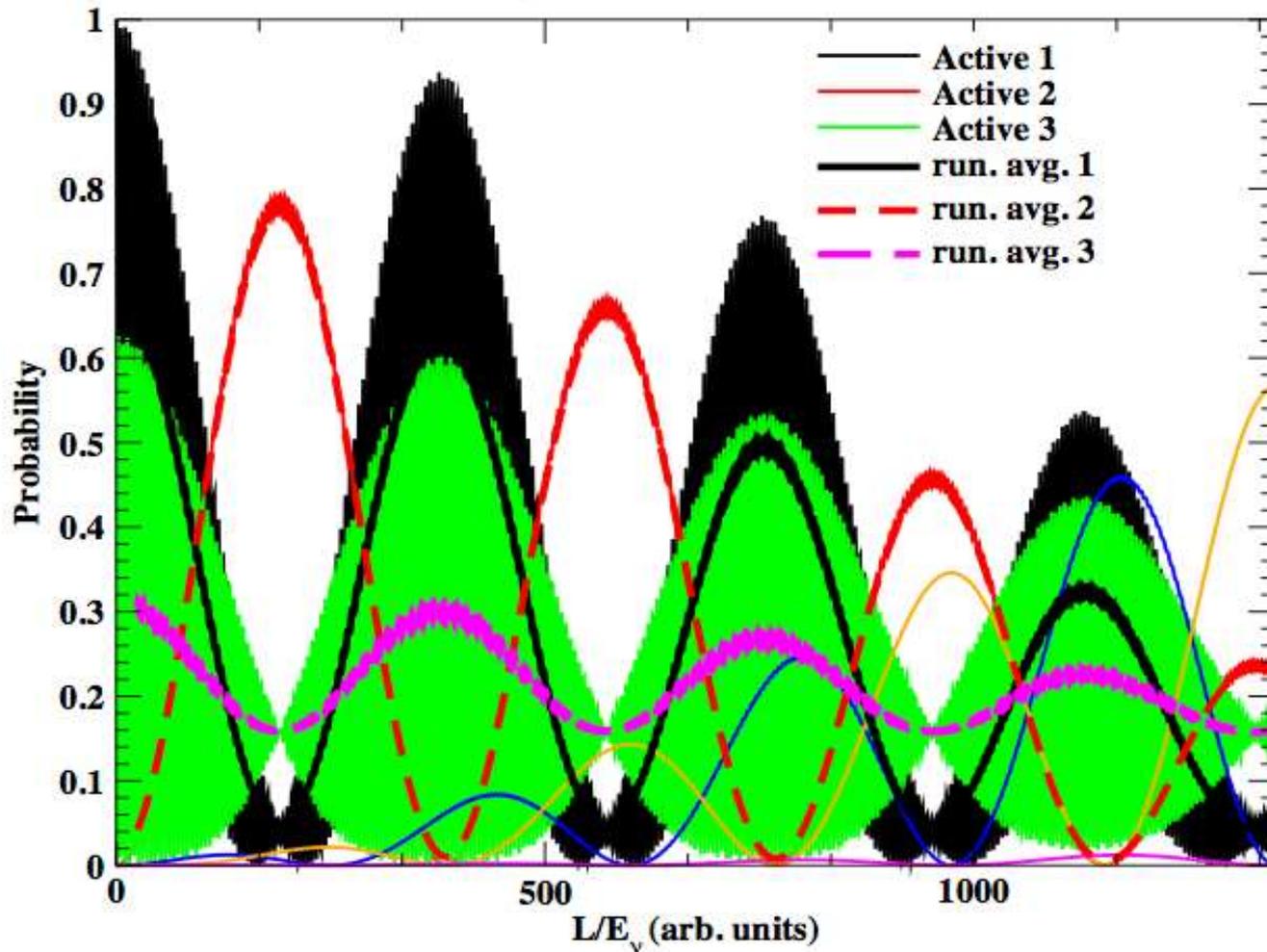
$$m_1, m_2, m_3 = 1.0, 1.1, 3.0; \theta = 9.324078^\circ, \phi = 2.25^\circ$$



Note probability scale for appearance

Oscillation Probabilities vs. Time

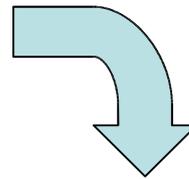
$m_1, m_2, m_3 = 1.0, 1.1, 3.0; \theta=9.324^\circ, \phi=2.25^\circ$



Effects of finite resolution

Add **CKM** (yes, same as **quarks**) **mixing** in **actives**

m_1	0	0
0	m_2	0
0	0	m_3

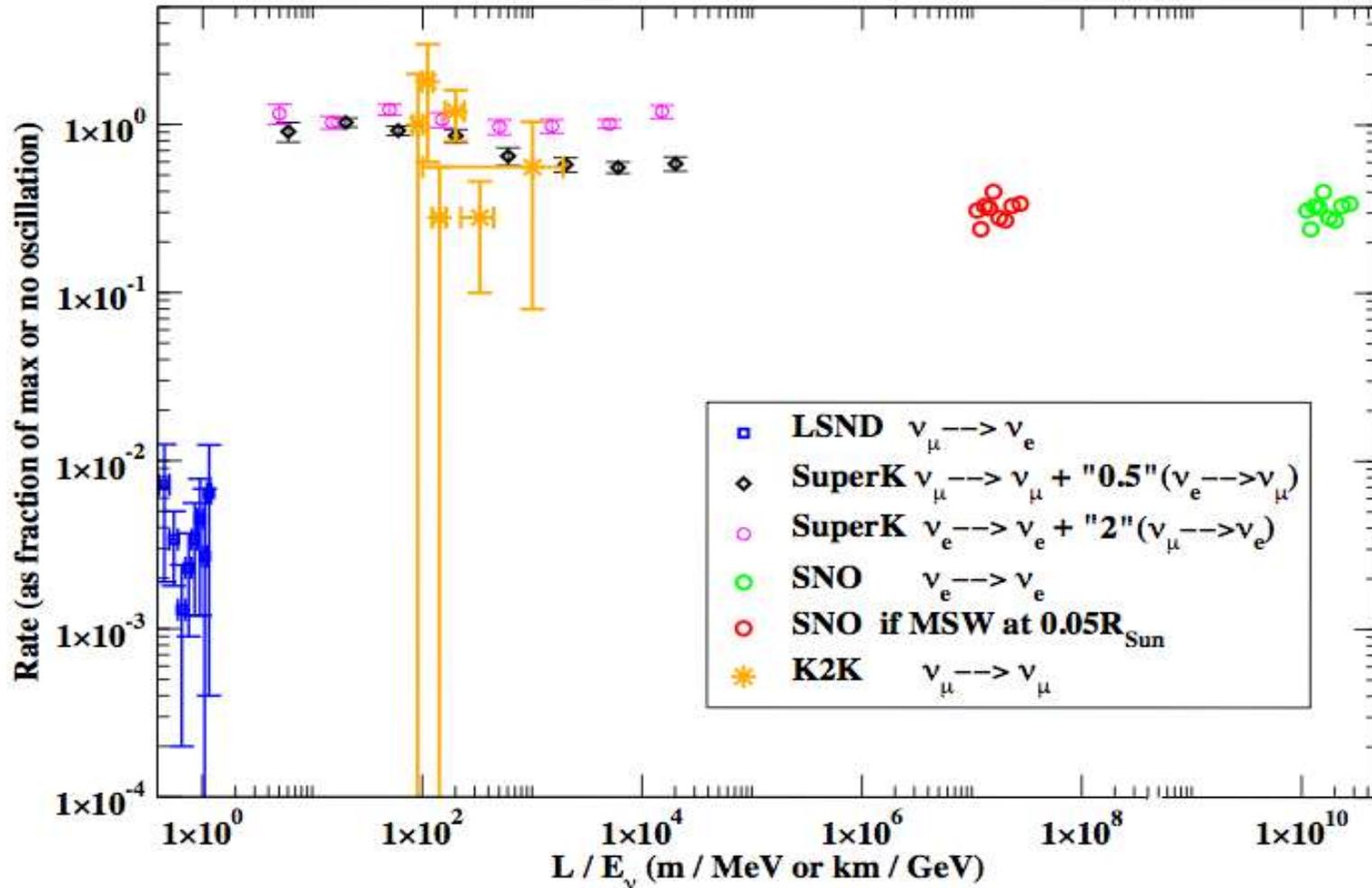


[Ignoring **CPV**]

U_{11}	U_{21}	U_{31}	m_1	0	0	U_{11}	U_{12}	U_{13}
U_{12}	U_{22}	U_{32}	0	m_2	0	U_{21}	U_{22}	U_{23}
U_{13}	U_{23}	U_{33}	0	0	m_3	U_{31}	U_{32}	U_{33}

- Without **CKM**, L/E scale mismatch for **LSND** effect
- Transition probability decreases when L/E scale is adjusted to fit atmospheric
- Adding **CKM** restores probability for ν_e appearance without further L/E scale change

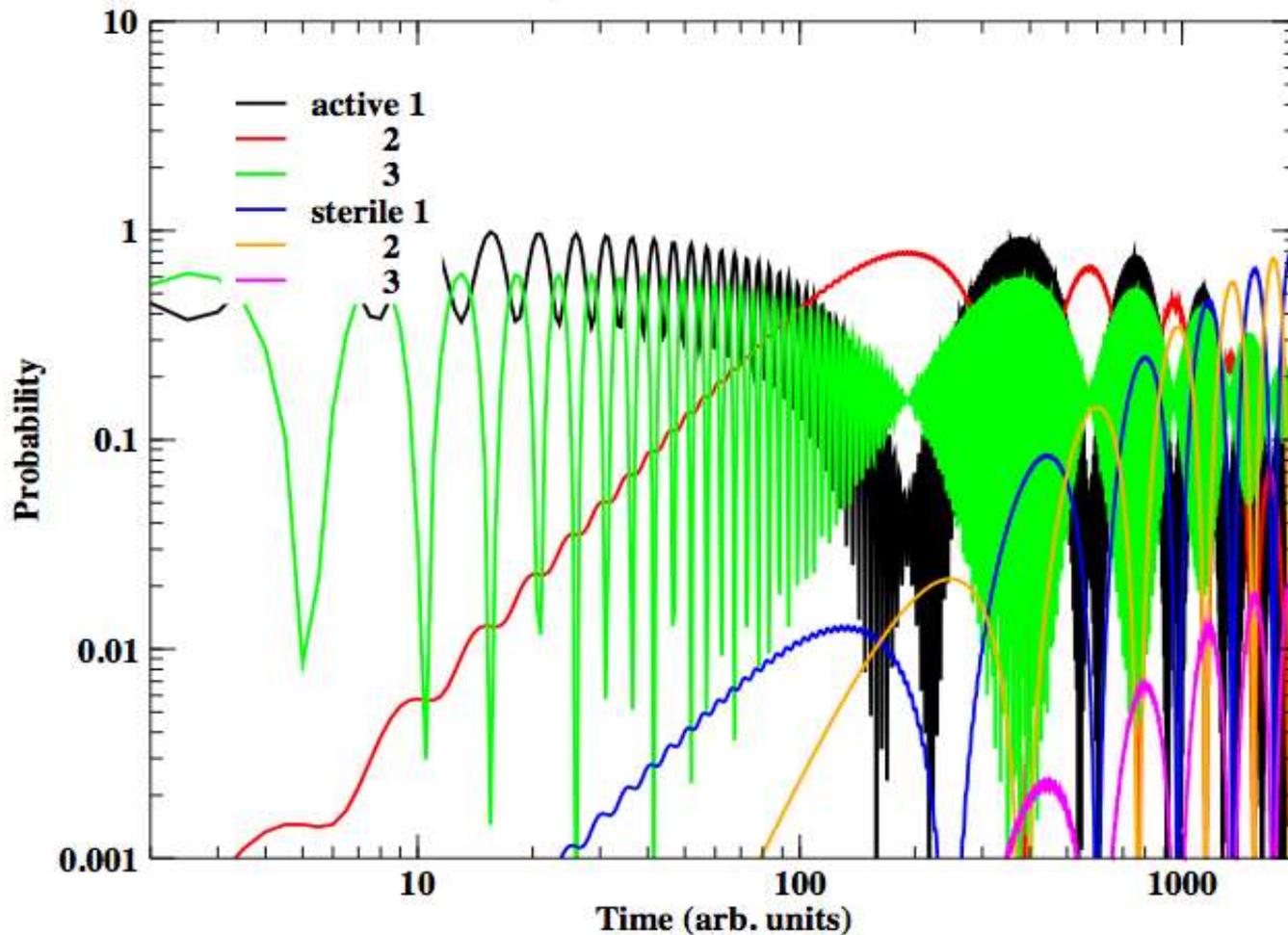
Neutrino Appearance and Disappearance Rates vs. L / E_ν (m / MeV or km / GeV)



Data in L/E form

Oscillation Probabilities vs. Time

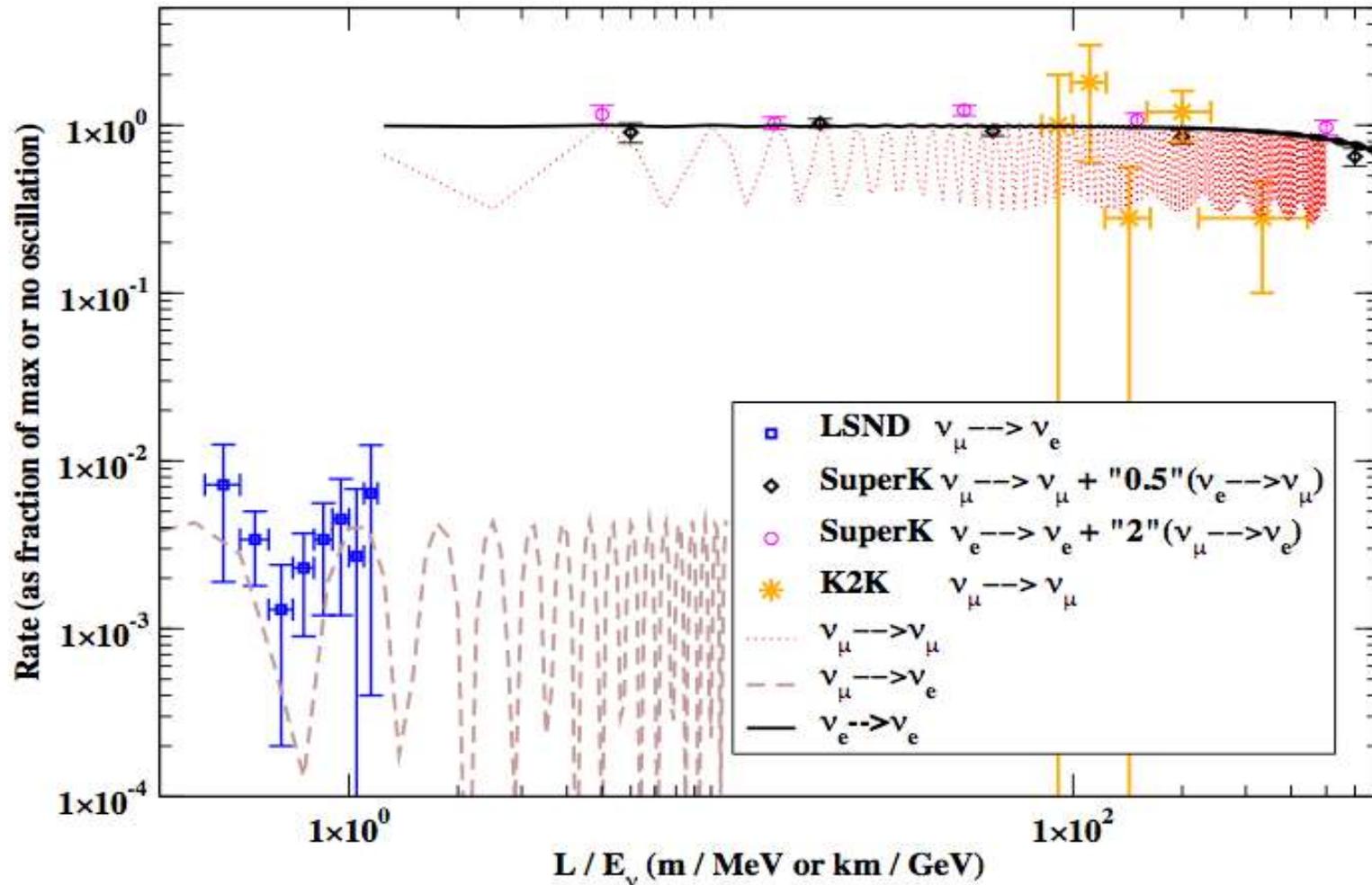
$m_1, m_2, m_3 = 1.0, 1.1, 3.0; \theta=9.324, \phi=2.25$



Non-CKM results on Log-Log plot as for data

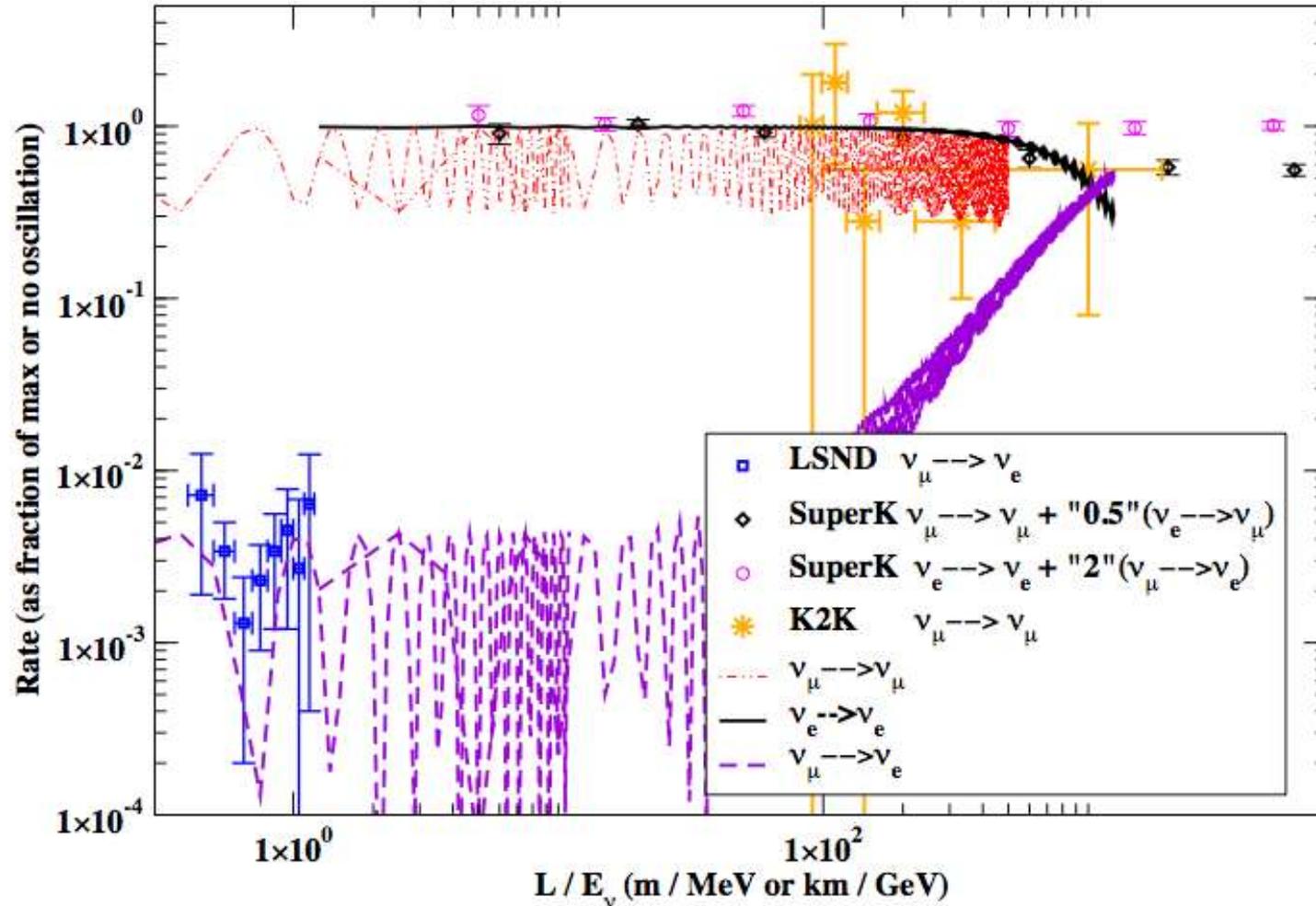
Neutrino Appearance and Disappearance Rates

vs. L / E_ν (m / MeV or km / GeV)



Neutrino Appearance and Disappearance Rates

vs. L / E_ν (m / MeV or km / GeV)



Mixing still large -- but too soon?

Remaining questions:

- Wolfenstein effect on ν_e through Earth?
- Further extend scale for ν_μ disappearance?
- Analyze Solar ν 's with multichannel MSW

CONCLUSIONS

1. Sterile and Dirac CKM/MNS angles raise questions re conventional analyses limited in channels
2. Reliable data analysis requires having L/E distributions to avoid two-channel biases.