

WG1 (Neutrino Oscillations) Overview

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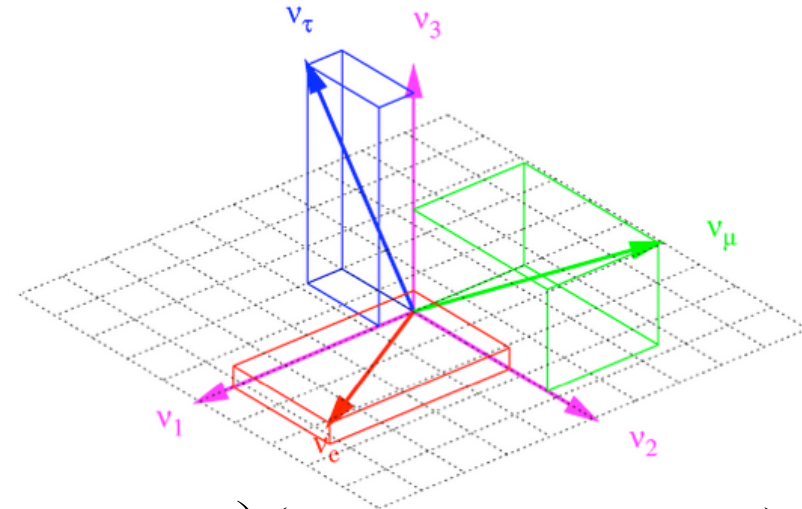
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08-26-2019

NuFACT2019, Daegu, KOREA

Neutrino Oscillation

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$



$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta_{CP}} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

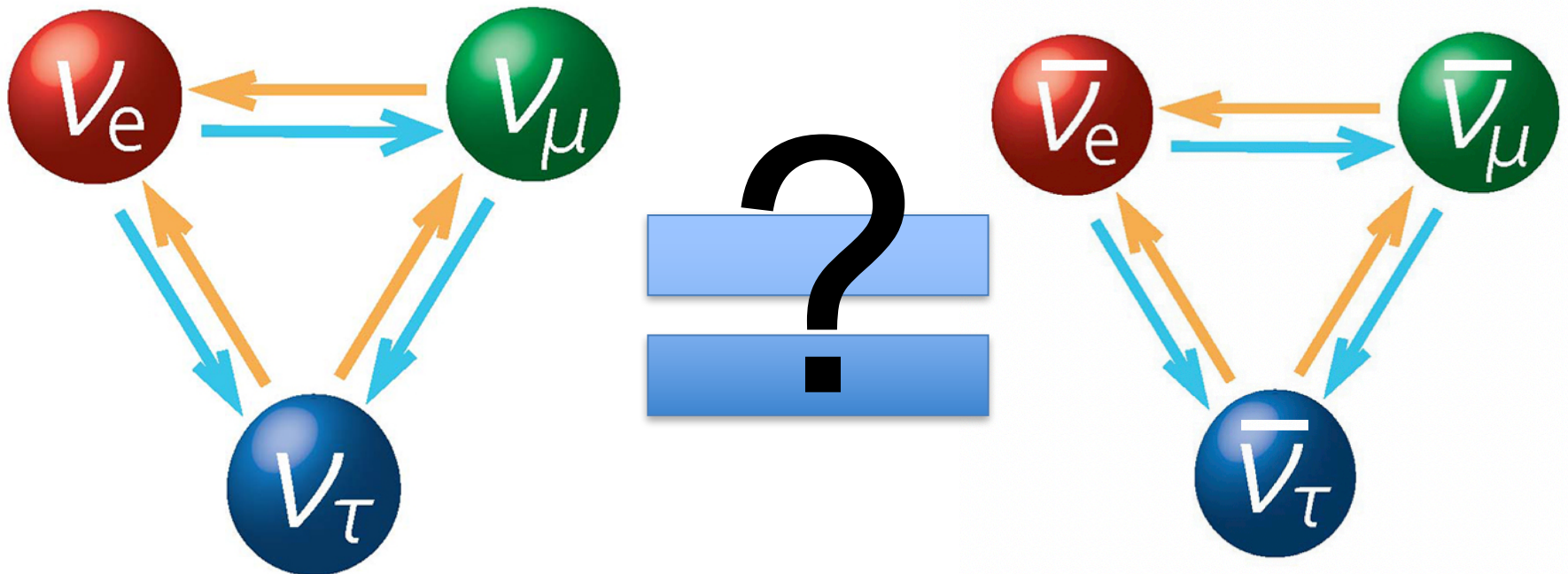
$$P(\nu_\alpha \rightarrow \nu_\beta) = \delta_{\alpha\beta} - 4 \sum_{i>j} \text{Re}(U_{\alpha i}^* U_{\beta i} U_{\alpha j} U_{\beta j}^*) \sin^2(\Delta m_{ij}^2 L / 4E) \\ + 2 \sum_{i>j} \text{Im}(U_{\alpha i}^* U_{\beta i} U_{\alpha j} U_{\beta j}^*) \sin(\Delta m_{ij}^2 L / 2E)$$

For three-flavor, 6 parameters determine neutrino oscillations :

$\theta_{12}, \theta_{23}, \theta_{13}, \delta_{CP}, \Delta m_{21}^2 = m_2^2 - m_1^2$ and $\Delta m_{32}^2 = m_3^2 - m_2^2$

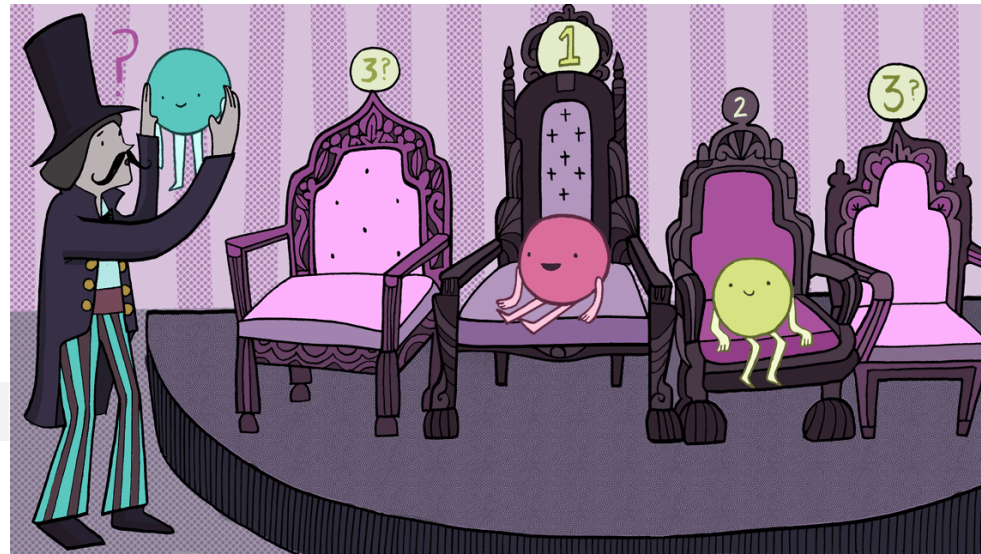
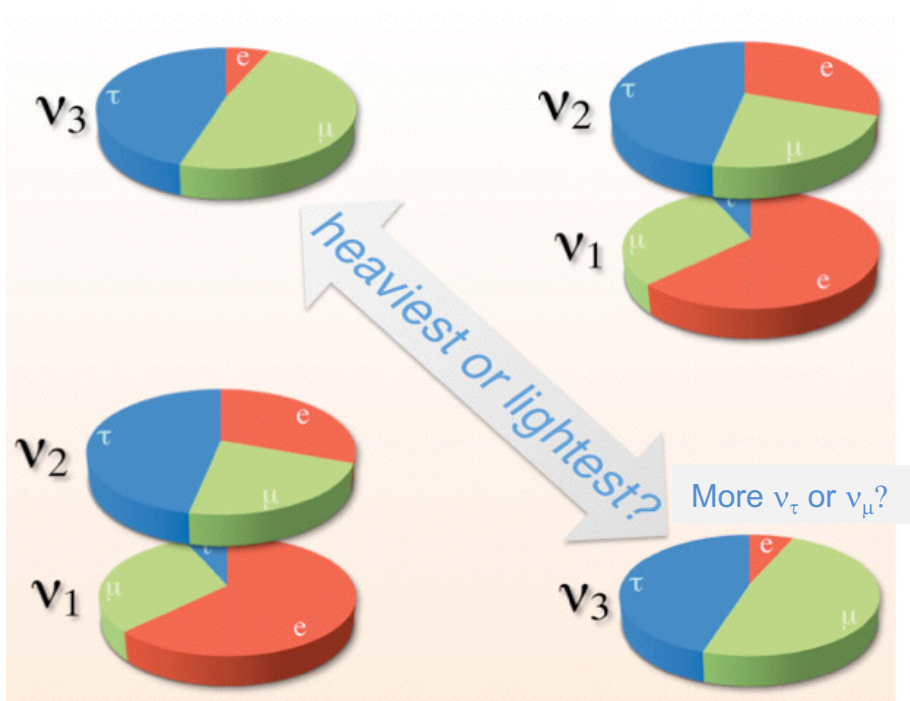
Remaining Questions for 3-flavor Oscillations

- **CP phase δ_{CP}** : whether neutrinos and antineutrinos behave the same way in oscillation? Implications for matter-antimatter asymmetry



Remaining Questions for 3-flavor Oscillations

- **Mass hierarchy**: $m_3 > m_{1,2}$ or $m_{1,2} > m_3$? Implications for absolute neutrino masses, unified theories and neutrino-less double beta decay searches
- **Octant of θ_{23}** : Is θ_{23} exactly 45° ? Is ν_3 more strongly coupled to ν_τ or ν_μ ?



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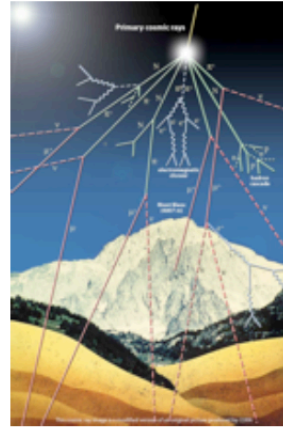
CP, Mass Hierarchy and θ_{23} Octant can be solved by neutrino appearance and disappearance experiments

Neutrino Oscillation Experiments

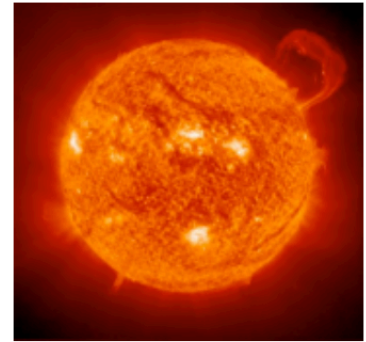
- A source (Atmospheric, Reactors, Sun, Accelerators ...)
- Detectors (Water Cherenkov, LArTPC, Scintillator ...) → New WG1+WG2 detector session
- Good understanding of signal vs. background (Evt Generator, Reconstruction, PID, Deep-learning ...)



Nuclear Reactors



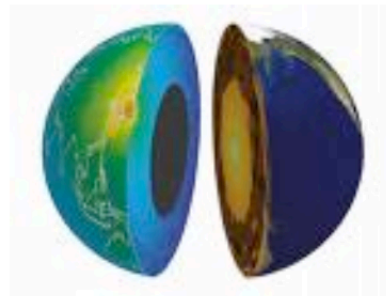
Cosmic Ray Showers



The Sun



Astrophysical (SuperNova/Big Bang)



The Earth (Radioactive Elements)



Accelerators

WG1 Questions (From NuFACT17,18)

- What are the next steps for a unitarity test?
- What are the needs for the hadron production measurements for the future experiments?
- How can we address the reactor anomaly (now that the “bump” is being “understood”)?
- How can we address the “tension” between NOvA and T2K for the maximal mixing?
- What are the implications of the most likely value of δ_{CP} for the future experiments?
- What are the current and future systematic limitations on these measurements and what can we do to address them?
- Is there physics beyond the standard PMNS mixing model?

Plenary Talks

Mon		
15:00	T2K	<i>Francis Bench</i>
16:00	NOvA	<i>Erica Smith</i>
16:30	Short baseline neutrino experiment (WG1+WG5)	<i>Joshua Spitz</i>
17:00	JUNO	<i>Juan Pedro Ochoa-Ricoux</i>
Tue	(WG1+5)	
11:30	Sterile neutrino search from disappearance measurements at Daya Bay and MINOS/MINOS+	Adam Jude Aurisano Zhuojun Hu
Thu	(WG1+2, Detector)	
9:50	Overview of new detector technology for neutrino experiments	<i>Zhimin Wang</i>
10:15	Photo sensor developments for neutrino experiments	Yasuhiro NISHIMURA
Fri		
15:00	DUNE	<i>Jae Yu</i>
16:00	Hyper-Kamiokande	<i>Takashi Kobayashi</i>
16:30	ESSnuSB Project	<i>Marcos Dracos</i>
17:00	KNO Report	<i>Intae Yu</i>

Parallel Session 1 and 2, Monday

Tue	Reactor	
14:00	New Results from Double Chooz	Denise Hellwig
14:22	New Results from RENO	Dong-Ha Lee
14:44	Daya Bay: Recent Results and Status	J. Pedro Ochoa
15:06	Neutrino oscillation studies in JUNO	Wenjie Wu

Tue	Atmospheric Neutrino	
16:00	Recent Results from Super-Kamiokande	Christophe Bronner
16:24	Status and results from the ANTARES and KM3NeT-ARCA neutrino telescopes	Paolo Fermani
16:48	KM3NeT-ORCA	Mathieu Perrin-Terrin
17:12	Latest Results on Neutrino Oscillation from the IceCube Neutrino Observatory	Étienne Bourbeau
17:36	Using low energy atmospheric neutrinos for precision measurement of mixing parameters	Hisakazu Minakata

Parallel Session 3, 4 and 5, Thursday

Thu	Long Baseline	
11:00	Details of the new NOvA oscillation analyses	Steven Calvez
11:30	Recent T2K Neutrino Oscillation Results	Christophe Bronner
12:00	Overview of ESSvSB experiment to measure δ_{cp}	Monojit Ghosh
Thu	Detector (WG1+WG2)	
14:00	DUNE Near Detector	Alan Bross
14:22	First Results from Singe-Phase ProtoDUNE at CERN Neutrino Platform	Jianming Bian
14:44	ARIADNE: A novel photographic 1-ton dual-phase LArTPC	Kostas Mavrokoridis
15:06	The double calorimetry system in JUNO	Jilei Xu
Thu	Detector (WG1+WG2)	
16:00	The upgrade of the T2K Near Detector ND280	Marco Zito John Nugent
16:22	First physics run of the WAGASCI-BabyMIND detector with full setup	Kenji Yasutome
16:44	Nuclear emulsion detector for future neutrino research - NINJA and EMPHATIC -	Tsutomu Fukuda
17:06	ENUBET	Francesco Terranova
17:28	SHIP	TBD
17:50	First cross section measurement of neutrino charged current interactions in the iron ECC	Hitoshi Oshima

Parallel Session 6 and 7, Friday

Fri	Long Baseline	
14:00	DUNE Oscillation Physics	Kim Siyeon
14:30	Physics potential of Hyper-Kamiokande for neutrino oscillation measurements	John Walker
15:00	Status of the detector design studies for ESSnuSB	Joochun Park

Fri	Sterile Neutrino (WG1+WG5)	
16:00	Status of SBND	Stephen Robert Dennis
16:25	Status of JSNS2 experiment	Fumihiko Suekane
16:50	Sterile Neutrinos search via NC Disappearance at NOvA	Adam Jude Aurisano
17:15	Sterile Neutrino Searches with IceCube	Joshua Hignight

Summary

- WG1 talks covering:
 - Oscillation measurements from Atmospheric, Reactor and Accelerator neutrinos
 - Current and future experiments
- Many parallel talks, provide details in analysis/software/hardware and help communications among experiments
- Two new joint sessions for detector technology