# Investigating Important Considerations for Neutrino Oscillation Experiments

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Scharff-Goldhaber Prize Ceremony - 7/9/20

Brookhaven NDI

Neutrino Discovery Initiative

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# Particle Physics

Investigates building blocks of nature and interactions

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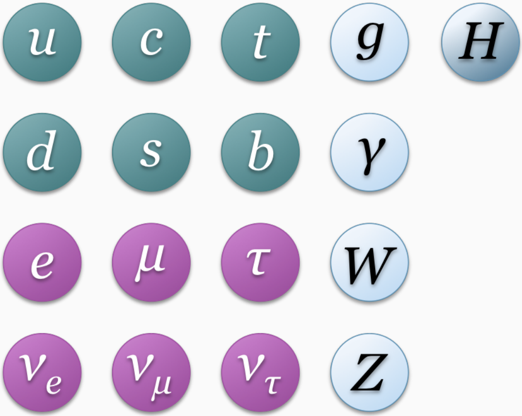
## The Standard Model

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# Particle Physics

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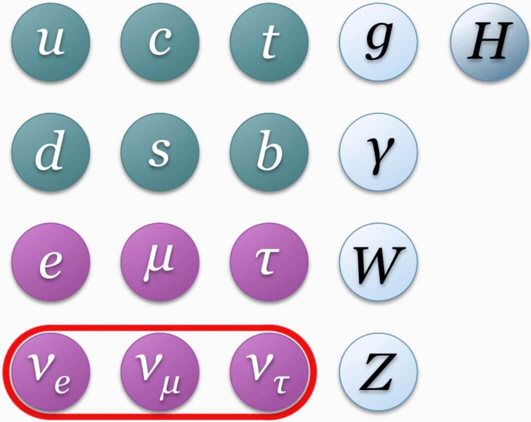
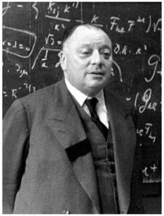
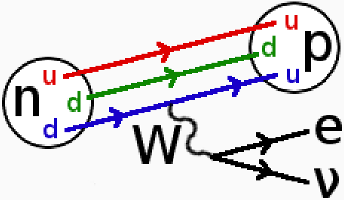


# Neutrinos

- Proposed by Wolfgang Pauli - 1930






- Interacts Weakly

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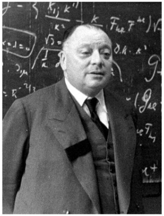

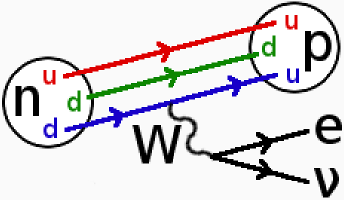


- Interacts Weakly
- 3 known types
  - Flavors: electron ($\nu_e$), muon ($\nu_\mu$), tau ($\nu_\tau$)
  - Different masses ($m_1 \neq m_2 \neq m_3$)


(from Particle Zoo)

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Mismatch of $\nu_i$ and $\nu_\alpha \Rightarrow$ Neutrinos can change flavor!

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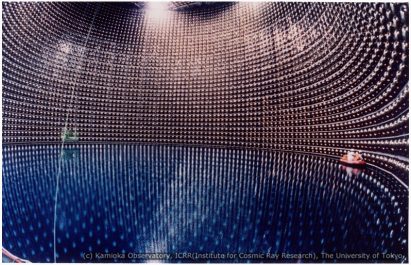
Neutrino Oscillation Parameters (for 3 neutrino flavors):

- 3 mixing angles: $\theta_{12}, \theta_{13}, \theta_{23}$
- 2 mass-squared differences: $\Delta m^2_{21}, \Delta m^2_{31}$
- 1 *CP*-violating phase: $\delta_{CP}$

# Neutrino Oscillation Experiments

- Sources: sun, atmosphere, reactor, accelerator, supernova, etc.
- Need large detector
- Neutrino oscillation confirmed by solar and atmospheric experiments (2015 Nobel Prize)



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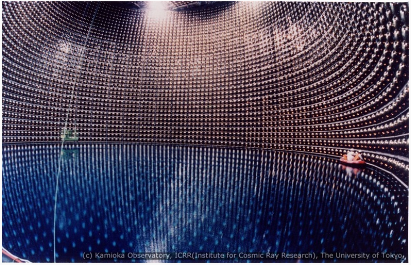



- Precision measurements of parameters by reactor/accelerator experiments

$\theta_{12} \approx 34^\circ \qquad \Delta m^2_{21} \approx 7.4 \times 10^{-5}\,\mathrm{eV}^2$

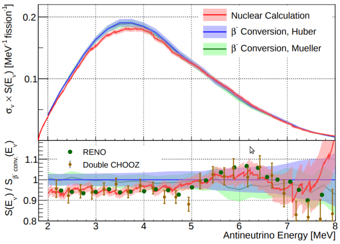
$\theta_{13} \approx 8.6^\circ \qquad \left|\Delta m^2_{31}\right| \approx 2.5 \times 10^{-3}\,\mathrm{eV}^2$

$\theta_{23} \approx 45^\circ$

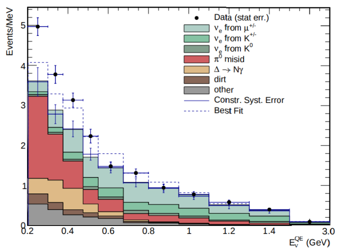
- Largely Unknown: $\delta_{CP}$ sign of $\Delta m^2_{31}$ octant of $\theta_{23}$

# Important Considerations

Anomalies have arisen...




D. Dwyer, et al (arXiv:1407.1281)




MiniBoone Collaboration (arXiv:1805.12028)

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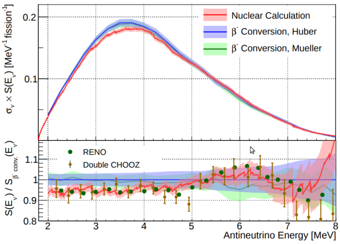


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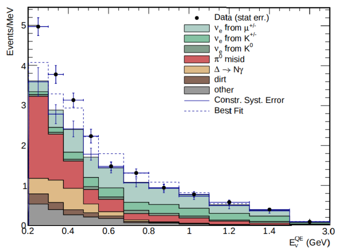


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Things to consider:

- Flux produced by source
- Other flavors of neutrinos
- Interaction cross-section
- Validity of assumptions

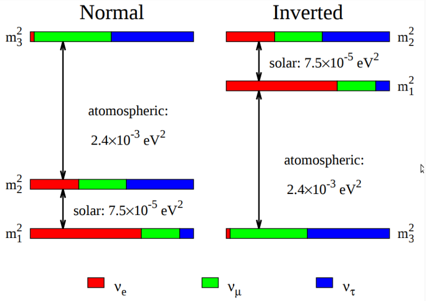
1 Introduction

2 **Benefits of a Near Detector for JUNO**
**(D. Forero, *R. Hawkins*, P. Huber)**

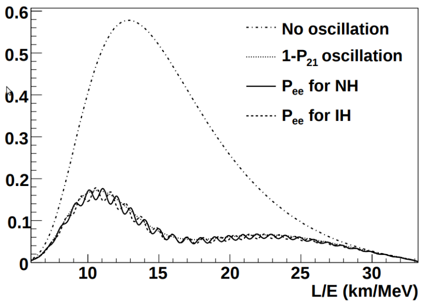
3 Summary

# JUNO: Jiangmen Underground Neutrino Observatory

Primary Goal: measure sign of $\Delta m^2_{31}$




JUNO Collaboration (arXiv:1507.05613)




L. Zhang, et al (arXiv:0807.3203)

Need $3\%/\sqrt{E}$ energy resolution

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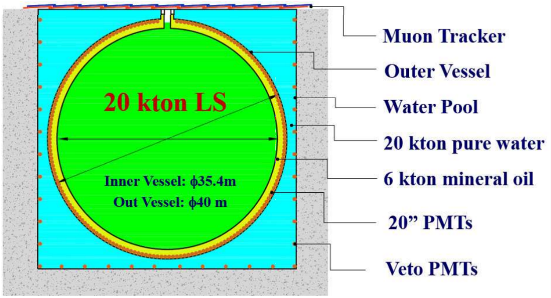


JUNO Collaboration (arXiv:1507.05613)

- 53 km from reactors at Yangjiang and Taishan
    - Reactors produce $\bar{\nu}_e$ via beta decay
- 20 kton Liquid Scintillator Detector
    - Measure $\bar{\nu}_e$ disappearance
    - Designed to have $3\%/\sqrt{E}$ energy resolution

# Simulation

In GLoBES,

- Far detector with JUNO's specs
- Near detector added
    - 5 ton liquid scintillator
    - 0.5 km from reactor
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- Data divided into 100 energy bins
- Source spectrum uncertainty:
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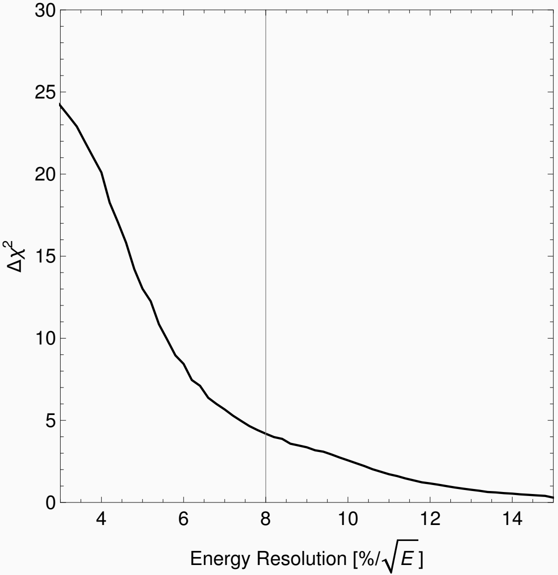
- Data divided into 100 energy bins
- Source spectrum uncertainty:
    - Added 1 parameter per bin to model (same for both detectors)
- $\chi^2$ calculated both for NH and IH in the model ($\Delta\chi^2 \equiv \chi^2_{IH} - \chi^2_{NH}$)

$$\chi^2_H = \sum_{i,D} \frac{\left(\phi^D_{\text{true}\,i} - \phi^{D,H}_{\text{fit}\ \ i}\right)^2}{\phi^D_{\text{true}\,i}} + \sum_j \left(\frac{s_j}{\sigma_j}\right)^2$$

    - Minimized over oscillation and systematic parameters

# Simulation Result



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3 **Summary**

# Summary

- Neutrino oscillation can provide hints for new physics
- Many anomalies $\Rightarrow$ need to not rely on theoretical calculations
- Due to spectral uncertainties, JUNO needs a near detector
    - JUNO-TAO proposed

# Thank you!

# Questions?

Thanks to those who made this award possible.

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