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Par
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Precision measurement of solar neutrino oscillation parameters with the JUNO small PMTs system and test of the unitarity of the PMNS matrix

Thèse présentée et soutenue à Nantes, le Too soon and too early at the same time
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Rapporteurs avant soutenance :

Someone	Very high position, Somewhere
Someone else	Another high position, Somewhere else

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List of Abbreviations

NMO	**N**eutrino **M**ass **O**rdering
JUNO	**J**iangmen **U**nderground **N**eutrino **O**bservatory
NO	**N**ormal **O**rdering
IO	**I**nverse **O**rdering

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Remerciements

Introduction

Chapter 1

Neutrino physics

The neutrino, or ν for the close friends, a fascinating and invisible particle. Some will say that dark matter also have those property but at least we are pretty confident that neutrinos exists.

1.1 Standard model

Decrire le standard Regarder LHC / O Kochebin

1.1.1 Limits of the standard model

Limite du standard essant/ju etudier le neutrinos violation ? Pb des ?

1.2 Historic of the neutrino

First theories

Discovery

Milestones and anomalies

1.3 Oscillation

1.3.1 Phenomologies

1.4 Open questions

Chapter 2

The JUNO experiment

The first idea of a medium baseline (60 km) experiment, was explored in 2008 where it was demonstrated that the Neutrino Mass Ordering (NMO) could be determined by a medium baseline experiment if $\sin^2(2\theta_{13}) > 0.005$ without requirements on accurate information of reactor antineutrino spectra and the value of Δm^2_{32}. [1] It was shown that for value of

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The JUNO (Jiangmen Underground Neutrino Observatory) is a neutrino detection experiment located in China. Its main objective is the determination of the mass ordering at the 3-4σ level in 6 years of data taking [2].

2.1 Neutrinos physics in JUNO

As said before, the main goals of JUNO are the determination of the NMO and the precise measurements of the oscillation parameters Δm^2_{21}, $\sin^2 2\theta_{12}$, Δm^2_{32} and, with less precision, $\sin^2\theta_{13}$.

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2.1.1 Reactor neutrino oscillation for NMO and precise measurements

Previous works [1, 3] shows that oscillation parameters and the NMO can be observed by looking at the $\bar{\nu}_e$ disappearance spectrum coming from medium baseline nuclear reactor. This disappearance probability can be expressed as [2] :

$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2 2\theta_{12} c^4_{13} sin^2 \frac{\Delta m^2_{21} L}{4E} - \sin^2 2\theta_{13}\left[c^2_{12}\sin^2\frac{\Delta m^2_{31} L}{4E} + s^2_{12}\sin^2\frac{\Delta m^2_{32} L}{4E}\right]$$

Where $s_{ij} = \sin\theta_{ij}$, $c_{ij} = \cos\theta_{ij}$, E is the $\bar{\nu}_e$ energy and L is the baseline. We can see the sensitivity to the NMO in the dependency to Δm^2_{32} and Δm^2_{31} causing a phase shift of the spectrum (Figure 2.1). By carefully fitting this spectrum, one can extract the NMO and the oscillation parameters.

Identification of the mass hierarchy

Continue
using 2.3
Neutrino
with JUN

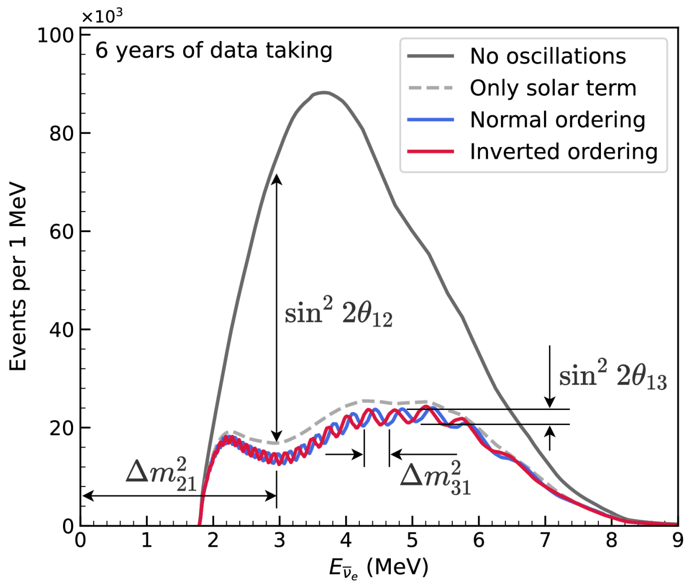

FIGURE 2.1 – Expected number of neutrinos event per MeV in JUNO after 6 years of data taking. The black curve shows the flux if there was no oscillation. The light gray curve shows the oscillation if only the solar terms are taken in account (θ_{12}, Δm^2_{21}. The blue and red curve shows the spectrum in the case of, respectively, NO and IO. The dependency of the oscillation to the different parameters are schematized by the double sided arrows. We can see the NMO sensitivity by looking at the fine phase shift between the red and the blue curve.

Precise measurement of the oscillations parameters

2.1.2 Other physics

Geoneutrinos

Atmospheric neutrinos

Beyond standard model neutrinos interactions

Supernovae burst neutrinos

Diffuse supernovae neutrinos background

Background in the neutrinos reactor spectrum

2.2 The JUNO detector

2.2.1 Central Detector (CD)

Acrylic containment sphere

Liquid scintillator

Large photo-multipliers (LPMTs)

Small photo-multipliers (SPMTs)

Data Acquisition System (DAQ)

Simulation

Software

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2.2.2 Veto detector

Cherenkov in water pool

Top tracker

2.3 Calibration strategy

2.3.1 Energy scale calibration

2.3.2 Calibration system

2.3.3 Calibration program

2.4 Event selection and background rejection

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2.4.2 Muon tagging

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2.5.1 Interaction vertex reconstruction

2.5.2 Energy reconstruction

2.5.3 Particle identification

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Vertex reconstruction

Energy reconstruction

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3.3 Artificial Neural Network (NN)

3.3.1 Fully Connected Deep Neural Network (FCDNN)

3.3.2 Convolutional Neural Network (CNN)

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3.3.4 Adversorial Neural Network (ANN)

Generative Adversorial Network (GAN)

Reinformcement Learning (RL)

Random Search (RS)

Bayesian Optimization

Chapter 4

Image recognition for IBD reconstruction with the SPMT system

Chapter 5

Graph representation of JUNO for IBD reconstruction with the LPMT system

Chapter 6

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Chapter 7

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Chapter 8

Conclusion

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