Research and Daily life in Quy Nhon

Phan To Quyen

Vietnam neutrino group
IFIRSE - ICISE

VSON7, 18 – 28 July, 2023

About me

- Full name: Phan To Quyen
- Hometown: Binh Dinh province
- 1st year PhD student at GUST, VAST.

2015 - 2019

Bachelor: Physics Teacher at Quy Nhon University

2019 - 2022

Master: Theoretical and Mathematical Physics at GUST, VAST.

2022 - present

PhD student in Theoretical and Mathematical Physics, at GUST, VAST

Member of VN neutrino group, IFRISE, ICISE.

T2K collaborator since 2019

My hometown

Sea

Martial art

Binh Dinh province

Food

ancient architecture (ChamPa)

Research at IFIRSE

- Simons Astrophysics group
- Environment group
- Neutrino group: hardware, software

Neutrino lab

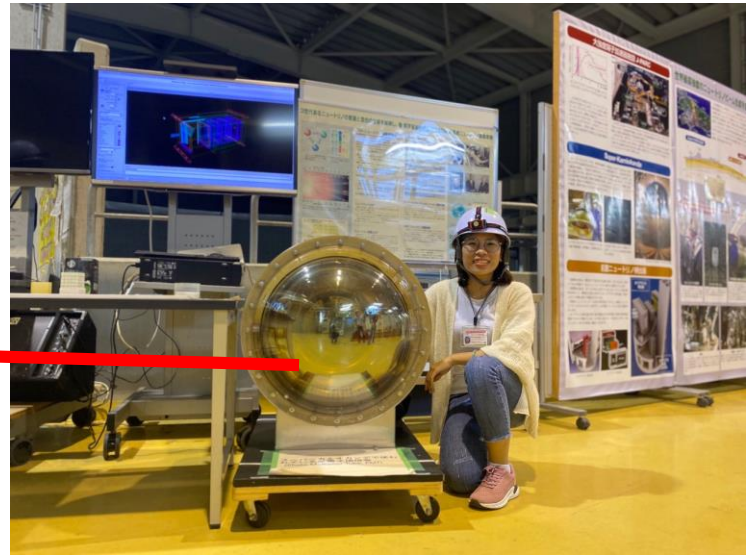
Group meeting room

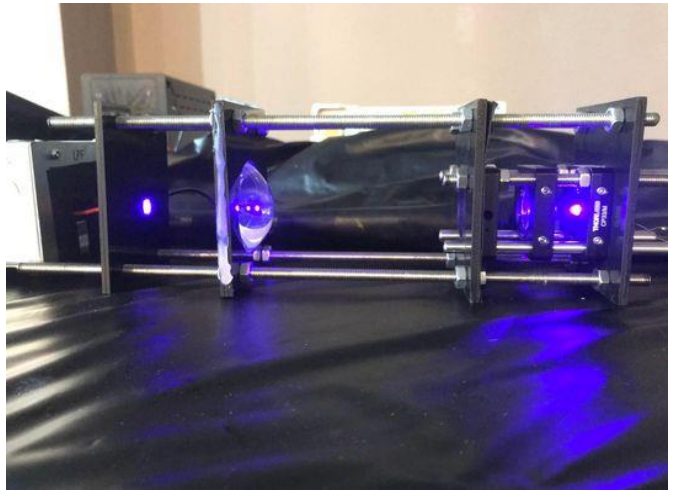
Research at IFIRSE

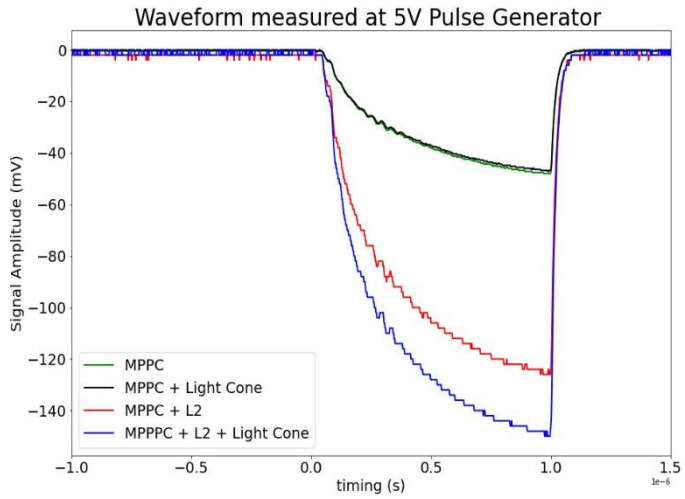
❖Hardware work at IFIRSE:

- MPPC and some equipments at the neutrino lab.
- Data readout and analysis
- *Develop the light cone for SiPM photosensor*

PMT

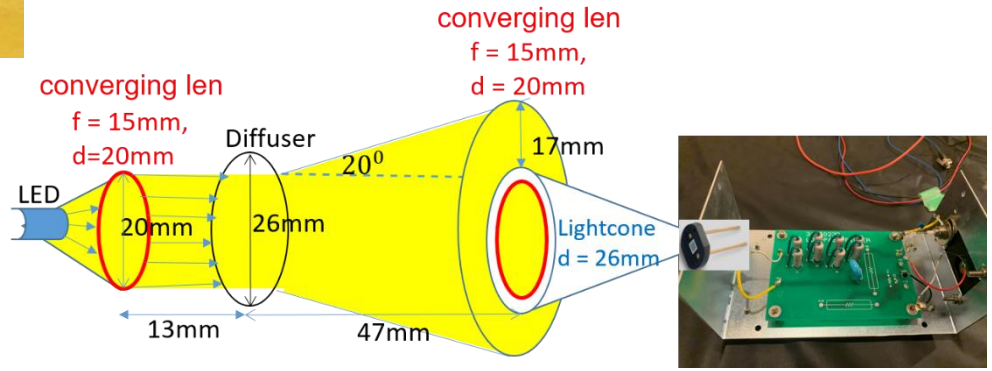






Initial result

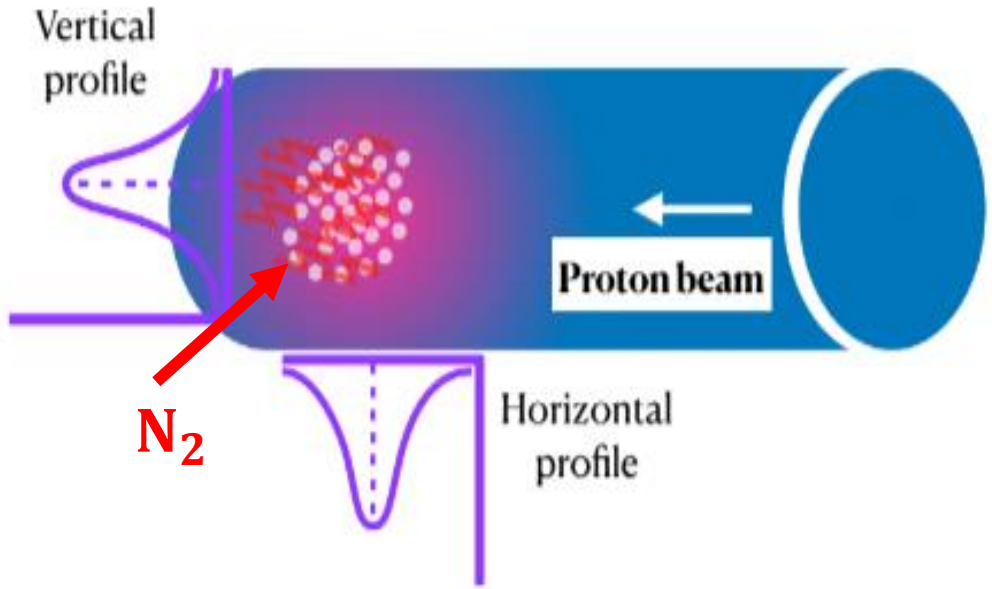
MPPC



Research at IFIRSE

❖Hardware work at J-PARC:

- Measure beamline profile by beam inducing fluorescence (BIF): Reconstructed Beam position, Proton Beam size and beam orbit



VN neutrino group at J-PARC

Research at IFIRSE

❖**Software work :** ROOT, GLoBES, GEANT4, NEUT,…

❖**Neutrino phenomenology:** CPviolation, Mass hierarchy, CPTviolation, θ_{23} octant, m_ν spectrum

- ✓ Master thesis: *Resolving the octant of leptonic mixing angle θ_{23} with Hyper-K experiment and the impact to the CP violation measurement.*
- ✓ PhD thesis: *Neutrino mass spectrum: hints from neutrino oscillation, cosmology, betadecay.*

Research at IFIRSE

- **Software work :** ROOT, GLoBES
- Some topics: CPviolation, Mass hierarchy, CPTviolation, **θ_{23} octant, m_ν spectrum**

VCTP45

Resolving the octant of leptonic mixing angle θ_{23} with Hyper-Kamiokande experiment

P. T. Quyen[1], S. Cao[2], N. T. Hong Van[3], A. Nath[4], , T. V. Ngoc[1]

[1]Institute For Interdisciplinary Research in Science and Education, Quy Nhon, Vietnam; [2]High Energy Accelerator Research Organization (KEK) , Tsukuba, Ibaraki, Japan; [3]Institute of Physics (IOP), VAST, Hanoi, Vietnam; [4]Tezpur University, Assam, India;

Neutrino & Neutrino Oscillation

Neutrinos are elementary particles; spin=1/2, have no electric charge; interact only via the weak force; come into three flavors. That neutrinos have mass is the only palpable evidence beyond the Standard Model.

Neutrino oscillations is a quantum mechanical phenomenon where neutrino can switch its identities when traveling. Probability for a α-flavor to oscillate into β-flavor, $P_{(\nu_\alpha \to \nu_\beta)}$, depends on three mixing angles $(\theta_{12}, \theta_{13}, \theta_{23})$, one CP-violating phase δ_{CP}, two mass square splittings $(\Delta m^2_{21}, \Delta m^2_{31})$, its energy, E_ν, propagation distance L, and matter density which neutrino passed through, ρ:

$$P_{(\nu_\alpha \to \nu_\beta)} = f\left(\theta_{12}, \theta_{13}, \theta_{23}, \delta_{CP}, \Delta m^2_{21}, \Delta m^2_{31}, E_\nu, L, \rho\right)$$

The $\mu - \tau$ symmetry & θ_{23} mixing angle

If θ_{23} **is maximal** ($\theta_{23} = \pi/4$) **it indicates some unknown** $\mu - \tau$ **exchange symmetry** since the mass matrix can be rewritten as

Results

- We assume both two possibilities of neutrino mass hierarchy (MH) include *normal hierarchy* (NH) and *inverted hierarchy* (IH). We use both $\nu_\mu \to \nu_e$ appearance and $\nu_\mu \to \nu_\mu$ disappearance samples in this simulation. The true values of oscillation parameters are assumed:

$$\left(\sin^2\theta_{12}, \sin^2\theta_{13}, \sin^2\theta_{23}, \delta_{CP}\right) = (0.310, 0.02241, 0.5, -\pi/2)$$
$$\left(\Delta m^2_{21}, \Delta m^2_{31}\right) = \left(7.39 \times 10^{-5} eV^2/c^4, 2.523 \times 10^{-3} eV^2/c^4\right)$$

- Given a true $\sin^2\theta_{23}$ (*octant is known*), we calculate the statistical significance $\sqrt{\Delta\chi^2}$ to exclude the *wrong octant*.

VCTP46

Characterizing the octant resolving of mixing angle θ_{23} in the neutrino oscillation and the impact to the CP violation measurement

P. T. Quyen[1,2], S. Cao[1], N. T. Hong Van[3], A. Nath[4], T. V. Ngoc[1,2]

[1]Institute For Interdisciplinary Research in Science and Education, Quy Nhon, Vietnam; [2]Graduate University of Science and Technology (GUST), VAST, Hanoi, Vietnam; [3]Institute of Physics (IOP), VAST, Hanoi, Vietnam; [4]Tezpur University, Assam, India;

Neutrino Oscillation & θ_{23} mixing angle

- Discovery of neutrino oscillation (Super-Kamiokande 1998, Sudbury Neutrino Observatory 2001 and others) establishes that neutrinos have mass and leptons mix. This phenomenon is beyond description of the Standard Model.
- **Neutrino oscillation** is a quantum mechanic phenomenon where one type of neutrino flavor can invert into others when traveling. Probability for a α-flavor to oscillate into β-flavor, $P_{(\nu_\alpha \to \nu_\beta)}$, depends on three mixing angles $(\theta_{12}, \theta_{13}, \theta_{23})$, one CP-violating phase δ_{CP}, two mass square splittings $(\Delta m^2_{21}, \Delta m^2_{31})$, its energy, E_ν, propagation distance L, matter density ρ.

Parameter	θ_{12}	θ_{13}	θ_{23}	δ_{CP}	$\frac{\Delta m^2_{21}}{10^{-5} eV^2/c^4}$	$\frac{\Delta m^2_{31}}{10^{-3} eV^2/c^4}$
Best-fit value	$33.44^{+0.78}_{-0.75}$	$8.57^{+0.13}_{-0.12}$	$49^{+1.3}_{-1.3}$	195^{+51}_{-25}	$7.42^{+0.21}_{-0.20}$	$2.514^{+0.28}_{-0.027}$

Table 1:Current knowledge of oscillation parameters

- Interestingly, if θ_{23} is maximal ($\theta_{23} = \pi/4$), it indicates some unknown $\mu - \tau$ exchange symmetry.
- At present, we don't know if θ_{23} is exactly equal to $\pi/4$, or in the lower octant $\theta_{23} < \pi/4$ or higher octant $\theta_{23} > \pi/4$. The future experiments like Hyper-K, DUNE can elucidate this ambiguity.

θ_{23} octant resolving in Hyper-Kamiokande

Hyper-Kamiokande (Hyper-K) [1], effectively 8 times larger than Super-K, started reconstruction in 2021 and aims for operation from 2027 with the

- From the eventrate spectrum of T2K for FHC mode [3], we calculate $\nu_\mu \to \nu_\mu$ and $\nu_\mu \to \nu_e$ probabilities and get $OR_{\theta_{23}}$ considering at 3 energy bin near to the oscillation dip 0.6GeV (the red lines) of MC simulation and T2K real data. At the best-fit value $\sin^2\theta_{23} = 0.512 \pm 0.0435$. we get $|U_{\mu 3}|^2 - |U_{\tau 3}|^2 = 0.110731 \pm 0.0102103$.

Figure 3:Left is spectrum of T2K data [3] and right is $OR_{\theta_{23}}$ with T2K real data.

2. Impacts of θ_{23} octant resolving to CP violation measurement

- The statistical significant of CPV measurement (SS_{CPV}) depends on the ratio of R_{CP} and the statistic uncertainty $\sigma_{stat} \sim \sqrt{P(\nu_\mu \to \nu_e)}$ (Figure. 4)

$$R_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)}, \quad SS_{CPV} = \frac{R_{CP}}{\sqrt{P(\nu_\mu \to \nu_e)}} \quad (2)$$

VCTP47

Neutrino mass spectrum with the present neutrino data

P. T. Quyen[1,2], S. Cao[1], N. T. Hong Van[3], T. V. Ngoc[1,2]

[1]Institute For Interdisciplinary Research in Science and Education, Quy Nhon, Vietnam; [2]Graduate University of Science and Technology, Hanoi, Vietnam, [3]Institute of Physics, Hanoi, Vietnam;

Neutrinos

- **Neutrinos** (ν_e, ν_μ, ν_τ) are elementary particles; spin=1/2, have no electric charge; interact only via the weak force.
- **Neutrino oscillation** discovered by Super-Kamiokande 1998, Sudbury Neutrino Observatory 2001, and others resulted in the existence of neutrino mass and this is beyond the Standard Model description.
- **Unknown answers** are the precise mass and the order of the neutrino mass eigenvalues (ν_1, ν_2, ν_3) as well. How do neutrinos get mass? Is it Higgs mechanism or something else?

Neutrino mass constraints

- Our present understanding of the neutrino mass spectrum is based on sources:

1. Cosmology Planck + BAO, 2018

$$\sum_i m_{\nu i} < 0.12 eV \text{ (at 95\% C.L.)}$$

2. Beta decay KATRIN, 2021

$$\langle m_{\nu_e} \rangle = \sqrt{|U_{ei}|^2 m_{ei}^2} < 0.8 eV \text{ (at 90\% C.L.)}$$

3. Neutrino-less double beta ($\beta\beta_{0\nu}$ decay) LamLAND-Zen, 2016:

$$m_{0\nu}^{\beta\beta} = \sum_i U_{ei}^2 m_{\nu i} < [61 - 165] MeV \text{ (at 90\% C.L.)}$$

- In this work, we explore neutrino mass spectrum using data from the above sources.

Mass hierarchy sensitivity to neutrino mass spectrum

- Figure 1 describes distributions of the elements' amplitude of the Majorana neutrino mass matrix obtained from Eq.1 and use the present constraints for neutrino mass in section II. The left is with normal neutrino MO and the right is with inverted neutrino MO. The neutrino mass matrix is calculated for two case of the neutrino MO.

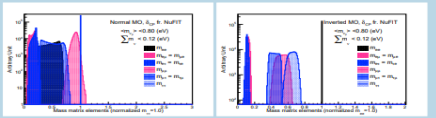


Figure 1

$$M^{Majorana}_{\nu_e NO} = \begin{pmatrix} 0.410 \pm 0.170 & 0.144 \pm 0.041 & 0.185 \pm 0.038 \\ 0.144 \pm 0.041 & 0.908 \pm 0.044 & 0.494 \pm 0.137 \\ 0.185 \pm 0.038 & 0.494 \pm 0.137 & 1 \end{pmatrix} \quad \mathcal{Y}_{\nu-type} = \begin{pmatrix} \epsilon^2_{FN} & \epsilon^3_{FN} & \epsilon^2_{FN} \\ \epsilon^3_{FN} & \epsilon^2_{FN} & \epsilon_{FN} \\ \epsilon^2_{FN} & \epsilon_{FN} & 1 \end{pmatrix}$$

$$M^{Majorana}_{\nu_e IO} = \begin{pmatrix} 1 & 0.125 \pm 0.013 & 0.109 \pm 0.010 \\ 0.125 \pm 0.013 & 0.526 \pm 0.055 & 0.438 \pm 0.044 \\ 0.109 \pm 0.010 & 0.438 \pm 0.044 & 0.650 \pm 0.044 \end{pmatrix} \quad \mathcal{Y}_{d-type} = \begin{pmatrix} \epsilon^2_{FN} & \epsilon^2_{FN} & \epsilon^2_{FN} \\ \epsilon_{FN} & \epsilon_{FN} & \epsilon_{FN} \\ 1 & 1 & 1 \end{pmatrix}$$

where $\epsilon_{FN} \sim \sin^2\theta_{Cabbio} \sim 0.05$

- For both cases of the neutrino MO, the matrix elements are in $\mathcal{O}(1)$. No hierarchy pattern is found in neutrino compared to quarks $\mathcal{Y}_{u-type}$, $\mathcal{Y}_{d-type}$ in which hierarchy pattern is clear [3].

Impacts of θ_{23} & δ_{CP} on neutrino mass spectrum

- Use the future expected constraints on $\sum_i m_{\nu i} < 0.06eV$ [4], $\langle m_{\nu_e} \rangle < 0.04eV$ [5] and Normal MO is assumed, we provide the patterns of the neutrino mass matrix elements for two extreme cases in Fig. 2 with $\delta_{CP} = 0$ (left) and $\delta_{CP} = -\pi/2$ (right). The sensitivity of θ_{23} to neutrino mass spectrum is shown in Fig.3 for non-maximal $\theta_{23} \neq \pi/4$ (left) and $\theta_{23} = \pi/4$ (right).

PHYSICAL REVIEW D **103,** 112010 (2021)

Physics potential of the combined sensitivity of T2K-II, NOνA extension, and JUNO

S. Cao, [1,2,*,†] A. Nath, [3,*] T. V. Ngoc, [1,4†] Ng. K. Francis, [3] N. T. Hong Van, [5] and P. T. Quyen [1,4]

[1]*Institute for Interdisciplinary Research in Science and Education, ICISE, Quy Nhon 55121, Vietnam*
[2]*High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*
[3]*Department of Physics, Tezpur University, Assam 784028, India*
[4]*Graduate University of Science and Technology, Vietnam Academy of Science and Technology, Hanoi 10000, Vietnam*
[5]*Institute of Physics, Vietnam Academy of Science and Technology, Hanoi 10000, Vietnam*

PHYSICAL REVIEW D **107,** 016013 (2023)

Stringent constraint on *CPT* violation with the synergy of T2K-II, NOνA extension, and JUNO

T. V. Ngoc, [1,2,*] S. Cao, [1] N. T. Hong Van, [3] and P. T. Quyen [1]

[1]*Institute for Interdisciplinary Research in Science and Education, ICISE, Quy Nhon 55121, Vietnam*
[2]*Graduate University of Science and Technology, Vietnam Academy of Science and Technology, Hanoi 10000, Vietnam*
[3]*Institute of Physics, Vietnam Academy of Science and Technology, Hanoi 10000, Vietnam*

(Received 24 October 2022; accepted 3 January 2023; published 24 January 2023)

Revisit the octant ambiguity and resolvability of the leptonic mixing angle θ_{23}

P. T. Quyen[1,2,*] S. Cao[2,†] N. T. Hong Van[3], T. V. Ngoc[1,2], and Ankur Nath[4]

[1]*Graduate University of Science and Technology, Vietnam Academy of Science and Technology, Hanoi, Viet Nam.*
[2]*Institute for interdisciplinary research in science and education, ICISE, Quy Nhon, Vietnam.*
[3]*Institute of Physics, Vietnam Academy of Science and Technology, Hanoi, Vietnam.*
[4]*Department of Physics, Tezpur University, Assam, India*

(Dated: July 18, 2023)

Among three leptonic mixing angles, θ_{23} angle, which characterize the fractional contribution of two flavor eigenstates ν_μ and ν_τ in the mass eigenstate ν_3, is known to be the largest (close to $\pi/4$) but the less precisely measured. Up-to-date data from neutrino oscillation experiments can not tell whether θ_{23} is exactly equal to $\pi/4$, or lies in the lower octant $\theta_{23} < \pi/4$ or higher octant $\theta_{23} > \pi/4$.

Preparation for Arxiv

Daily life in Quy Nhon

- Interfere between mountain and sea: go swimming, hiking, fishing,….
- Friendly and kindly local people
- Free fresh air
- Fresh and cheap sea foods

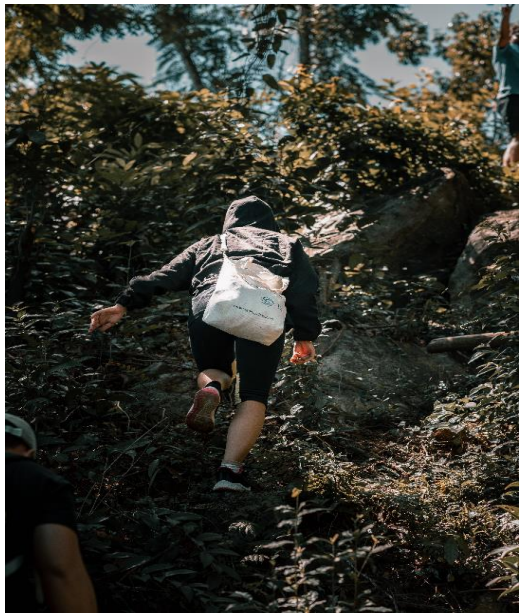
Daily life in IFIRSE

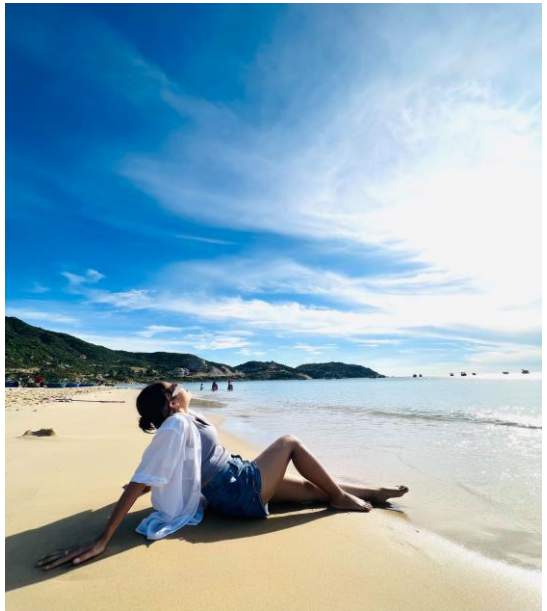
Morning

Afternoon *(sometime)*

Evening *(sometimes)*

Happy weekend





Some words to say about life of PhD student at IFIRSE????

Happy

COmfortable

Peaceful

Scientific

An ideal place for living and doing research

Thank you for your attention

Welcome to Quy Nhon