



Research and Daily life in Quy Nhon

Phan To Quyen

Vietnam neutrino group
IFIRSE - ICISE

VSON8, 15 – 26 July, 2024



About me

- Full name: Phan To Quyen
- Hometown: Binh Dinh province
- 2nd year PhD student at GUST, VAST.



2022 - present



2015 - 2019



Bachelor: Physics Teacher at Quy Nhon University

2019 - 2022



Master: Theoretical and Mathematical Physics at GUST, VAST.



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

Member of VN neutrino group, IFRISE, ICISE.

T2K collaborator since 2019

My hometown



Sea



Food



Martial art

ancient architecture (ChamPa)



Research at IFIRSE



- Simons Astrophysics group (SAGI)
- Environment group
- Neutrino physics group



Neutrino lab



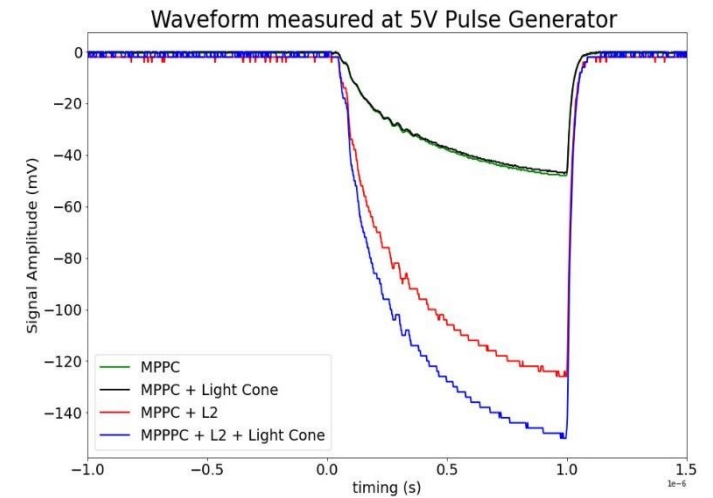
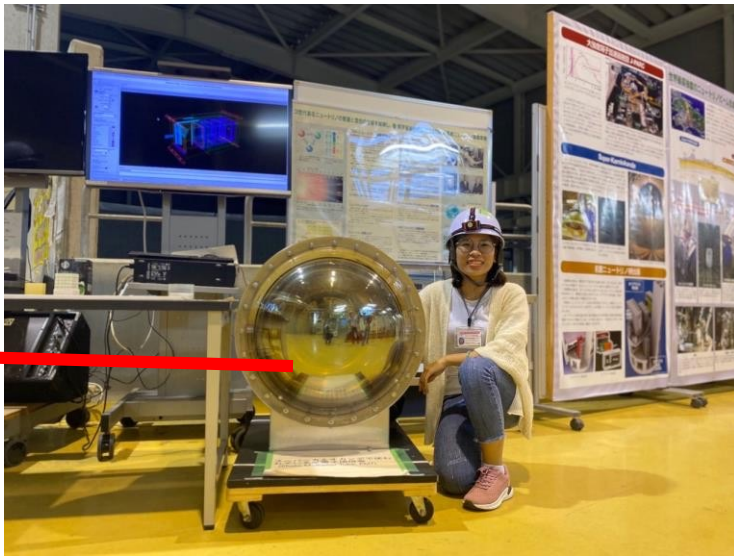
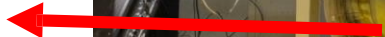
Group meeting room

Research at IFIRSE

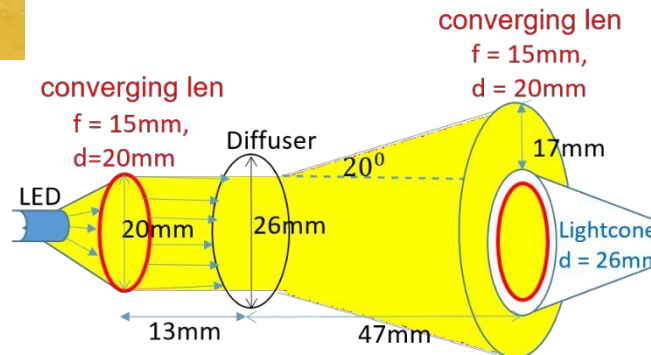
❖ Hardware work at IFIRSE:

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

PMT



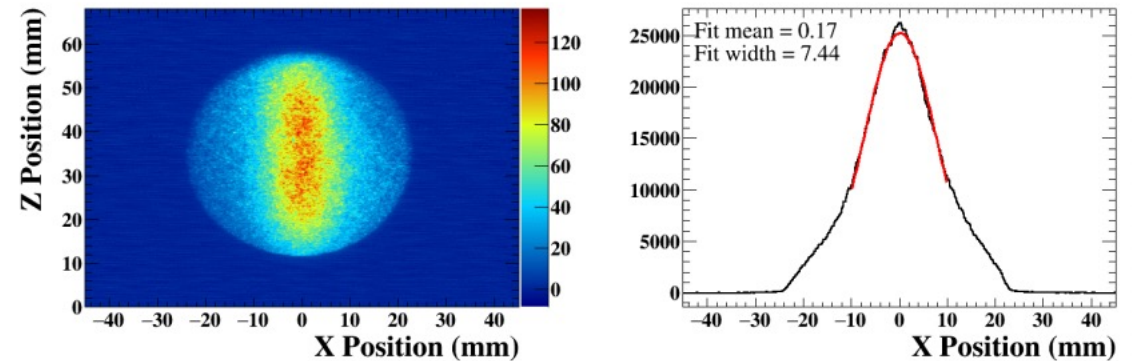
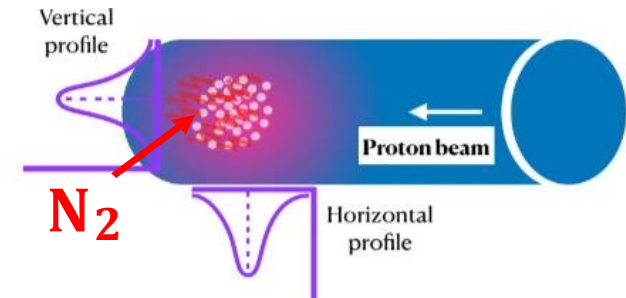
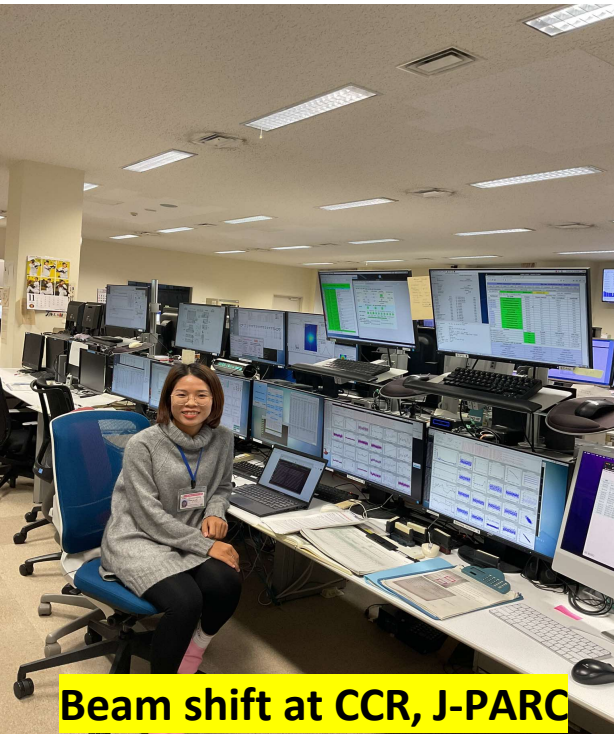
Initial result



Research at IFIRSE

❖ Hardware work at J-PARC:

- Take beamshift at J-PARC.
- Beamloss monitor during beamline operation.
- Investigate beamline profile by beam inducing fluorescence (BIF).



Beam profile from BIF

Research at IFIRSE



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

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

m_ν spectrum

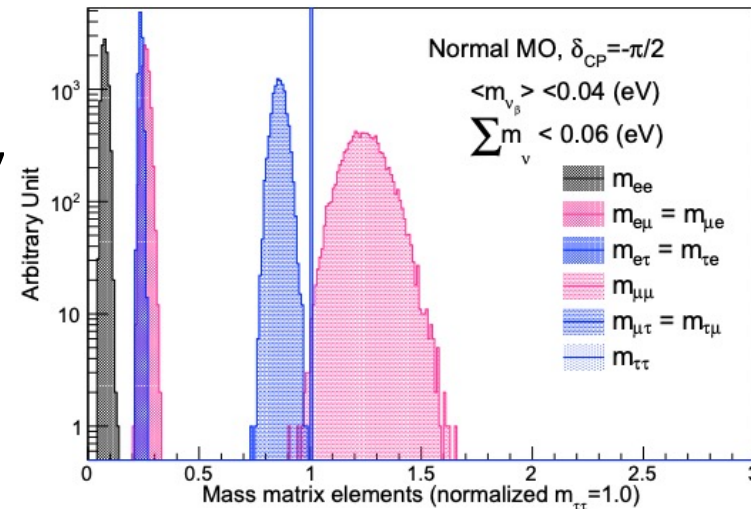
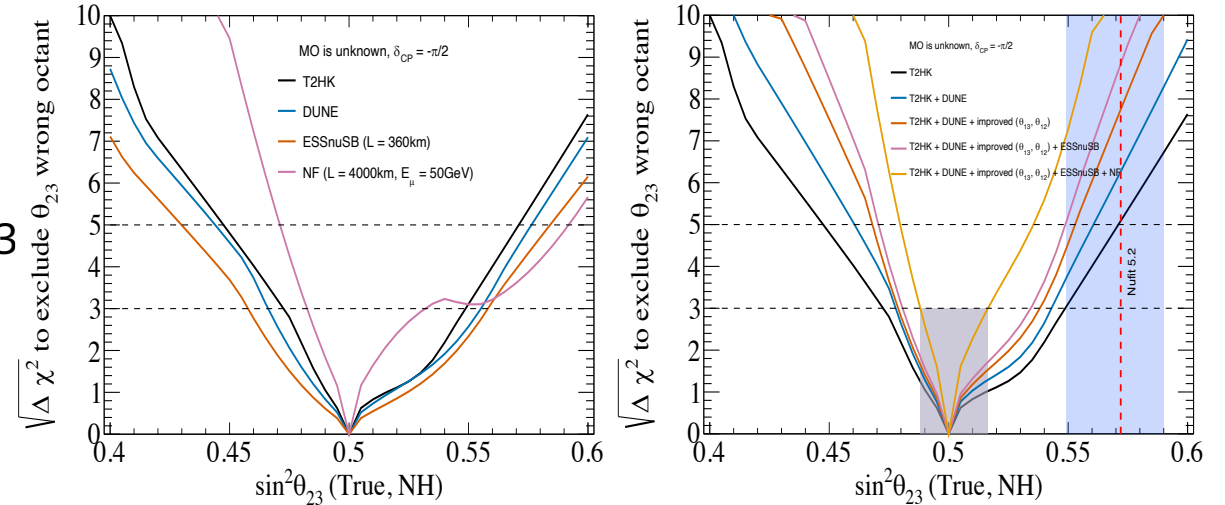
✓ **Master thesis**:

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: CP violation, Mass hierarchy, CPT violation, θ_{23} octant, m_ν spectrum

VCTP45

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

P. T. Quyen^{1,2}, S. Cao², N. T. Hong Van³, A. Nath⁴, T. V. Ngoc^{1,2}

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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, $P_{\alpha\beta}$, depends on three mixing angles ($\theta_{12}, \theta_{13}, \theta_{23}$), one CP-violating phase δ_{CP} , two mass square splittings ($\Delta m_{21}^2, \Delta m_{31}^2$), its energy, E_ν , propagation distance L , and matter density which neutrino passed through, ρ .

$P_{\alpha\beta} = f(\theta_{12}, \theta_{13}, \theta_{23}, \delta_{CP}, \Delta m_{21}^2, \Delta m_{31}^2, E_\nu, L, \rho)$

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

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. Cao¹, N. T. Hong Van³, A. Nath⁴, T. V. Ngoc^{1,2}

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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 leptone 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 $P_{\alpha\beta}$, depends on three mixing angles ($\theta_{12}, \theta_{13}, \theta_{23}$), one CP-violating phase δ_{CP} , two mass square splittings ($\Delta m_{21}^2, \Delta m_{31}^2$), its energy, E_ν , propagation distance L , matter density ρ .

Parameter	θ_{12}	θ_{13}	θ_{23}	δ_{CP}	Δm_{21}^2	Δm_{31}^2
Best-fit value	$33.44^{+0.75}_{-0.77}$	$8.57^{+0.11}_{-0.11}$	49^{+1}_{-1}	195^{+20}_{-20}	$7.42^{+0.04}_{-0.04}$	$2.51^{+0.09}_{-0.09}$

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 main goal in resolving the leptonic CP violation (CPV), matter density

From the eventrate spectrum of T2K for FHC mode [3], we calculate $\nu_\mu \rightarrow \nu_\mu$ and $\nu_\mu \rightarrow \nu_e$ probabilities and get $OR_{\mu e}$, 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 $|U_{e\mu}|^2 - |U_{\mu e}|^2 = 0.110731 \pm 0.0102103$.

Figure 3. Left is spectrum of T2K data [3] and right is $OR_{\mu e}$ 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 $\sigma_{stat} \sim \sqrt{P(\nu_\mu \rightarrow \nu_e)}$ (Figure 4)

$$R_{CP} = \frac{P(\nu_\mu \rightarrow \nu_e) - P(\nu_\mu \rightarrow \nu_\mu)}{P(\nu_\mu \rightarrow \nu_e) + P(\nu_\mu \rightarrow \nu_\mu)}, SS_{CPV} = \frac{R_{CP}}{\sqrt{P(\nu_\mu \rightarrow \nu_e)}} \quad (2)$$

Neutrino mass spectrum with the present neutrino data VCTP47

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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 (m_1, m_2, m_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:
 - Cosmology** Planck + BAO, 2018

$$\sum_i m_{\nu_i} < 0.120 \text{ eV (at 95\% C.L.)}$$
 - Beta decay** KATRIN, 2021

$$(m_{\nu_e}) = \sqrt{|U_{e1}|^2 m_1^2} < 0.8 \text{ eV (at 90\% C.L.)}$$
 - Neutrino-less double beta ($\beta\beta_{0\nu}$ decay)**

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

$$M_{\nu\nu}^{Majorana} = \begin{pmatrix} 0.410 \pm 0.179 & 0.144 \pm 0.041 & 0.185 \pm 0.038 \\ 0.144 \pm 0.041 & 0.908 \pm 0.044 & 0.404 \pm 0.137 \\ 0.185 \pm 0.038 & 0.404 \pm 0.137 & 1 \end{pmatrix} \quad \mathcal{M}_{\nu\text{-type}} = \begin{pmatrix} \epsilon_{FN}^+ & \epsilon_{FN}^- & \epsilon_{FN}^+ \\ \epsilon_{FN}^- & \epsilon_{FN}^- & \epsilon_{FN}^- \\ \epsilon_{FN}^+ & \epsilon_{FN}^- & 1 \end{pmatrix}$$

$$M_{\nu\nu}^{Majorana} = \begin{pmatrix} 1 & 0.125 \pm 0.013 & 0.109 \pm 0.010 \\ 0.125 \pm 0.013 & 0.526 \pm 0.055 & 0.438 \pm 0.044 \\ 0.109 \pm 0.010 & 0.438 \pm 0.044 & 0.650 \pm 0.044 \end{pmatrix} \quad \mathcal{M}_{\nu\text{-type}} = \begin{pmatrix} \epsilon_{FN}^+ & \epsilon_{FN}^- & \epsilon_{FN}^+ \\ \epsilon_{FN}^- & \epsilon_{FN}^- & \epsilon_{FN}^- \\ 1 & 1 & 1 \end{pmatrix}$$

where $\epsilon_{FN}^\pm \sim \sin^2 \theta_{CMB\mu\tau} \sim 0.05$

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 $\mathcal{M}_{u\text{-type}}, \mathcal{M}_{d\text{-type}}$ in which hierarchy pattern is clear [3].

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

- Use the future expected constraints on $\sum_i m_{\nu_i} < 0.06 \text{ eV}$ [4], ($m_{\nu_3}) < 0.04 \text{ eV}$ [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).

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Physics potential of the combined sensitivity of T2K-II, NO ν A extension, and JUNO

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Stringent constraint on CPT violation with the synergy of T2K-II, NO ν A extension, and JUNO

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

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(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 $\theta_{23} > \pi/4$.

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

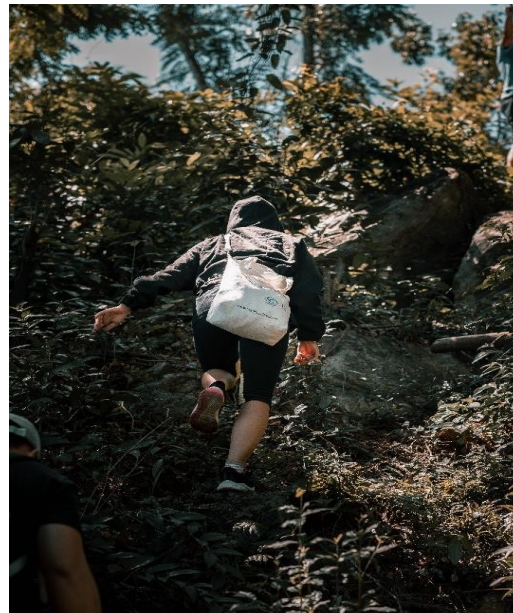


Afternoon (sometimes)



Evening (sometimes)

Happy weekend



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



Happy



COMfortable



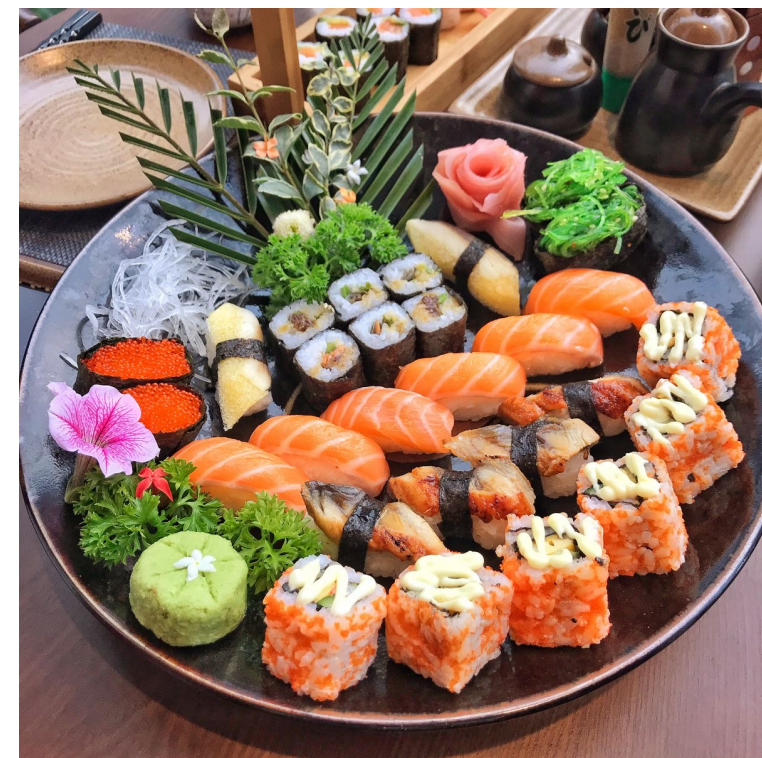
Peaceful



Scientific

An ideal place for living and doing research

*If you want to enjoy **neutrino physics**, **beach life in ICISE**, **sashimi in Japan**.
Come with us, your dreams become true.*



Thank you for your attention

Welcome to Quy Nhon