ESSnuSB – Detecting CP violation in 2nd neutrino oscillation maximum

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on behalf of the ESSnuSB project

ESS NEUTRINO SUPER BEAM

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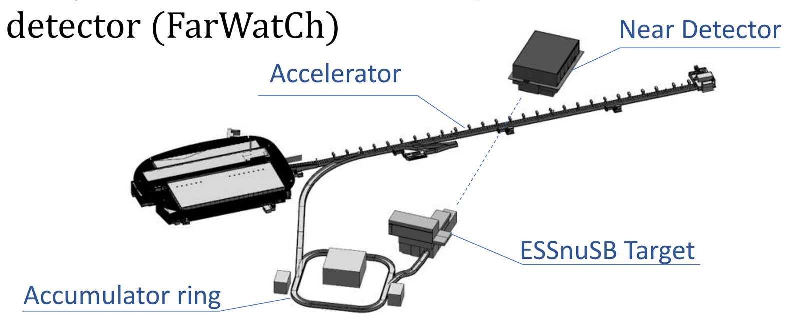
Abstract: European Spallation Source Neutrino Super Beam (ESSnuSB) is a design study for a future experiment, based on ESS linac in Sweden, which aims to measure CP violation in 2nd neutrino oscillation maximum. This poster presents the overview of the ESSnuSB project, from the creation of the neutrino beam to the physics performance of the proposed experiment.

What is ESSnuSB?

- European Spallation Source Neutrino Super Beam (ESSnuSB) is a design study aiming to measure CP violation in the 2nd neutrino oscillation maximum

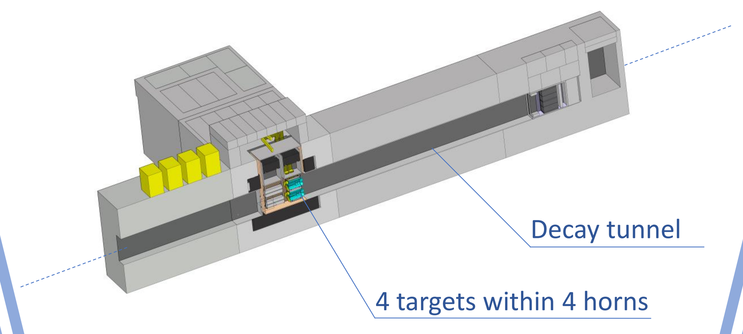
$$P(\nu_\mu \to \nu_e) \neq P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

- ESSnuSB will use ESS linear accelerator (linac), currently under construction in Lund, Sweden, for the production of the neutrino beam
- There will be two detector sites: Near Detector composed of Water Cherenkov (NearWatCh), Emulsion and Super Fine-Grained Detector (SFGD) and a Far Detector composed of a Water Cherenkov detector (FarWatCh)



How is neutrino beam produced?

- H⁻ ion pulses are accelerated through the ESS linac at 14 Hz into the ESSnuSB accumulator ring
- Each pulse is separated into 4 bunches, each sent to one of four targets made of titanium
- Pions produced in the collision are then focused by the horn system



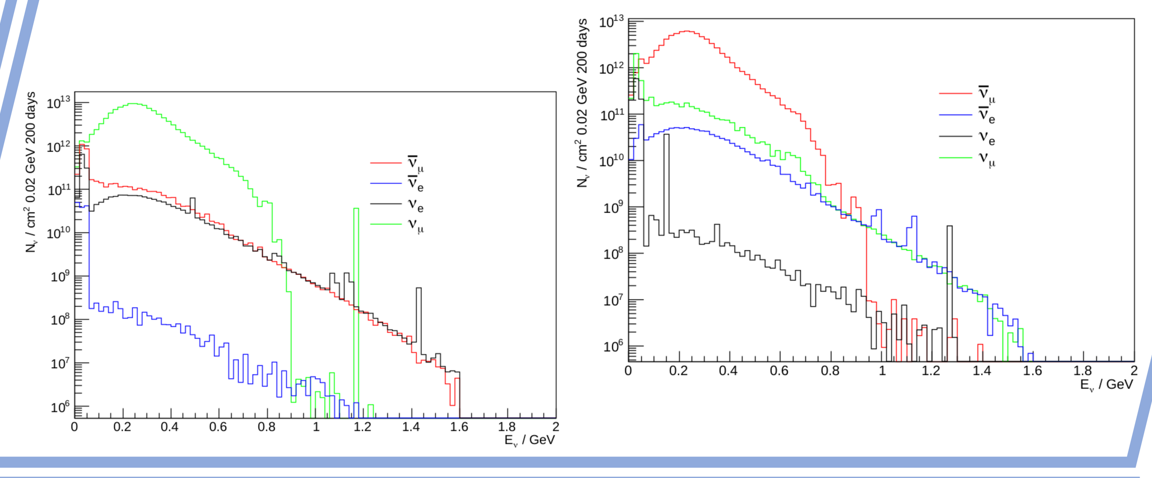
How is neutrino beam produced?

- Positive pions decay into positive muons (puons) and muon neutrinos

$$\pi^+ \to \mu^+ + \nu_\mu$$

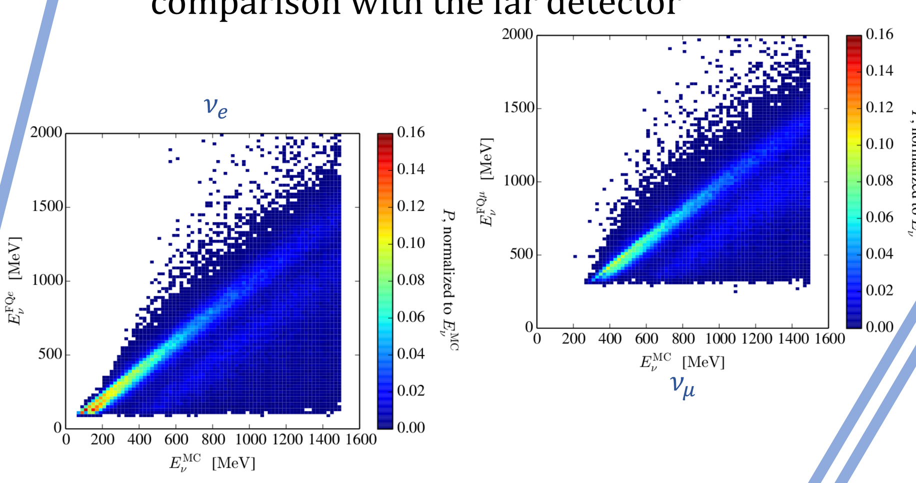
- Negative pions decay into negative muons and muon antineutrinos

$$\pi^- \to \mu^- + \bar{\nu}_\mu$$



What is NearWatCh?

- Near Water Cherenkov Detector has a fiducial mass of 750 t filled with water placed 250 m from the neutrino production target
- Proximity to the neutrino production target means that neutrino oscillations are negligible
- NearWatCh will be used for event-rate measurement and flux normalization, neutrino interaction cross-section measurements in water and event reconstruction comparison with the far detector



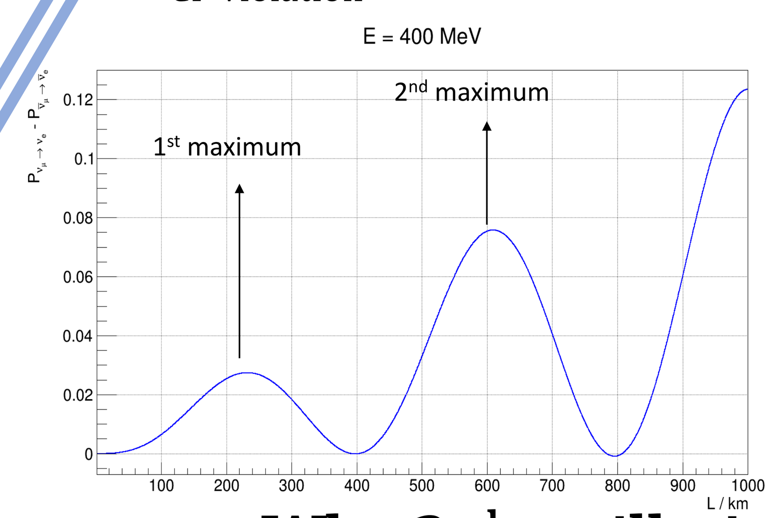
- The amount of CP violation is measured by Jarlskog invariant

$$J = s_{12}c_{12}s_{13}c_{13}s_{23}c_{23}c_{13}\sin\delta_{CP}$$

- If J = 0 (any mixing angle is 0 or π/2 or δ_{CP} is 0 or π) there is no CP violation

$$A_{CP} = P_{\nu_\mu\to\nu_e} - P_{\bar{\nu}_\mu\to\bar{\nu}_e} = -16J\sin\frac{\Delta m^2_{31}L}{4E}\sin\frac{\Delta m^2_{32}L}{4E}\sin\frac{\Delta m^2_{21}L}{4E}$$

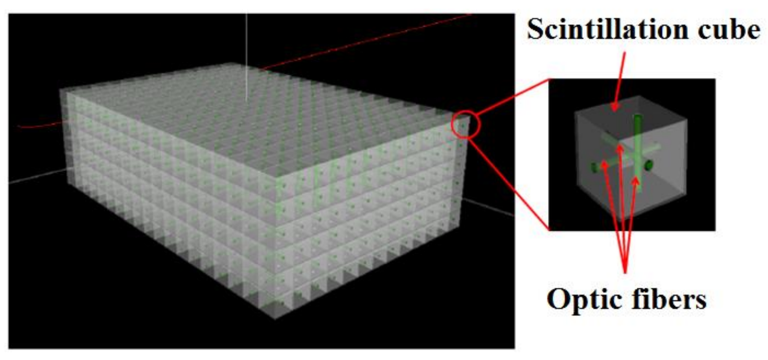
- The second oscillation maximum has a greater sensitivity to CP violation



$$\frac{A_{CP}\ @\ 2^{nd}\ oscillation\ maximum}{A_{CP}\ @\ 1^{st}\ oscillation\ maximum} \sim 2.7$$

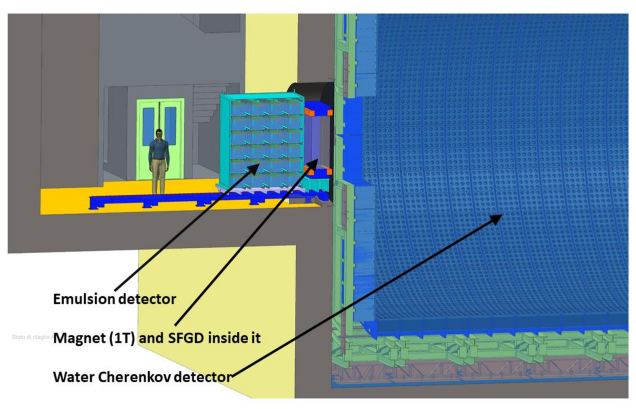
What is SFGD?

- Super Fine-Grained detector will consist of $\sim 10^6$ scintillator cubes of $1 \times 1 \times 1\ cm^3$
- Within the SFGD there will be a magnetic field of 1 T which will bend the path of the outgoing charged particles making the energy reconstruction and particle identification more precise
- SFGD will be used for precision measurements of neutrino cross-sections in the available energy region (~60-600 MeV)



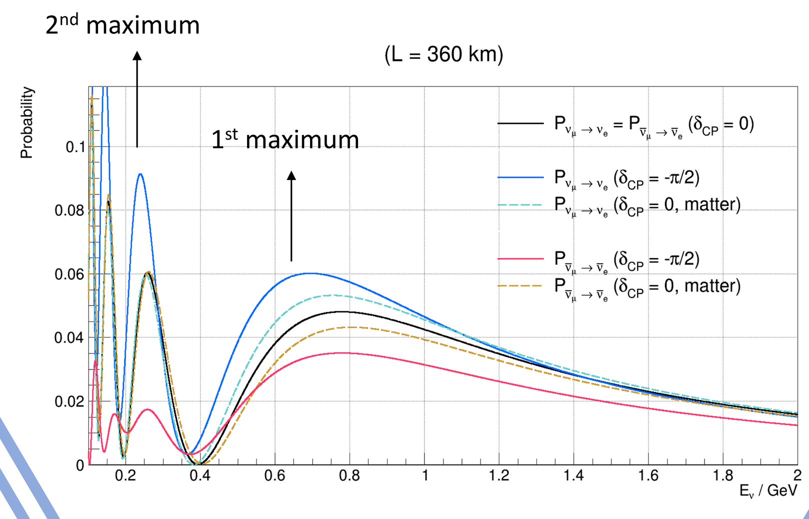
What is Emulsion detector?

- A NINJA-like emulsion detector of 1 kt water mass will be constructed and placed immediately upstream of the SFGD
- Emulsion detectors have much better spatial resolution than other types of detectors
- It will consist of two types of layers: tracking layer (emulsion film) and a target layer (water)
- The goal of the emulsion detector is to measure neutrino-water cross sections and event topology



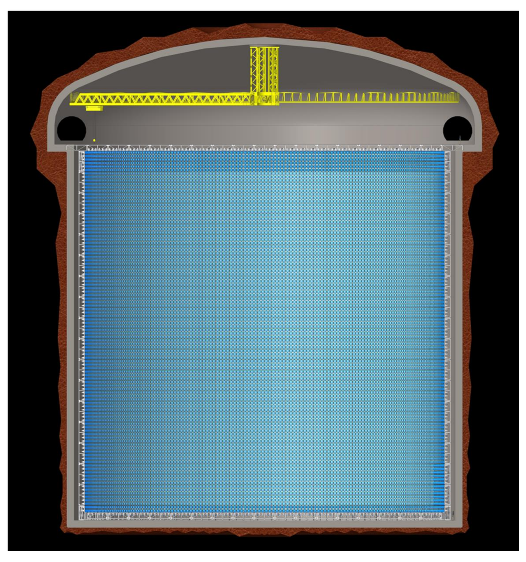
Why 2nd oscillation maximum?

- Neutrinos travelling through Earth will experience distortion of oscillation probabilities due to elastic scattering with electrons which can mimic distortions caused by CP violation
- Second oscillation maximum is far less susceptible to distortions caused by matter effects, making it a much better option to study the CP violation
- Only downside of the second oscillation maximum is that it is further away from the source of neutrinos, reducing the flux



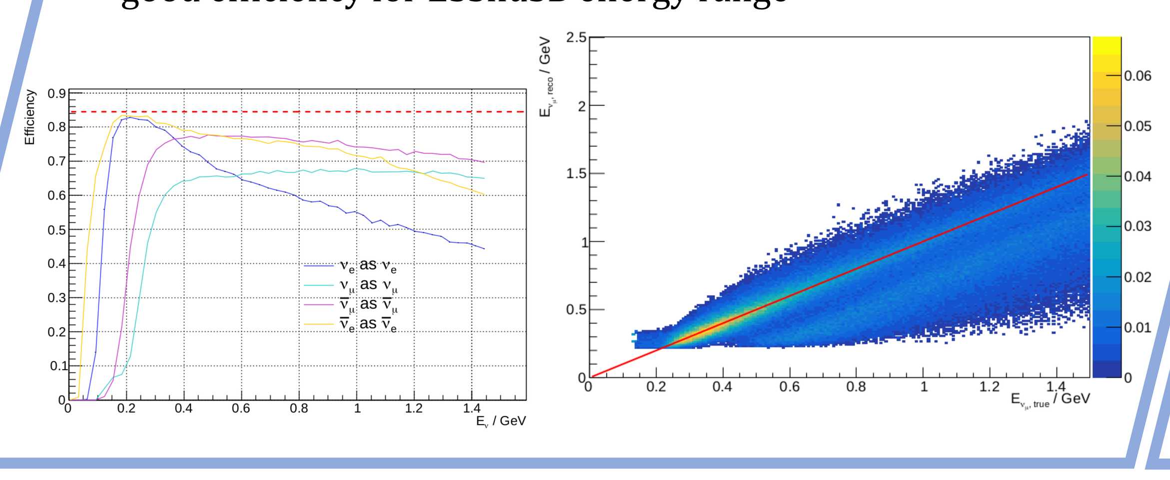
What is FarWatCh?

- Far Water Cherenkov detector will consist of two tanks of water with total fiducial mass of 538 kt
- It will be located 360 km from the neutrino production target at the Zinkgruvan mine
- Main purpose is to measure number of ν_e and $\bar{\nu}_e$ that originated as ν_μ and $\bar{\nu}_\mu$ to determine if there is a difference between oscillations of neutrino and antineutrinos



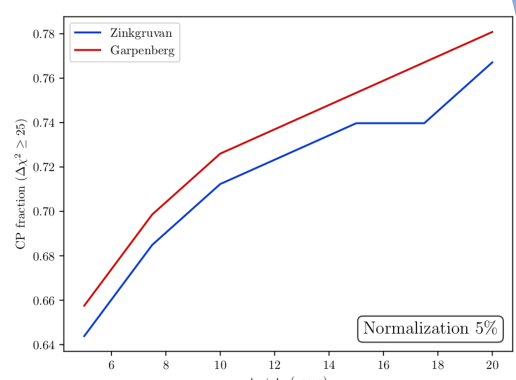
How does FarWatCh perform?

- External software used in simulations
  - GENIE MC Event Generator to simulate neutrino interactions with water
  - WCSim for particle propagation and PMT response
  - fiTQun reconstruction algorithm to reconstruct produced events
- Migration matrices are used to reconstruct incident neutrino energy
- Flavour identification algorithm optimized for ESSnuSB flux has a good efficiency for ESSnuSB energy range



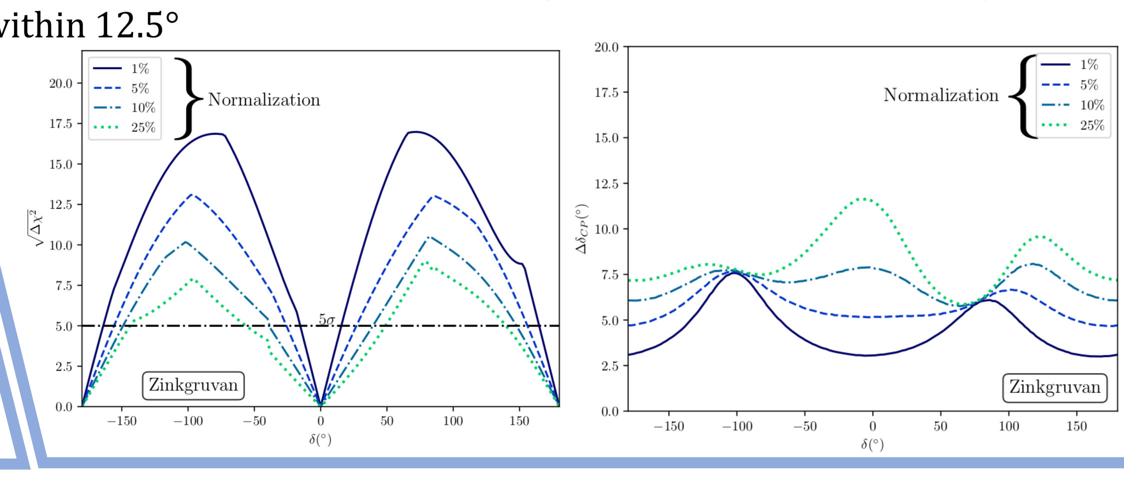
What do we conclude?

- ESSnuSB is a design study aiming to measure CP violation in 2nd oscillation maximum
- There will be 2 detectors NearWatCh with Emulsion and SFGD and FarWatCh
- Using the 2nd oscillation maximum provides better sensitivity to CP violation while reducing the impact of matter effects and other systematics
- CP discovery potential reaches 5 σ for 71 % of possible δ_{CP} values, while standard error of δ_{CP} is smaller than 7° for all δ_{CP} values



How good is physics performance?

- CP discovery potential or the significance with which ESSnuSB would be able to disfavour CP-conservation ($\delta_{CP} = 0$ or $\delta_{CP} = \pi$) reaches 5 σ for 71 % of possible δ_{CP} values in 10 years
- Precision of the measurement of δ_{CP} by ESSnuSB could range from 5° to 7° depending on its value (for assumed normalization error of 5 %)
- Even at normalization errors larger than 10 %, ESSnuSB can still provide a 5 σ result for CP discovery and have a precision of δ_{CP} within 12.5°



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