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WP5 Progress - Detectors

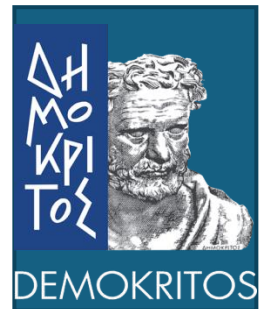
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4st ESSnuSB+ annual meeting
05 October 2026



WP5 detector-related presentations next days

1	FD simulation and Gd doping	Mahesh
2	Implications of GNN at END	Peter
3	T114 at J-PARC: Towards ESSnuSB Neutrino Cross-Section Measurement	Bruno
4	Recent update on cross-section results and emulsion technology	Fukuda
5	Software framework	Georgi
6	Cross-section at LEMMOND	Spyros

Update on FD simulation and Gd doping

Led by IRB and the University of Cukurova

Finished implementation of Far detector software using GEANT4

- Gadolinium doped water.
- PMT signal digitization.
- Muon and neutron separation using Gd capture time.
- Tested with neutrino and anti-neutrino events

Planning to write a paper with tentative title

“Classification of ν_μ and anti- ν_μ events using gadolinium doped water cherenkov detector at ESSnuSB far detector”

More by Mahesh in this meeting

Update on GNN at the ESSnuSB Near Detector (END)

Led by Lund University

WP5 _{id}	Title	Corresponding authors	Type of publication (WP or collaboration)	arXiv id	Journal name	DOI	Status
4	Classification of Electron and Muon Neutrino Events for the ESSnuSB Near Water Cherenkov Detector using Graph Neural Networks	Kaare Endrup Iversen, Peter Christiansen, Joakim Cedercäll, Alexander Burgman and Joochun (Jason) Park	Collaboration	2503.15247	JINST	10.1088/1748-0221/20/08/P0830	Published
9	Exploring ESSnuSB Near Water Cherenkov Detector Designs Through Graph Neural Network Flavor Identification.	Kaare Endrup Iversen, Peter Christiansen, Joakim Cedercäll, Alexander Burgman and Joochun (Jason) Park	Collaboration	2608.23773	JINST		With the Journal

- The results on electron/muon neutrino classification are obtained faster and more efficiently with GNN than with traditional methodology.
- Investigating the GNN power of classification with different size detectors.

More by Peter in this meeting

Update on the Software framework

Led by the University of Sofia

- The ESSnuSB Software Network has been developed in 5 stages:
 1. Migration to newer Linux version
 2. Added Utilities
 3. Added Detector geometries
 4. Added support to Ubuntu
 5. Added Docker support

More by Georgi in this meeting

Update on the development of ML tools for cross section measurement at LEMMOND

Led by Demokritos and the University of Thessaloniki

- Powerful Convolutional Graph Neural Network developed for neutrino and antineutrino event reconstruction.
- Accurate classification (Flavor and contained/uncontained events) using GNN.
- Genie neutrino and antineutrino events generated using ESSnuSB Software Network Docker in Ubuntu and two Nuclear Interaction models.
- Estimation of neutrino cross sections as a function of the neutrino energy; evaluation of their statistical accuracy and systematical biases using LEnuSTORM fluxes.
- Evaluation of differential cross sections integrated over the full antineutrino energy spectrum delivered by LEnuSTORM to the LEMMOND fiducial volume.
- Capability of distinguishing between Nuclear models if enough neutrino flux is available.
- Estimating the energy spectrum of the incoming anti-neutrino flux statistically using the observed lepton distributions by employing a Stochastic ANN methodology.

More by Spyros in this meeting

Additional Input on Emulsion technology and neutrino cross sections

Led by IRB and Nagoya University

- T114 at J-PARC: Towards ESSnuSB Neutrino Cross-Section Measurement
- More by Bruno in this meeting

- Recent update on cross-section results and emulsion technology
- More by Fukuda san in this meeting

IAP report: responds to recommendations

Detector development - Far Detector: Gd - doping

Comments from IAP members:

○ Encouraged:

- Clear formulation benefits for all physics goals in a comprehensive way.
- Cost evaluation.
- Consider concerns on additional background from loaded material as well as eventual impact on long term stability. Any drawbacks for CP violation sensitivity? Problems with water transparency?

Our Reply:

- Studies being performed with various concentrations of Gd in the detector to understand the capability of identifying neutrons originating from neutrino interactions. Preliminary results are presented at monthly meeting to show that muons and neutrons can be separated using the Gd capture time. Full scale study with neutrino interactions will be presented at the annual meeting in October.
- It is very hard to judge the cost of Gadolinium doping due to ever increasing cost of procuring Gadolinium Sulphate. Based on the Super Kamiokande experience and current Gadolinium Sulphate cost, we estimate a minimum of 180 million euros with 40 million for 0.1% Gadolinium Sulphate and rest for the loading+filtration system.
- According to the SK publications on Gd loaded water (<https://doi.org/10.1016/j.nima.2024.169480>), the water quality parameters such as radiation length and transparency are same as before the tank is loaded with Gd. In addition, the radioactive background arising from contaminants in the Gadolinium Sulphate are less than radiation backgrounds from all other sources in the detector. This was achieved through careful planning while maintaining a clean preparation and transportation of the materials. The same can be replicated for ESSnuSB far detector.

Detector development - Far Detector: Software development

Comments from IAP members:

- Far detector design has been implemented in the ESSnuSB software framework.
We encourage to continue this effort with further implementation of various details. Physics sensitivity evaluations would strongly benefit from this.

Our Reply:

The software has been further prepared to study Gd in the detector with full PMT readout capabilities. A preliminary reconstruction software using ML is under development.

Near Detector Physics

Comments from IAP members:

○ **Cross-section measurement analyses.**

The collaboration is working on all aspects to study the sensitivity of neutrino interaction cross-section measurements, and the initial study has been completed (MS16). This includes flux prediction for LEnuSTORM (MS21), neutrino interaction generations with GENIE, detector simulation for the LEMMOND (MS10) including event reconstructions (MS11). There is some work left for improvements, but the collaboration is ready for initial realistic cross-section measurement sensitivity studies (D13). This can be done with LEMNB flux prediction (MS19, to be completed) with systematic errors correctly propagated.

1. Total cross-section measurements: By assuming neutrino energy reconstruction, the event rate with unfolded spectrum shows the total charged current interaction cross section. This shows the relevant energy range of this experiment, and it allows for comparison with other experiments including the errors.

2. Differential cross-section measurements: Although the total cross-section allows the overlay of data points of different experiments, modern neutrino experiments around 1-10 GeV focus on measuring flux-integrated differential cross-sections which have way more detailed information on neutrino interactions. This is because nuclear effects prevent to unfold the true neutrino energy, and we need to compare cross-sections between data and theory with observable kinematic variables (lepton energy, lepton scattering angle, final state pion energy etc) and not inferred kinematic variables (neutrino energy, momentum transfer, energy transfer, Bjorken x , inelasticity y , etc).

3. LEnuSTORM specific analyses on differential cross-section measurements (higher priority): Explore LEnuSTORM-specific neutrino cross-section measurement analyses by utilizing the well-known spectrum. For example, charged lepton energy can be related to true neutrino energy to measure the total cross-section with a function of neutrino energy (see Fig. 3a of <https://arxiv.org/abs/2110.14023> how MicroBooNE approaches this problem). Such analysis based on LEnuSTORM hasn't been done, and it will receive high attention and high demand in the neutrino interaction physics community.

Near Detector Physics... continued

Comments from IAP members:

○ **Cross-section measurement analyses ... continued**

4. LEMNB specific analyses on differential cross-section measurements (higher priority):

Explore LEMNB-specific neutrino cross-section measurement analyses by utilizing the well-known spectrum or tagged neutrinos. It is not clear tagged beam is possible, however, there is no demonstration to use such beam to measure neutrino cross-sections. For example, one can speculate to measure neutrino interaction with a function of energy transfer (see Fig. 6 of <https://arxiv.org/abs/2509.07664> how DUNE approaches this problem) which is the smoking gun of nuclear models with axial current interactions.

Our Reply:

The answers to the above questions (items 1-3) and the procedure/methods followed for the determination of total and differential cross sections using LEMMOND are described in detail in deliverable D5.3 (Performance of neutrino interaction cross-section measurement) which can be found in the following link of ESSnuSB DocDB:

(<https://essnusb.eu/DocDB/private/ShowDocument?docid=2270>).

Concerning the last item (item 4 – LENMB facility) the final design of LENMB is still in progress. Furthermore, as the International Advisory Panel notices, LEMNB does not provide event-by-event energy tagging thus the same method used with LenuSTORM is going to be followed. Concerning energy determination, we have been working on a probabilistic energy determination procedure (based on a ANN, on event-by-event basis) and preliminary results indicate that can be used as alternative technique of estimating the cross section as a function of the neutrino energy. The results will be reported in the annual collaboration meeting.