Status of the detector design studies for ESSvSB

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Table of contents

1. Introduction
2. The near detector designs
3. The far detector design
4. Software development
5. Summary and outlook
Introduction

“Discovery and measurement of leptonic CP violation using an intensive neutrino Super Beam generated with the exceptionally powerful ESS linear accelerator”

15 institutes from 11 European countries, including CERN and ESS

\[ \theta_{13} = 1^\circ \]

Measure \( \delta_{CP} \) at 2nd oscillation maximum

\[ \theta_{13} = 10^\circ \]

Prospective mine locations

P. Coloma and E. Fernandez-Martinez, arXiv:1110.4583v2

Introduction

- 2.0-GeV protons
- 5-MW beam power
- 14-Hz repetition rate, 2.86-ms pulses
- $10^{15}$ protons per pulse, $> 10^{23}$ per year

Upgrades desired for ESSvSB and other experiments

ESSvSB work packages and presentations at NUFAC'T 2019

M. Dracos, plenary

B. Folsom, WG3
Y. Zou, WG3
L. D’Alessi, WG3

M. Ghosh, WG1

WP2
WP3
WP4
WP5
WP6

This talk

M. Ghosh, WG1

WP2, WP3, WP4

WP5, WP6

ESSvSB work packages and presentations at NUFAC'T 2019
The near detector (ND)

Characterization of the neutrino beam near the production point
• Energy and flavor measurement – neutrino flux
• Neutrino interaction cross section measurement

Aim: < 5% systematic uncertainties in signal/background normalization
5% signal, 10% background uncertainties assumed in white paper


ND design criteria/requirements:
• Large mass to provide a sufficient number of neutrino interactions
• Acceptance for charged leptons (muons and electrons) in large scattering angle
• Capability to reconstruct and identify short tracks of low-energy hadrons around the interaction vertex
ND – background

Characterization of the neutrino beam near the production point

- Energy and flavor measurement – neutrino flux
- Neutrino interaction cross section measurement

\[ z_{ND} = 500 \text{ m}, R_{ND} = 500 \text{ cm} \]

**Flavour**
- $\nu_\mu$
- anti-$\nu_\mu$
- $\nu_e$
- anti-$\nu_e$

**Neutrinos/antineutrinos**

**Charged leptons from neutrino interactions**

ND designs

Water Cherenkov detector

PMT or LAPPD readout

Fiducial volume: 100-1000 tonnes

Simulations implemented in:
WCSim – Geant4 and ROOT-based water Cherenkov detector simulation, open source
EsbRoot – based on FairRoot framework

Super Fine-grained detector
(SuperFGD)

1 × 1 × 1 cm³ plastic scintillator cubes with wavelength-shifting fibers inside magnetic field

Mass: 1-10 tonnes

Tracking and momentum measurement

Simulated in EsbRoot

A. Burgman, MSc thesis presentation

A. Blondel et al., Jour. Instrum. 13, P02006 (2018)
WC-ND development

Motivation: same neutrino interaction material and detection mechanism as for the water Cherenkov far detector (FD)
→ Possible reduction or cancellation in systematic uncertainties in energy reconstruction and flavor identification between ND and FD

Questions to be addressed as a function of ND geometry:
• Which reconstruction algorithm, especially at < 200 MeV energies?
• Keeping neutrino flavor misidentification rates to << 1%
• Energy/momentum/vertex reconstruction performance

Several conclusions drawn from beam profile and charged lepton propagation in water (next slide)

Detector performance and geometry under investigation
WC-ND physical requirements

Conclusions from MSc thesis by A. Burgman, Lund University (2015)

$Z_{ND} = 500$ m proposed for more shielding from cosmic background

- The length of the near detector: $L_{ND} \gg 3$ m.
- The radius of the near detector: $R_{ND} \gg 2$ m, $R_{ND} \leq \frac{z_{ND}}{50}$.
- The distance between the neutrino beam production and the near detector: $z_{ND} \geq 200$ m.
- The detector must have a space resolution smaller than 10 cm.
- The detector must have a time resolution shorter than 100 ps.
The far detector (FD)

MEMPHYS-like Water Cherenkov detector
(MEgaton Mass PHYSics)


- Neutrino oscillations
- Proton decay
- Astroparticles
- Neutrinos from supernovae
- Solar/atmospheric neutrinos

500-kt fiducial volume (~20 x SuperK)
~240k 8-inch PMTs, 30% optical coverage
Cost: ~€700M
Mixing Angles and Masses

FD hall design and core drillings to be examined by consultancy mining engineering firm

Project for Neutrinos (GRIPnu)


A Socio-economic and Industrial Study of the Consequences of constructing a World-leading Neutrino Detector in Garpenberg in Region Dalarna commissioned by Garpenberg Council

FD hall design and core drillings to be examined by consultancy mining engineering firm
FD simulations

Simulated in EsbRoot and WCSim event displays

\[ \nu_\mu + p \rightarrow \mu^- + \Delta^{++} \rightarrow \mu^- + p + \pi^+ \]

\[ E_{\nu} = 0.6 \text{ GeV} \]

- Charged lepton simulation and hit digitization complete
- Working on consistency in physics parameters and simulation output between EsbRoot and WCSim
- Assessing different reconstruction strategies and design dimensions
Software development - simulations

FairRoot framework (material from K. Gertsenberger, ESSvSB meeting in Strasbourg, 2018)

“EsbRoot” was developed for WP5 based on FairRoot framework
Detector software block diagram

- Preliminary studies
  - SuperFGD
    - WP4 Neutrino files
    - WP6 neutrino xsec
  - EsbRoot
    - Migration matrices
    - Visualisation
  - EsbWCDetector (sim and digit)
    - WCSim
      - Far WC
      - Near WC
    - Preliminary studies
      - Preliminary studies

[Courtesy of B. Klichek]
Detector software block diagram

- Preliminary studies
- GENIE
  - WP4 Neutrino files
  - WP6 neutrino xsec
- EsbWCDetector (sim and digit)
- WCSim
  - Integration pending
- SuperFGD
- EsbRoot
  - Integration pending
  - Migration matrices
  - Visualisation
  - Full response of detectors
- Far WC
- Near WC

Ongoing

Implementation pending

3rd software workshop held in July 2019

[Courtesy of B. Klicek]
Event display tool - EsbRootView

Courtesy of G. Barrand, CNRS/IN2P3/LAL

- 2D/3D event topologies
- Rotatable view
- Web browser/app development
- Timing information?

CCQE interaction inside SuperFGD, Chernkov radiation in water detector

Important cross checking tool for event reconstruction and PID
Summary and outlook

Initial designs and performance studies
- Water Cherenkov ND/FD
- SuperFGD tracker

Software frameworks
- EsbRoot, WCSim implemented
- Reconstruction algorithm under development

Tasks:
- Integrate GENIE Monte-Carlo neutrino interaction generator (arXiv:1510.05494) into EsbRoot
- Develop reconstruction algorithm for both ND and FD
- Finalize detector location, dimensions, components, and data analysis strategies

Design studies to be completed by the end of 2021 with a conceptual design report
Acknowledgements

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