Partikeldagarna 2021

Report from the Lund University ESSnuSB Group

ESS NEUTRINO SUPER BEAM

A. Burgman

Division for Nuclear Physics
Lund University

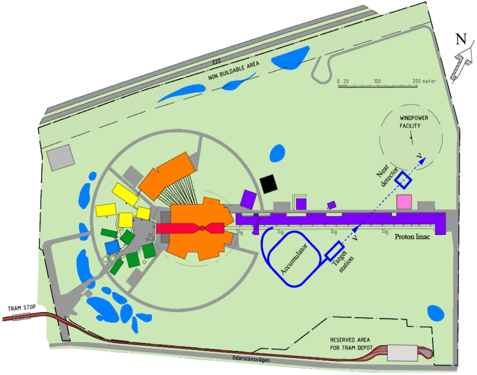
2021.11.23

ESSnuSB

The ESS Neutrino Super-Beam

Purpose

- Measure ν-oscillation (incl. δ_{CP})
- ν- & BSM-physics



- 2^{nd} oscillation max. of high-intensity neutrino beam from the European Spallation Source

The Collaboration

$\sim$ 50 active researchers, $>$ 10 countries

- Sweden: UU + LU
- Collaboration meeting this week (CERN)

CDR in early 2022

LU group $\rightarrow$ water-Cherenkov near detector

J. Cederkäll, professor

P. Christiansen, professor

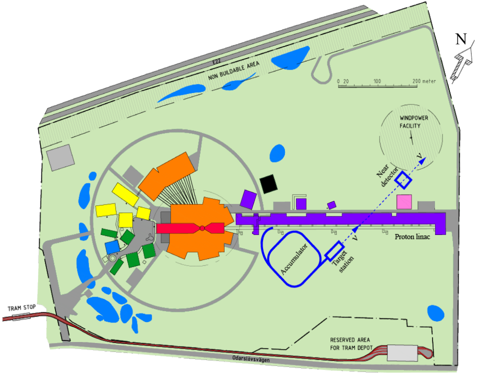
J. Park, postdoc *(now at IBS, Korea)*

A. Burgman, postdoc

The ESS Neutrino Super-Beam

Purpose

- ▷ Measure ν-oscillation (incl. δ_{CP})
- ▷ ν- & BSM-physics

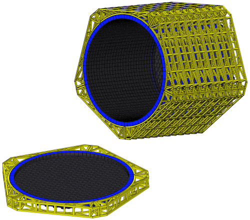


- ▷ 2[nd] oscillation max. of high-intensity neutrino beam from the European Spallation Source

Producing the neutrino beam

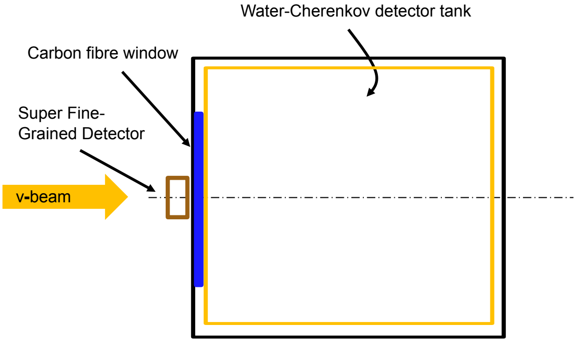
- ↪ ESS linac upgrade for dedicated p-beam
  - ▷ 5 MW, 2.5 GeV E_{kin}, 14 Hz repetition
- ↪ Compress pulses to 1.1 µs
- ↪ Produce $\pi^{\pm}$ with p-beam on four Ti-targets
  - ▷ Sign-select with magnetic focusing horn
- ↪ Produce ν-beam in 50 m decay tunnel
- ↪ Unoscillated beam at near detector, $\sim$ 250 m
- ↪ Oscillated beam at far detector, 360 km (Zinkgruvan) or 540 km (Garpenberg)

Near Detector



Two-fold purpose

- Measure ν-flux: $\sim 10^7$ events yr^{-1} (200 d, 2.16×10^{23} p.o.t.)
- Measure $\sigma_{\nu_e N}$: ν_e-fraction $< 0.5\,\%$
  - $\rightarrow$ requires efficient selection of ν_e



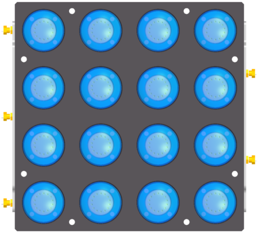
Two main components

SFGD
- $1.4 \times 1.4 \times 0.5\,\mathrm{m}^3$
- $\sim 10^6$ plastic scintillator cubes, $(1 \times 1 \times 1)\ \mathrm{cm}^3$

Similar to Hyper-K SuperFGD

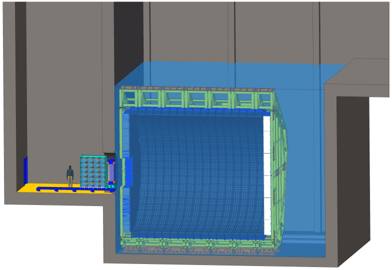
WC
- 11 m length
- 4.7 m radius
- 30 % PMT coverage
- 3.5 inch PMTs

Near Detector



Two-fold purpose

- Measure ν-flux: $\sim 10^7$ events yr^{-1} (200 d, 2.16×10^{23} p.o.t.)
- Measure $\sigma_{\nu_e N}$: ν_e-fraction $< 0.5\,\%$
  - $\rightarrow$ requires efficient selection of ν_e



Two main components

SFGD
- $1.4 \times 1.4 \times 0.5\,\text{m}^3$
- $\sim 10^6$ plastic scintillator cubes, $(1 \times 1 \times 1)\,\text{cm}^3$

Similar to Hyper-K SuperFGD

WC
- 11 m length
- 4.7 m radius
- 30 % PMT coverage
- 3.5 inch PMTs

Electron-Neutrino Event Selection

1. Separating $e^{\pm}$ from $\mu^{\pm}$
2. Separating ν_e from ν_μ

Separating $e^{\pm}$ from $\mu^{\pm}$

Sub-Cherenkov cut

Reject muons below Cherenkov threshold posing as electrons

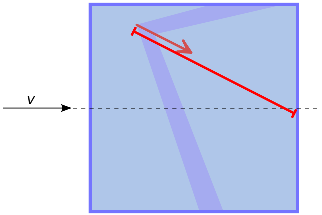
Reco. quality cut

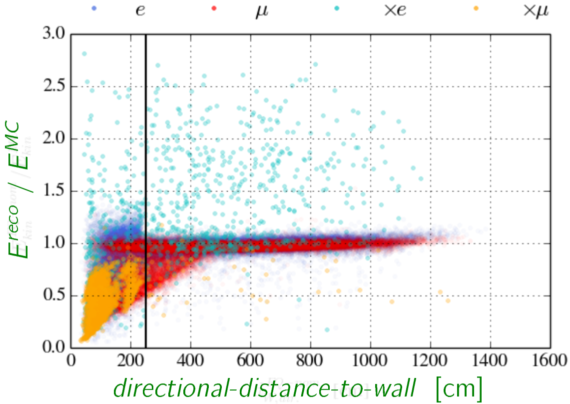
Reject low-brightness and close-to-wall events for reco. quality

Cherenkov-ring resolution cut

Reject events too close to tank wall in propagation direction

- Simulated with WCSim
- Reconstructed using fiTQun tuned to our detector



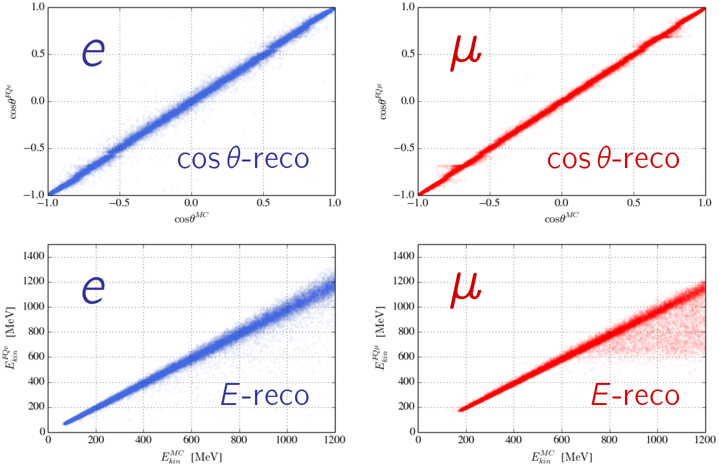


Thank you to Hyper-Kamiokande members:
E. O'Sullivan, *M. Wilking*,
C. Vilela, *H. Tanaka*, *B. Quilain*

Separating $e^{\pm}$ from $\mu^{\pm}$

Selection acceptance

e	54.9 %
μ	50.3 %



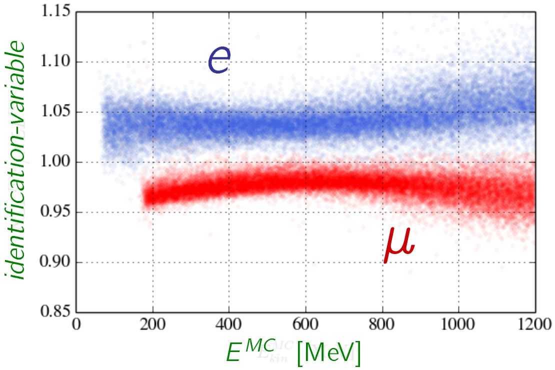
Separating $e^{\pm}$ from $\mu^{\pm}$

Selection acceptance

e	54.9 %
μ	50.3 %

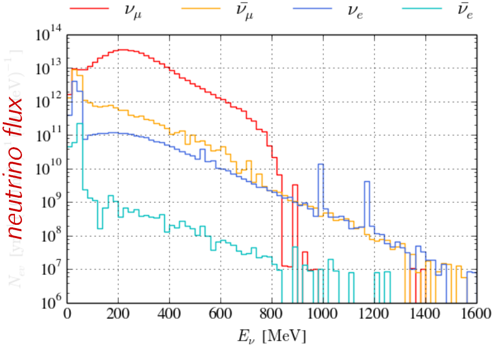
Reco. performance

e	corr-ID	97.9 %
	mis-ID	2.1 %
μ	corr-ID	99.8 %
	mis-ID	0.2 %



Separating ν_e from ν_μ

- Selection criteria for neutrino events
  - Rejecting events with $\pi^\pm$



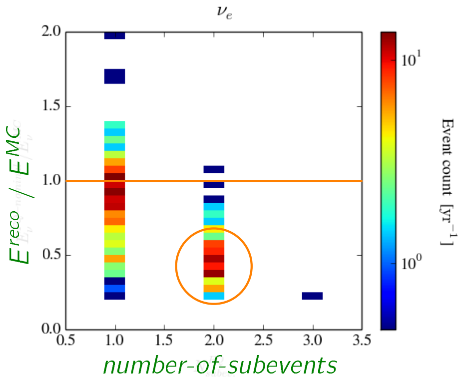
Pion-like cut
: Reject events identified as electrons, but more likely to be (neutral) pions

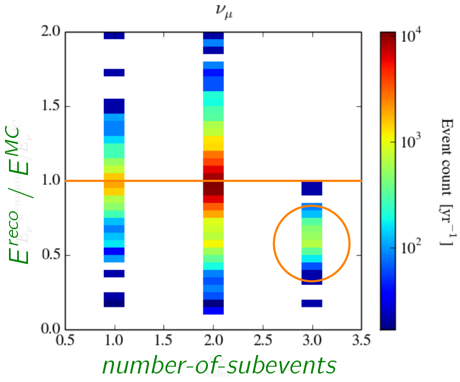
Multi-subevent cut
: Reject events with multiple subevents

Multi-subevent cut

Multi-subevent cut
Reject events with multiple subevents (≥ 2 for e, ≥ 3 for μ)

- Assuming one final-state particle (when there are multiple) gives poor initial-energy reconstruction performance





Event rate per 200 d running-year

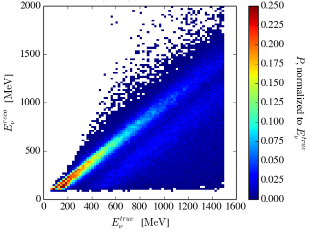
Positive polarity (ν-select)

	ν_μ	ν_e	$\bar{\nu}_\mu$	$\bar{\nu}_e$
Tot. interactions	7.25×10^7	3.57×10^5	1.89×10^5	8.33×10^2
Trigger	3.81×10^7	5.61×10^4	9.09×10^4	9.35×10^1

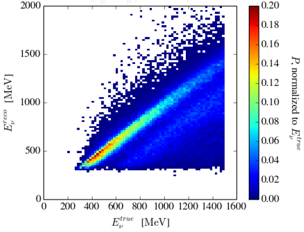
Negative polarity ($\bar{\nu}$-select)

	ν_μ	ν_e	$\bar{\nu}_\mu$	$\bar{\nu}_e$
Tot. interactions	6.88×10^5	4.74×10^3	1.39×10^7	4.12×10^4
Trigger	3.48×10^5	6.45×10^2	6.84×10^6	5.04×10^3

ν_e E_ν-reco



ν_μ E_ν-reco



- Efficient energy reconstruction

Quasi-elastic assumption:

$$E_\nu = \frac{m_F^2 - m_{IB}^2 - m_l^2 + 2m_{IB}E_l}{2\left(m_{IB} - E_l + p_l \cos\theta_l\right)}$$

Event rate per 200 d running-year

Positive polarity (ν-select)

	e-ID ν_μ	e-ID ν_e	e-ID $\bar{\nu}_\mu$	e-ID $\bar{\nu}_e$
Trigger	1.09×10^7	5.26×10^4	2.66×10^4	8.82×10^1
Charged-lepton cuts	5.72×10^5	2.29×10^4	1.43×10^3	3.58×10^1
Neutrino cuts	1.50×10^4	1.10×10^4	4.11×10^1	3.27×10^1

$S(\nu_e + \bar{\nu}_e)/B(\nu_\mu + \bar{\nu}_\mu) \sim 0.7$

Negative polarity ($\bar{\nu}$-select)

	e-ID ν_μ	e-ID ν_e	e-ID $\bar{\nu}_\mu$	e-ID $\bar{\nu}_e$
Trigger	1.08×10^5	6.05×10^2	1.87×10^6	4.74×10^3
Charged-lepton cuts	6.72×10^3	2.59×10^2	5.12×10^4	2.12×10^3
Neutrino cuts	1.23×10^2	1.23×10^2	1.93×10^3	1.86×10^3

$S(\nu_e + \bar{\nu}_e)/B(\nu_\mu + \bar{\nu}_\mu) \sim 1$

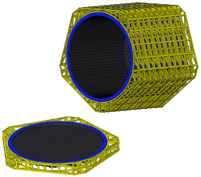
- Efficient increase of $\nu_e(\bar{\nu}_e)$ fraction $\Rightarrow$ measure $\sigma_{\nu_e N}$

Summary

Summary

LU Group → ESSnuSB ND

- Super Fine-Grained Detector ($\sim 1\,\mathrm{m}^3$)
- Water-Cherenkov Detector ($\sim 1\,\mathrm{kt}$)



Purpose

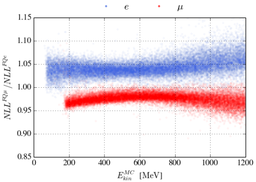
- Measure ν_μ-flux
- Measure $\sigma_{\nu_e N}$

Measuring $\nu_e N$ cross-section

- Enhance ν_e fraction

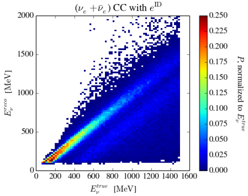
Charged-lepton separation

- Selecting well-reconstructed and -identified events



Neutrino separation

- Rejecting pion-contaminated events



ν_e selection:

Pos. pol. $S/B \sim 0.7$

Neg. pol. $S/B \sim 1$

Thank you

Backups

Backup 1.1 — Super Fine-Grained Detector

Similar to Hyper-K SuperFGD

- $1.4 \times 1.4 \times 0.5\,m^3$
- $\sim 10^6$ plastic scintillator cubes
  - $1 \times 1 \times 1\,cm^3$

Mass 1030 kg

C_8H_8 1014.55 kg

$C_{18}H_{14}$ 15.45 kg

Positive horn polarity (selecting ν)

	Time	Molecule	ν_μ	ν_e	$\bar{\nu}_\mu$	$\bar{\nu}_e$
CC	200 days	C8H8	57 334.5	309.178	120.694	0.557
		C18H14	828.734	4.46	1.644	0.007
		Total	58 163.3	313.638	122.339	0.565
NC	200 days	C8H8	39 471	167.746	117.034	0.4649
		C18H14	560.937	2.383	1.768	0.0066
		Total	40 031.9	170.129	118.802	0.4715

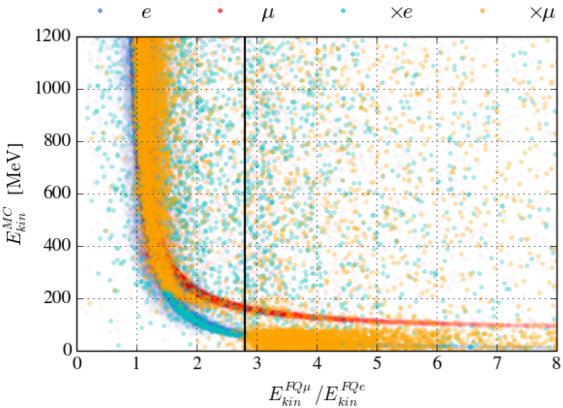
Negative horn polarity (selecting $\bar{\nu}$)

	Time	Molecule	ν_μ	ν_e	$\bar{\nu}_\mu$	$\bar{\nu}_e$
CC	200 days	C8H8	524.282	3.874	8 888.4	28.709
		C18H14	7.574	0.056	120.994	0.391
		Total	531.856	3.929	9 009.34	29.101
NC	200 days	C8H8	391.182	2.432	8 336.22	22.447
		C18H14	5.553	0.034	117.87	0.317
		Total	396.736	2.467	8 454.09	22.764

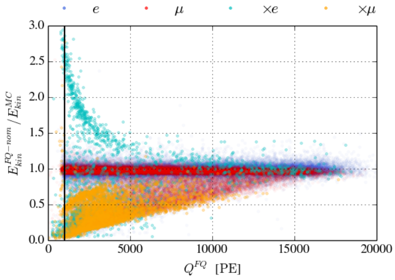
Backup 2.1 — Separating $e^{\pm}$ from $\mu^{\pm}$

Sub-Cherenkov cut

Reject muons below Cherenkov threshold posing as electrons

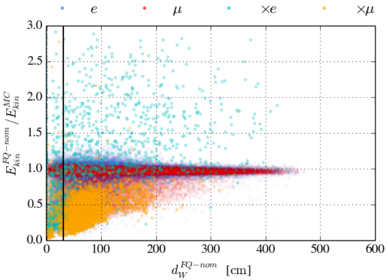


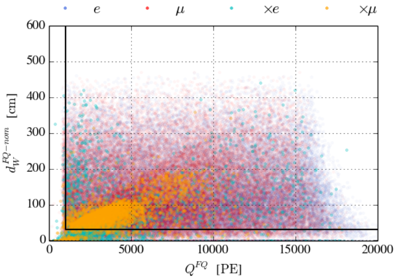
Backup 2.2 — Separating $e^{\pm}$ from $\mu^{\pm}$



Reco. quality cut

Reject low-brightness and close-to-wall events for reco. quality

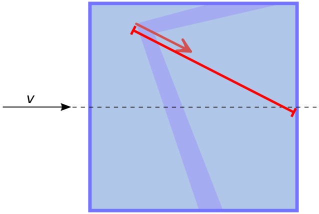


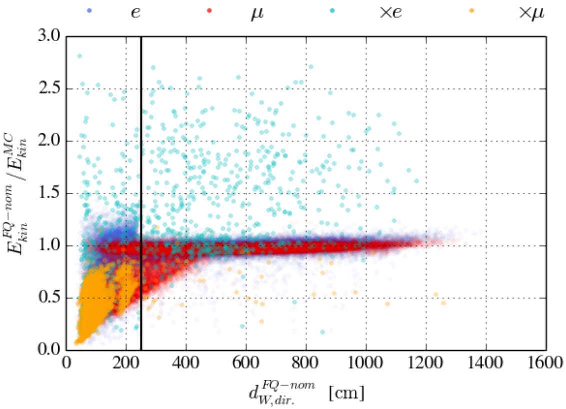


Backup 2.3 — Separating $e^{\pm}$ from $\mu^{\pm}$

Cherenkov-ring resolution cut

Reject events too close to tank wall in propagation direction

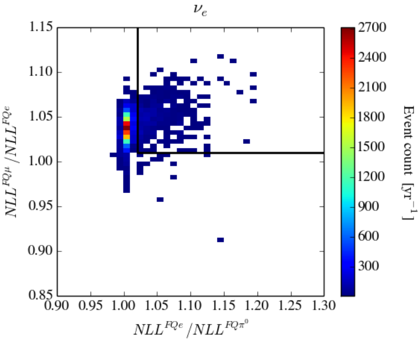


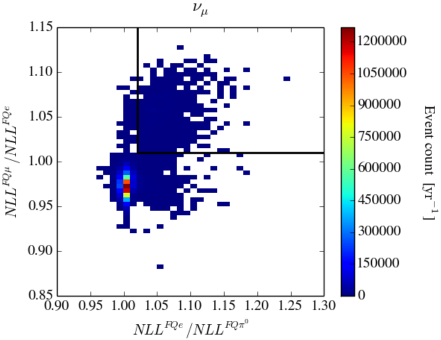


Backup 3.1 — Separating ν_e from ν_μ

Pion-like cut

Reject events identified as electrons, but more likely to be (neutral) pions





Backup 3.2 — Separating ν_e from ν_μ

Multi-subevent cut

Reject events with multiple subevents