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Near detector for the ESSνSB facility

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Why near detector?

- Flux monitoring
- Event rates/cross-section measurements
- Low energy neutrino physics ?

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The beam

- Wide-band beam
- Mixture of four neutrino flavours (no τ-neutrinos)
- Typical energy – few hundred MeV, e.g. 60 – 600 MeV

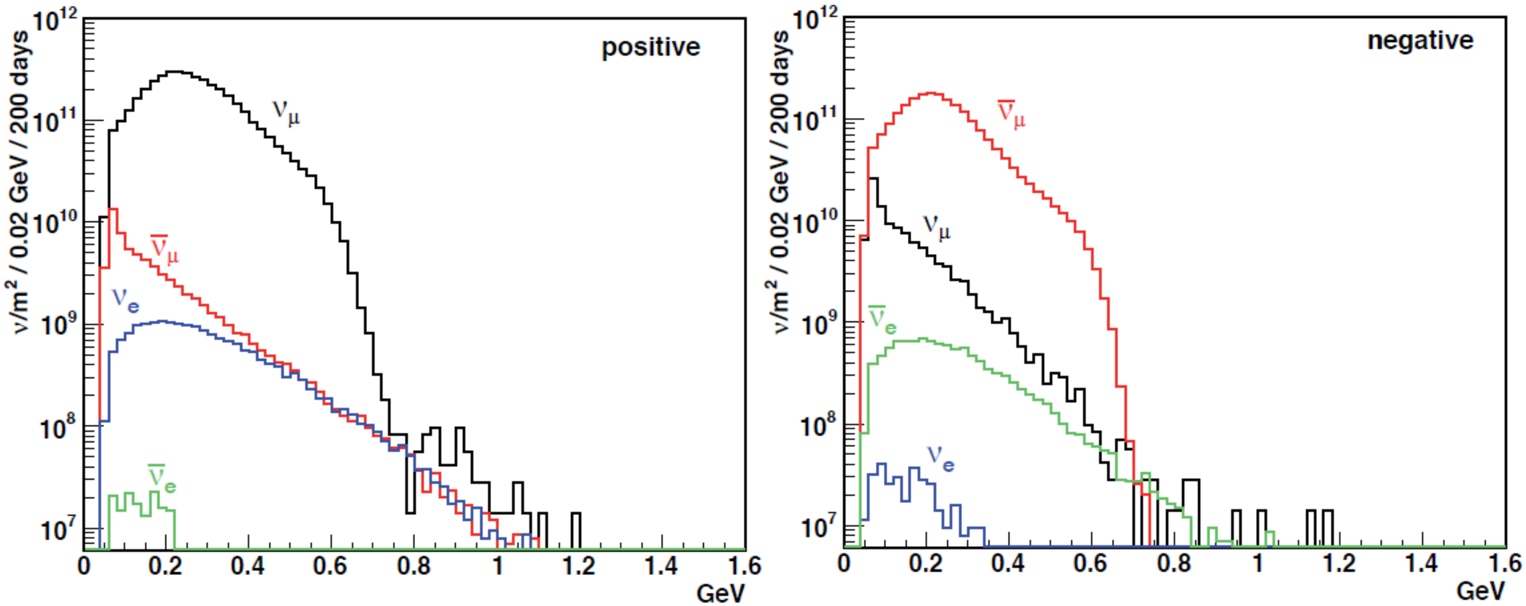

Figure 3. Neutrino fluence as a function of energy at a distance of 100 km on–axis from the target station, for 2.0 GeV protons and positive (left) and negative (right) horn current polarities, respectively.

ESSνSB paper, arXiv:1309.7022

ν cross sections in this energy range

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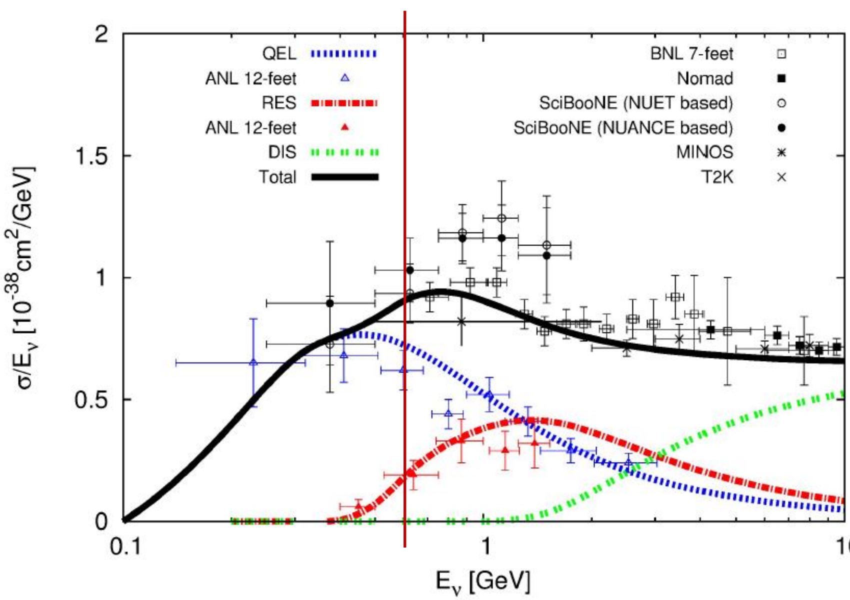
- Poorly measured for muon neutrinos (BooNE, T2K, Minerva, ArgoNeuT)
- **Not** measured for electron neutrinos

Morfin et al, arXiv:1209.6586



Formaggio, Zeller, RevModPhys.84.1307

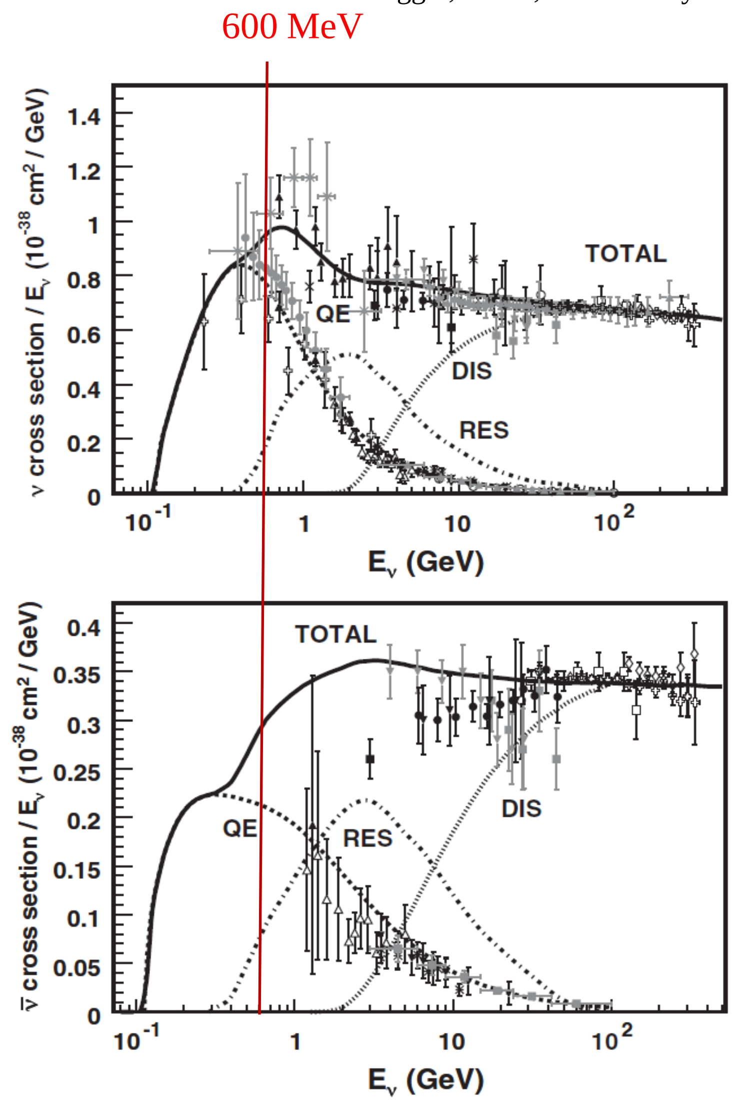


FIG. 9. Total neutrino and antineutrino per nucleon CC cross sections (for an isoscalar target) divided by neutrino energy and

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Processes to be measured

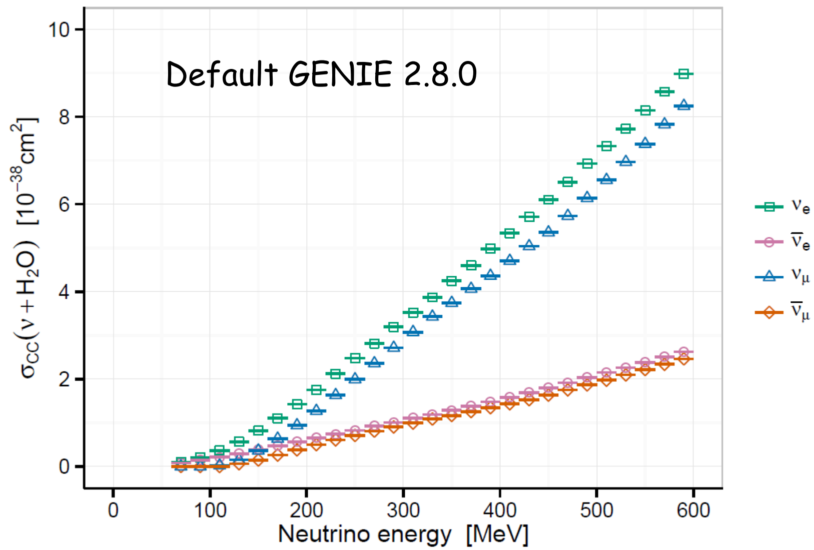
QE with a muon in the final state

$$\nu_\mu + n \to \mu^- + p \qquad \tilde{\nu}_\mu + p \to \mu^+ + n$$

QE with an electron/positron in the final state

$$\nu_e + n \to e^- + p \qquad \tilde{\nu}_e + p \to e^+ + n$$

There will be no need to identify the lepton charge as the neutrino and antineutrino fluxes in a given beam mode are very different → no magnetic field.



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Detector requirements

They depend strongly on what we want:

- For flux monitoring and event rate/cross-section measurements one needs large statistics, i.e. large fiducial volume.
- For precise physics measurements a general purpose detector with good tracking/energy/PID capabilities is needed

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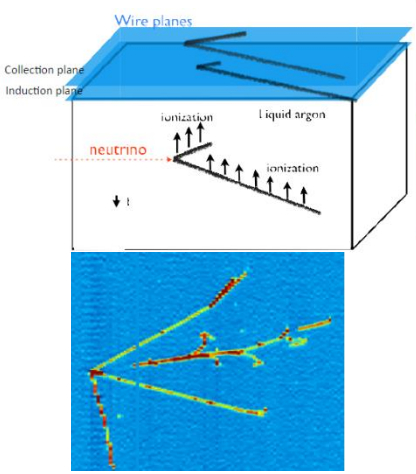
Detector design

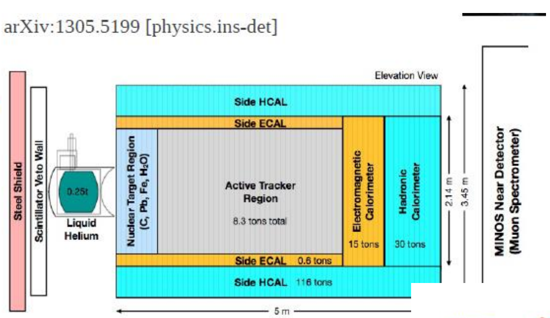
- For flux and event rate measurements a very natural choice is a kton mass **water Cherenkov detector** (*a la* old KamiokaNDE detector or **K2K near detector**).
- For precise measurements there is a variety of (expensive) options:
  - T2K ND280 type detector (scintillation tracker + gas TPC)
  - LqAr TPC + muon catcher
  - Sandwich type scintillation tracker with passive target material
  - Fine grained calorimetric detector

ArgoNeuT

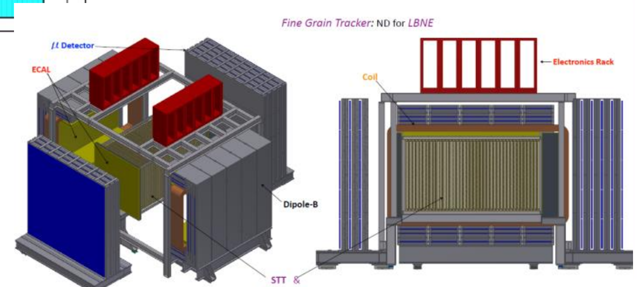


Minerva

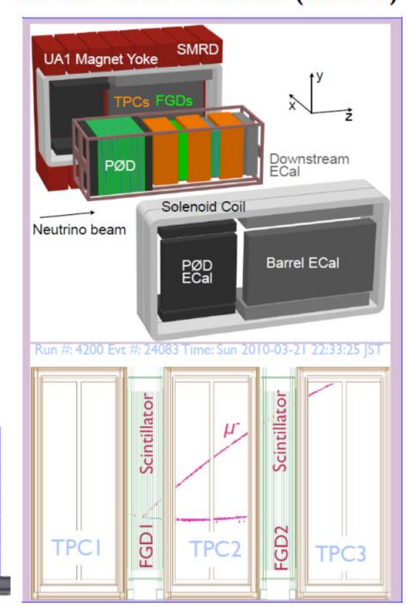
arXiv:1305.5199 [physics.ins-det]



HiResMν: ND for LBNE

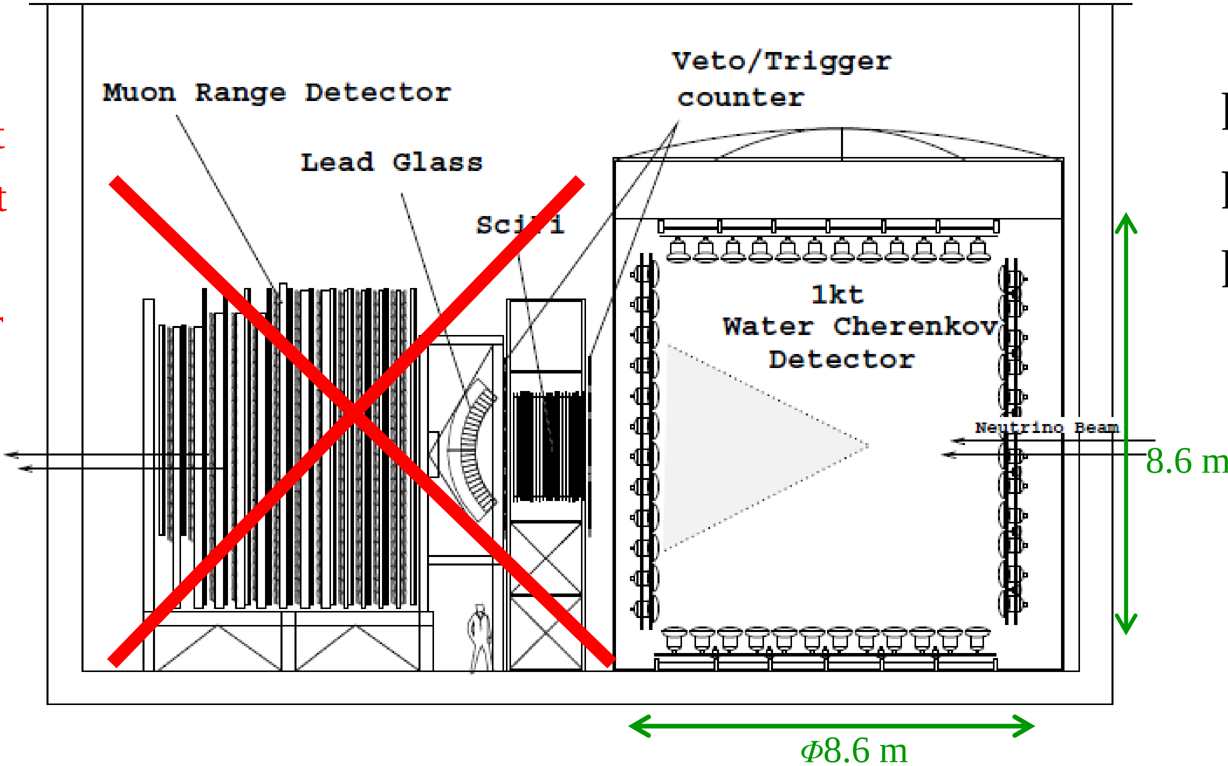


Off-axis Near Detector (ND280)



K2K near detector

In the simplest case we do not need this part, because of our much lower energy.



hep-ex/0103001

hep-ex/0212007

hep-ex/0408134

Fig. 1. The layout of the K2K near detector. It consists of a 1-kt water Cherenkov detector, a scintillating fiber detector, a hodoscope of plastic scintillation counters, a lead glass detector, and a muon range detector.

A muon event in MEMPHYS

PhysRevSTAB.16.061001

Range of a 600 MeV muon in water is ~2.5 m.

Water rad. length is ~38 cm.

Thus, we will contain almost all muon and electron events in a detector with dimensions $\Phi 8 \times 20 m^3$.

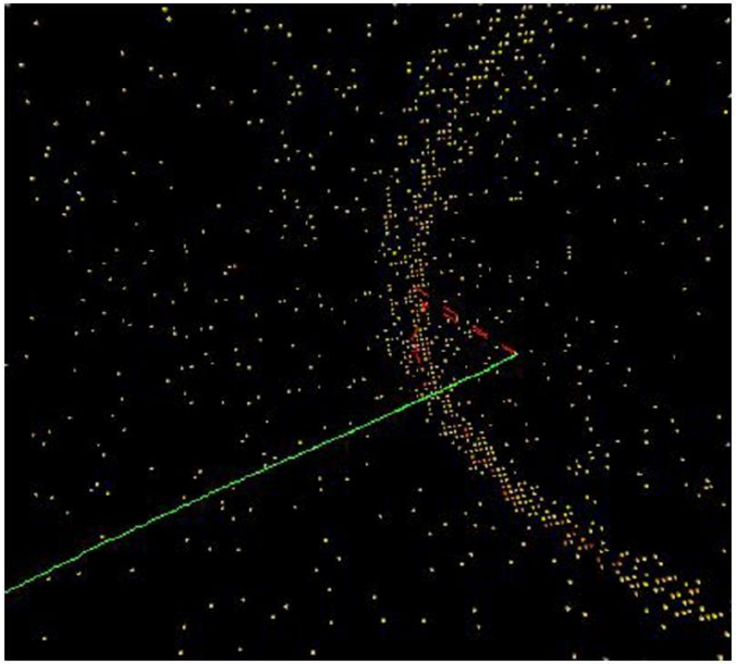


FIG. 4. Pattern of hit PMTs after the interaction of a 500 MeV muon with the full MEMPHYS simulation. The green line is the muon track, the red dashed lines are gammas from muon capture, each white dot represents one hit PMT.

Event rates
at 100 m from the source

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ESSvSB paper, arXiv:1309.7022

Table 2. Number of neutrinos per m^2 crossing a surface placed on–axis at a distance of 100 km from the target station during 200 days for 2.0 GeV protons and positive and negative horn current polarities.

	positive		negative	
	N_ν ($\times 10^{10}$)/m^2	%	N_ν ($\times 10^{10}$)/m^2	%
ν_μ	396	97.9	11	1.6
$\bar{\nu}_\mu$	6.6	1.6	206	94.5
ν_e	1.9	0.5	0.04	0.01
$\bar{\nu}_e$	0.02	0.005	1.1	0.5

Order of magnitude estimation:

Beam divergence (from kinematics) ~40 mrad.

Beam spot at **100 m** ~50 m^2 . At this distance

the numbers in Table 2 would correspond to a flux per **mm^2**

if the illumination is uniform.

Thus, at ~100 m from the source one would have had

~**5x10^7** ν_e crossed a surface of ~50 m^2 for 200 days.

Event rate for $\boldsymbol{\nu_e}$ CC interactions in **1 kt** water Cherenkov detector for 200 days:

$(1.9 x 10^{10} x 100) x (1/18 x 6 x 10^{23} x 10^{9}) x (2 x 10^{-38}) x (0.5_{eff})$

$\approx$ **6x10^5 events.**

Thus, the event rate is not a problem.

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Conclusions & questions

- A near detector with ~kton mass would help in:
  - monitoring the neutrino flux,
  - having better control over systematics in δ_{CP} by measurement of the $\nu_e N$ and anti-$\nu_e N$ cross sections in the respective energy range.
- For ~500km baseline the detector would be practically at the surface and the background conditions would be heavy (cosmic ray muons, atmospheric neutrinos).
- Detailed MC study is needed for further evaluation of the near detector impact on the ESSνSB project:
  - What is the influence of flux knowledge on the δ_{CP} measurement (appearance experiment; do we need precise knowledge of the flux)?
  - What precision is needed in the (unmeasured so far) $\nu_e N$ and anti-$\nu_e N$ cross sections/event rates in water?
- Do we want to do a general study of neutrino interactions in this energy region? The physics is not very rich…