Prospects for large-volume neutrino detectors

Tobias Lachenmaier
Technische Universität München

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Why large neutrino detectors?

With the discovery of neutrino oscillations, there is a clear sign for physics beyond the Standard Model.

GUT

baryon/anti-baryon asymmetry

proton decay

leptogenesis

There are still open questions to complete our knowledge on fundamental neutrino properties and to understand neutrino mixing in detail: $\theta_{13}$, CP-violation, mass hierarchy, absolute mass scale, nature of the neutrino.

Strong interest and growing effort for large-volume neutrino detectors in Europe, US, and Asia.

Complementary to LHC:

LHC: Higgs mechanism, SUSY, rare decays
LAGUNA: Proton decay, neutrino astronomy, CP violation in leptons

Many thanks to R. Svoboda, T. Kobayashi and M. Shiozawa for contributions.
• current limits in most channels dominated by Super-Kamiokande. Want to improve at least factor of 10.
• observation would be de-facto discovery of Grand Unification
If there \textit{does} exist a RH heavy partner for the LH neutrinos, \textbf{and} if such a partner violates CP in its decay, it could influence the baryon/anti-baryon symmetry of the universe (leptogenesis).

CP violation in the light neutrinos does not \textit{prove} that neutrinos have a heavy CP-violating partner, but it is strong circumstantial evidence.

Search for CP violation with the channels $\nu_\mu \rightarrow \nu_e$ / $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ in long baseline neutrino experiments by looking for a difference between $\nu_e \sqrt{\nu}_e$ appearance probability

$\rightarrow$ size of observable effect is depending on $\sin \theta_{13}$

$\rightarrow$ sensitive to any mechanism that creates nu/anti-nu asymmetry, separation of non-CPV effects needed
Why large neutrino detectors?

• Galactic Supernova Burst
• Diffuse Supernova Neutrino Background
• Solar Neutrinos
• Geo neutrinos
• Reactor neutrinos
• Neutrino oscillometry
• Atmospheric Neutrinos
• Dark Matter
Detector technologies under discussion

- Water Cherenkov detector
- Liquid Argon TPC
- Liquid Scintillator detector
Water Cherenkov detectors

IMB
3 ktons

Kamiokande
1 kton

SNO
1 kton

Super-Kamiokande
22 ktons

Large and useful experience: performance, calibration and operation are well established.
Water Cherenkov technique

- basic technology is well established
- aim is to go to 0.5-1 Megaton
- good tracking especially at 1 GeV or less
- good PID capability at low energy
- energy resolution for e and $\mu \sim 3\%$ (SK)
- for long-baseline beam experiment: good at low E ($< 1\text{GeV}$) narrow band beam
- technique is still evolving: e.g. better efficiency for muon decay electrons

Challenges:

- huge amount of photosensors needed ($\sim 200,000$ for 40% coverage as SK). Reduction by a factor of 2 works well for high energy applications (beam and proton decay). To what extent is additional reduction possible?
- very large underground cavities needed
- cost implied by these two points

see T. Kajita
Liquid Argon TPC

- electronic "bubble chamber", detailed event topology
- brilliant energy reconstruction and track resolution of every particle, capable up to higher energies
- PID with dE/dx and separation of tracks possible
- basically background-free for many applications
- aim at O(100kt)

Challenges:

- "complicated" detector technology
- huge number of channels (depending on position resolution)
- limited drift length leads to large span of the cavity
- staged R&D program: prototypes detecting cosmics and beam, ICARUS T600 @ Gran Sasso, ArgoNeuT @Fermilab, KEK 250lt

see P. Sala, O. Palamara
Liquid Scintillator technology

- mature technology (Borexino, KamLAND, SNO+)
- good energy and position resolution, very low energy threshold
- aim at 50kt

Challenges:
- cavity excavation (size comparable to SuperK)
- improvement for PMs and electronics needed
- keep Borexino purity in larger volume (surface-to-volume ratio is advantageous)
  -> relevant for sub-MeV neutrino detection

see L. Oberauer
e/µ discrimination and tracking

CNGS neutrino induced muons in Borexino.
World-wide efforts to realize a huge detector

- Japan
- U.S.
- Europe
Japan: Hyper-Kamiokande

Hyper-K
1Mton total volume
540kton fiducial vol.
Inner (D43m x L250m) x 2
Outer >2m
Photo coverage 20% (1/2 x SK)
Japan: Three possible scenarios under discussion

see T. Kobayashi
Scenario JPARC-HK (540kt, 295 km, 1.66 MW) as an example:
Hyper-K near-future plans

**Future plan**

- Global survey of the candidate site in this year
  (precise location and layout of the cavern)
- Optimize Water tank design, sensors, electronics
- Construction scheduling and precise cost estimation

- Design report in a year
U.S.
DUSEL Excavation Plan

- Davis Cavern
- Yates Shaft
- Ross Shaft
- Existing Drifts
- Lab Modules
- Large Cavities
- Excavation Drifts at 5040L
- Access Drifts at 4850L
- New Winze to 7400L
- #6 Winze
Conceptual design parameters:

- PMT coverage: 6(3) p.e./Mev for LE(HE) option.
- Could achieve with 40k to 80k 25 cm HQE PMT’s
- veto: top only or “thin” option being studied.
- cavern size/shape
- gadolinium loading option
- Initial costing going well

LBNE Science Collaboration
Sensitivity to mass hierarchy and CP violation

700 kW, 8+8 years
2x10^7 s/yr, 120 GeV
LBNE Schedule

- Initial design and costing complete by Fall, 2010
- Detector(s) choice for FD/Science Program defined by Science Collaboration: end of 2010
- DOE CD-1, late 2010 or early 2011
- National Science Board, Summer 2011
- Preliminary Design (~CD-2), end of 2012
- DUSEL construction start, end of 2013
- LBNE construction, 2015-2019 (this could be earlier depending on DUSEL lab readiness)

for more on the DUSEL program, see C. Mariani
Europe
Europe: LAGUNA

Consortium composed of 21 beneficiaries in 9 countries
9 university entities (ETHZ, Bern, Jyväskylä, OULU, TUM, UAM, UDUR, USFD, UA)
8 research organizations (CEA, IN2P3, MPG, IPJ PAN, KGHM CUPRUM, GSMiE PAN, LSC, IFIN-HH)
4 private companies (Rockplan, Technodyne, AGT, Lombardi)
Additional university participants (IPJ Warsaw, Silesia, Wroclaw, Granada)

Discuss and assess:
- rock engineering → feasibility
- needed infrastructure
- cost of excavation
- assembly of underground tank
- physics programme

Detector R&D to be funded at national level
Europe: LAGUNA

- Three options considered (MEMPHYS, LENA, GLACIER) with total mass in the range 50-500 kton.

- Water Cerenkov [MEMPHYS]
- Liquid scintillator [LENA]
- Liquid Argon TPC [GLACIER]
Europe: LAGUNA

7 potential sites

1. Boulby
2. Canfranc
3. Fréjus
4. Pyhäsalmi
5. Sieroszowice
6. Slanic
7. Umbria
Europe: LAGUNA

Design Study (EU FP7 funded): 2008 - 2010
Interim safety, socio-economic, environmental report: finished
Interim geotechnical reports on the seven sites: finished
Prioritize the sites and down-select: 2010

Final LAGUNA general meeting in Modane these days!
As a Water Cherenkov detector, suited for low energy (<1 GeV) beam
-> original concept in connection with beta-beam from CERN
-> connects this detector type in Europe presumably to the Fréjus site
GLACIER

Max drift length

\[ \varnothing \approx 70 \text{ m} \]

\[ h = 20 \text{ m} \]

Passive perlite insulation

950 km

2300 km
LENA

Low-Energy Neutrino Astronomy

Liquid Scintillator
ca. 50kt PXE/LAB

Inner Nylon Vessel
radius: 13m

Buffer Region
inactive, $\Delta r = 2m$

Steel Tank, 13500 PMs
$r = 15m$, $h = 100m$,
optical coverage: .3

Water Cherenkov Veto
1500 PMTs, $\Delta r > 2m$
fast neutron shield

Egg-Shaped Cavern

Overburden: 4000 mwe

see L. Oberauer
Simulated energy spectrum of 20000 proton decay events into Kaon channel (light yield 180 p.e./MeV)

Two peaks:
- Kaon + Muon $\sim 257$ MeV
- Kaon + Pions $\sim 459$ MeV

Energy-cut efficiency $\varepsilon_E = 99.5\%$, bound protons of $^{12}$C included.

Potential of LENA (10 y measuring time)
- For Superkamiokande current limit: $\tau = 2.3 \cdot 10^{33}$ y
  - About 40 events in LENA and $\lesssim 1$ background
- Limit at 90% (C.L) for no signal in LENA:
  - $\tau > 4.1 \cdot 10^{34}$ y with $\varepsilon = 65\%$

Variety of other channels can be tested.
Diffuse Supernova Neutrino Background

- Excellent background rejection (inverse beta decay)
- Energy window 10 to 30 MeV.
- High efficiency (100% with 50 kt target)
- High discovery potential in LENA
  - ~2 to 20 events per year are expected (model dependent)
A galactic SN in LENA

Possible reactions in liquid scintillator

- $\bar{\nu}_e + p \rightarrow n + e^+$
- $\bar{\nu}_e + ^{12}\text{C} \rightarrow ^{12}\text{B} + e^+$
- $\nu_e + ^{12}\text{C} \rightarrow e^- + ^{12}\text{N}$
- $\nu_x + ^{12}\text{C} \rightarrow ^{12}\text{C}^* + \nu_x$
- $\nu_x + e^- \rightarrow \nu_x + e^-$
- $\nu_x + p \rightarrow \nu_x + p$

- Antielectron $\nu$ spectrum with high precision
- Electron $\nu$ flux with $\sim 10\%$ precision
- Total flux via neutral current reactions
- Separation of SN models
- independent from (collective) oscillations in NC reactions

ca 15.000 events for a galactic SN

high statistics energy dispersive time dispersive flavour resolving
Geo neutrinos

Detect anti-neutrinos of the U, Th decay chains \((\text{inverse } \beta-\text{decay energy threshold on proton is 1.8 MeV})\).

Within the discussed detector options, only LS is able to determine the geoneutrino flux.

**LENA**

Expected event rate at Pyhäsalmi:
- 300-3000 events/year in 50 kt
- Background from reactors:
  - 240 events/year in 50 kt
  - in the relevant energy window

Determine U/Th ratio

disentangle continental/oceanic crust with more than one detector location (e.g. HanoHano)

Separation of geological models
CERN - Pyhäsalmi 2288 km
5 years nu + 5 years anti-nu
1st maximum @ 4.2 GeV
Wide band beam 1 – 6 GeV, 1.5 MW
Conclusions

Strong physics case for large-volume neutrino detectors.

Growing community for the realization of large-volume underground detectors.

New laboratories planned world-wide. Site and excavation studies with encouraging result for the feasibility of such labs. Site selection in US, in Europe with the LAGUNA final report priorization and down-selection of proposed sites, in Japan study scenarios until mid-2011.

3 detector technologies. Broad R&D program on all 3 technologies, progress towards realization.