APPEC

International Meeting for Large Neutrino Infrastructures

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ICFA Neutrino Panel Report

K. Long
Imperial College London/STFC

K.Long@Imperial.ac.uk

23rd June 2014

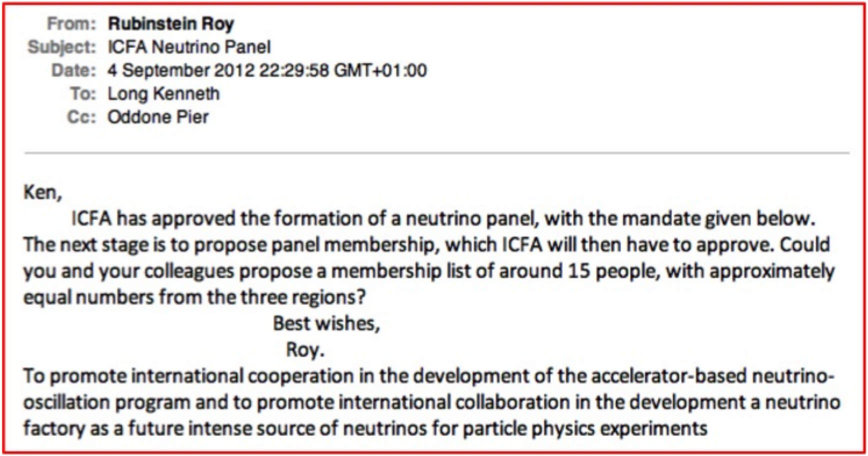
Outline

1. Inception
2. Regional Town Meetings
3. Initial Report
4. Observations, next steps and vision

Section 1

Inception

Mandate, September 2012



From: **Rubinstein Roy**
Subject: ICFA Neutrino Panel
Date: 4 September 2012 22:29:58 GMT+01:00
To: Long Kenneth
Cc: Oddone Pier

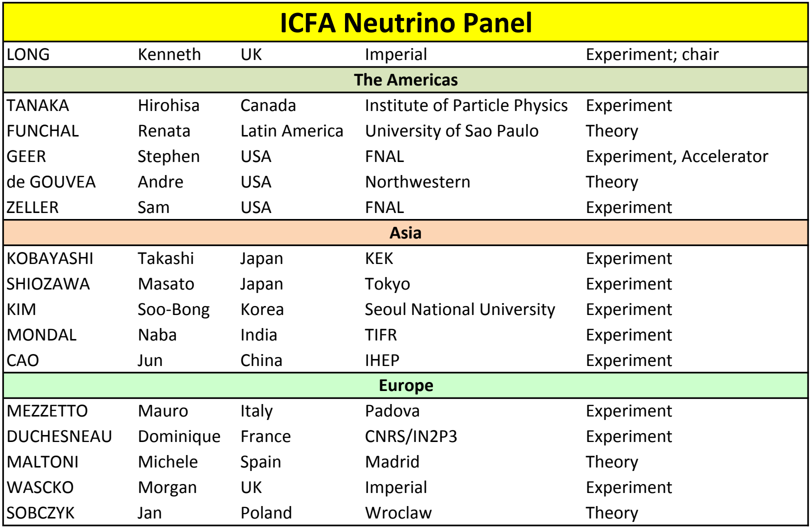
Ken,

ICFA has approved the formation of a neutrino panel, with the mandate given below. The next stage is to propose panel membership, which ICFA will then have to approve. Could you and your colleagues propose a membership list of around 15 people, with approximately equal numbers from the three regions?

Best wishes,
Roy.

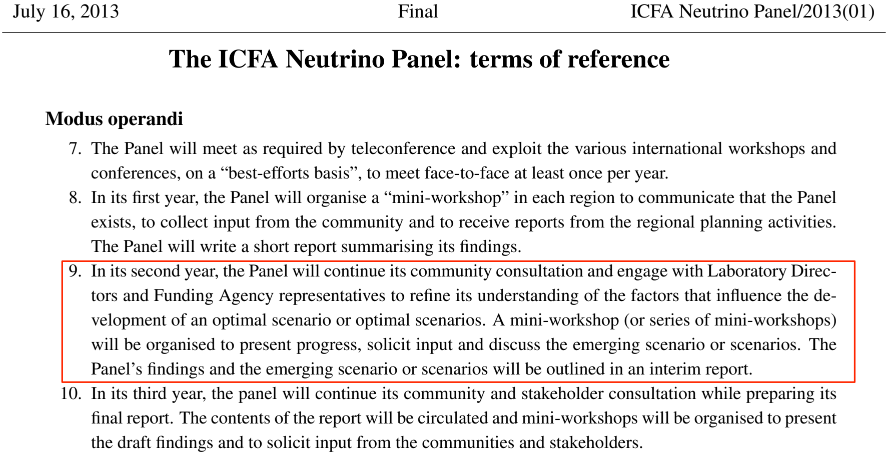
To promote international cooperation in the development of the accelerator-based neutrino-oscillation program and to promote international collaboration in the development a neutrino factory as a future intense source of neutrinos for particle physics experiments

Panel membership; February 2013



ICFA Neutrino Panel				
LONG	Kenneth	UK	Imperial	Experiment; chair
The Americas				
TANAKA	Hirohisa	Canada	Institute of Particle Physics	Experiment
FUNCHAL	Renata	Latin America	University of Sao Paulo	Theory
GEER	Stephen	USA	FNAL	Experiment, Accelerator
de GOUVEA	Andre	USA	Northwestern	Theory
ZELLER	Sam	USA	FNAL	Experiment
Asia				
KOBAYASHI	Takashi	Japan	KEK	Experiment
SHIOZAWA	Masato	Japan	Tokyo	Experiment
KIM	Soo-Bong	Korea	Seoul National University	Experiment
MONDAL	Naba	India	TIFR	Experiment
CAO	Jun	China	IHEP	Experiment
Europe				
MEZZETTO	Mauro	Italy	Padova	Experiment
DUCHESNEAU	Dominique	France	CNRS/IN2P3	Experiment
MALTONI	Michele	Spain	Madrid	Theory
WASCKO	Morgan	UK	Imperial	Experiment
SOBCZYK	Jan	Poland	Wroclaw	Theory

Terms of Reference, July 2013



July 16, 2013 Final ICFA Neutrino Panel/2013(01)

The ICFA Neutrino Panel: terms of reference

Modus operandi

7. The Panel will meet as required by teleconference and exploit the various international workshops and conferences, on a “best-efforts basis”, to meet face-to-face at least once per year.
8. In its first year, the Panel will organise a “mini-workshop” in each region to communicate that the Panel exists, to collect input from the community and to receive reports from the regional planning activities. The Panel will write a short report summarising its findings.
9. In its second year, the Panel will continue its community consultation and engage with Laboratory Directors and Funding Agency representatives to refine its understanding of the factors that influence the development of an optimal scenario or optimal scenarios. A mini-workshop (or series of mini-workshops) will be organised to present progress, solicit input and discuss the emerging scenario or scenarios. The Panel’s findings and the emerging scenario or scenarios will be outlined in an interim report.
10. In its third year, the panel will continue its community and stakeholder consultation while preparing its final report. The contents of the report will be circulated and mini-workshops will be organised to present the draft findings and to solicit input from the communities and stakeholders.

Section 2

Regional Town Meetings

Town Meetings and context

- **Asia:** 13 November 2013, Kavli IPMU, Kashiwa, Japan
  - KEK roadmap finalised April 2013;

- **The Americas:** 30 January – 1 February 2014, FNAL, Batavia, IL, USA
  - Canada:
    - 2015-2020 TRIUMF 5-year plan;
    - 2012-2016 Canadian (NSERC) long range plan in subatomic physics.
  - US:
    - Community Summer Study (Snowmass): community process complete;
    - Particle Physics Projects Prioritisation Panel (P5) was "in session";
    - What was known of considerations informed discussion.

- **Europe:** 8–10 January 2014, University of Paris Diderot, Paris, France
  - European Strategy for Particle Physics 2012

Points of consensus

- **Scientific imperative:**
  - *Programme* to measure neutrino properties with a precision sufficient to elucidate the underlying physics;
- **Key steps:**
  - Completing the picture:
    MH, CPiV, $\mathrm{sgn}(\theta_{23} - 45^\circ)$
  - Testing the framework:
    Redundant set of measurements to over constrain SνM
- **Accelerator-based programme essential:**
  - Only means to measure all transitions precisely;
  - Conventional facilities sufficient to:
    - Determine MH, make initial search for CPiV, $\mathrm{sgn}(\theta_{23} - 45^\circ)$
  - Novel facilities required to:
    - Test the framework:
      Neutrino Factory recognised to offer ultimate sensitivity and precision

Section 3

Initial Report

Headline measurements programme

arXiv:1405.7052v1

Mission:

Programme to determine the parameters of the SνM and make the tests necessary to establish it as a precise and self-consistent description of nature.

Headline measurements programme

arXiv:1405.7052v1

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Programme to determine the parameters of the SνM and make the tests necessary to establish it as a precise and self-consistent description of nature.

Principal conclusion (preview):

To ensure neutrino commuity has timely access to the requisite facilities requires the development of existing infrastructures in Asia, Europe and The Americas such that each region makes a unique and critically important contribution.

Headline measurements [1]

CPiV:

- Measure appearance at L/E s.t. interference between oscillation modes is manifest;
- Sensitivity to δ arises from terms in $\sin\delta \times \sin\theta_{12} \times \sin\theta_{23} \times \sin\theta_{13}$;
  $\Rightarrow$ need precise θ_{12}, θ_{23} and θ_{13} measurements;
- Classification of proposed experiments:
  - Narrow-band beams (e.g. Hyper-K, ESSnuSB);
  - Wide-band beams (e.g. LBNE, LBNO);
  - Novel beams (e.g. Neutrino Factory, Deadalus, ISODAR, MOMENT);
- Complementarity:
  NBB and WBB probe CPiV in different oscillation regimes:
  - Degree of matter effect;
  - Detector technology;
  - Composition, and size, of systematic uncertainties;
  - Opportunity to distinguish L, E, L/E effects
- Benefit of μ-decay-based source (Neutrino Factory):
  $\overset{(-)}{\nu}_e \rightarrow \overset{(-)}{\nu}_\mu$: golden channel “tag” $\mu^\pm$

Headline measurements [2]

Mass hierarchy:

- CC elastic $\overset{(-)}{\nu}_e$ scattering → matter effect → $P(\nu) \neq P(\bar{\nu})$;
  Modification depends on Δm^2_{32};
- LBL & atmospheric:
  Good sensitivity for small $\Delta m^2_{32}/E$ and large enough L;
- Reactor:
  Measure modulation of oscillated energy spectrum;

$\mathrm{sgn}(\theta_{23} - 45^\circ)$:

- Determined from detailed analysis of $\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e$ oscillation pattern;

Complementary measurements with different techniques essential since effects of CPiV, MH and $\mathrm{sgn}(\theta_{23} - 45^\circ)$ entangled.

Headline measurements [3]

Testing the SνM:

- Comparison of measurements:
  - θ_{13} from $\bar{\nu}_e$ disappearance at reactors;
  - θ_{23} & θ_{13} from $\overset{(-)}{\nu}_\mu$ disappearance, $\overset{(-)}{\nu}_e$ appearance at LBL;

  Yields consistency check or constraint on δ.
- Future programme must maintain complementarity:
  Precise measurements to search for inconsistencies or determine δ;
- Anomalies and sterile neutrinos:
  - Reactor/radio-isotope experiments suited to study of $\bar{\nu}_e$ disappearance at $\Delta m^2 \sim 1\,\text{eV}^2$;
  - Accelerator-based programme required to test sterile-neutrino interpretation of LSND, MiniBooNE anomalies;
  - **Generic searches for sterile neutrino states should be developed in synergy with the neutrino-nucleus scattering programme.**

Required supporting experimental programme

- Future LBL programme: high-power sources; large-mass detectors;
  $\Rightarrow$ large data sets; small statistical uncertainties
- Experimental programme req$^{\mathrm{d}}$ to reduce systematic uncertainties.

νN scattering measurements:

- Uncertainties $\sim$ 5%–10% in energy range of interest;
  Differential cross section uncertainties $30\% - 50\%$;
- First measurements of $\overset{(-)}{\nu}_e N$ cross sections reported;
- Complex model space: QE, resonance, DIS;
- Requires well-considered measurement & phenomenology programme.

Hadroproduction:

- Precision of flux prediction limited by knowledge of hadroproduction;
- Present flux-prediction uncertainties $\sim 10\%$;
- Future programme requires that this be reduced to $< 5\%$;
- Requires well-considered measurement & phenomenology programme.

Essential R&D programme

Extensive R&D programme required to:

- Underpin present and near-term programme;
- Realise potential of medium- and long-term programme.

R&D programme must encompass:

- A new generation of high-power, pulsed proton sources;
- Intense neutrino sources based on stored muon beams;
- Neutrino detector system of unprecedented size and granularity;
- Magnet systems that can produce an adequate magnetic field over a large detector volume in the absence of iron; and
- Simulation tools which encapsulate the physics of neutrino-nucleus interactions and models of the detector response.

An internationally coordinated R&D programme needed to maximise the impact of the efforts of individual countries and regions.

Theory & phenomenology programme

- To reduce the systematic-uncertainty budget require to develop theoretical/phenomenological description and modelling of νN, pN and $\pi^{\pm}N$ interactions to include, for e.g.:
  - Improved resonance-excitation models;
  - Collective nucleon-nucleon effects;
  - Improved modelling of final-state interactions;
- Combination of data from neutrino-oscillation experiments:
  Appropriate treatment of correlated systematic errors;
- Correlation of neutrino-oscillation measurements with observables in other areas of particle and particle astro-physics and cosmology.

Uniform implementation of "best practice" benefits from coordinating activities such as NuInt, NuStec.

Towards figures of merit [1]

Necessary in order to compare and contrast different proposals and directions. Two different categories:

Physics Beyond the SνM

- More than three neutrino mass eigenstates: sterile neutrinos;
- If masses small enough, only manifest in neutrino oscillation experiments;

  → new oscillation length (short-baseline), or apparent violation of three-flavour unitarity (long-baseline).
- New, weaker-than-weak interactions → nonstandard matter effects (mainly), directly probed in long-baseline neutrino oscillation experiments.
- Nonstandard neutrinos propagation → deviation from L/E oscillation, violation of three-flavour unitarity, etc.;
- Oscillations are unique probe of Lorentz invariance, decoherence, CPT-theorem (e.g., do fermions and antifermions have exactly the same mass?)

Towards figures of merit [2]

Precision Measurements: Targets

There are no unambiguous answers, but there are “robust” targets, more or less independent of the flavour model.

- Flavour models → algebraic relations among mixing parameters (e.g. $\theta_{23} = \pi/4 + \sqrt{2}\theta_{13}\cos\delta$).
  Requires different components known with similar precision: measure all mixing angles at $\mathcal{O}(\theta_{13})$ (or better).
- Flavour models → relate mixing angles to small parameters in the theory.
  In the neutrino sector, small parameters include $\sin^2\theta_{13}$, $\cos 2\theta_{23}$, and the ratio of the mass-squared differences.
  E.g., ratio of the mass-squared differences provides successive precision targets:
  $$\sqrt{\Delta m^2_{12}/|\Delta m^2_{13}|} \sim 17\% \rightarrow \Delta m^2_{12}/|\Delta m^2_{13}| \sim 3\% \rightarrow (\Delta m^2_{12}/\Delta m^2_{13})^2 \sim 0.1\%$$

The approved programme

Long-baseline:

- **T2K:** $\sigma(\theta_{23}) \sim 2\%$;
  $\overset{(-)}{\nu}_e$ appearance $\oplus$ reactor: δ at 1σ for $-150^\circ \lesssim \delta \lesssim -30^\circ$;
- **NOνA:** $\mathrm{sgn}(\Delta m^2_{31})$ at 2σ level:
  $\Delta m^2_{31} \lesssim 0$ if $-150^\circ \lesssim \delta \lesssim -10^\circ$ or $\Delta m^2_{31} > 0$ if $20^\circ \lesssim \delta \lesssim 140^\circ$;
- **MINOS+:** WBB to search for effects beyond SνM;

Supporting experimental programme:

- **Hadroproduction:** NA61/SHINE
  Goal: constrain J-PARC flux at 5%; near/far ratio at 3%
- **νN scattering:** MINERνA, MINOS+, NOνA, T2K(ND280), MiniBooNE, [ArgoNeut, SciBooNE]:
  $\overset{(-)}{\nu}_\mu N$ at 10%–30% level; $\overset{(-)}{\nu}_e N$ at 20%–50% level;

Steriles:

- **MicroBooNE:**
  Goal: elucidate origin of MiniBooNE low-energy excess;

Near future

Long-baseline:

- **LBNE:** WBB: $L = 1\,300$ km; LAr TPC, 35 kT; 10 yr exposure:
  $\mathrm{sgn}(\Delta m^2_{31})$ at $5 - 6\sigma$ for all δ; CPiV at 3.5σ for 50% of all δ;
- **Hyper-K:** NBB: $L = 295$ km; H_2O Cherenkov, 560 kT; 10 yr exposure (assume MH known):
  CPiV at 3σ over 76% of all δ;
- **Design studies:**
  - **LBNO:** WBB: $L = 2\,300$ km; MH at 5σ in ~ 2 yr exposure; CPiV at 3σ over 55% of δ in 10 yr exposure;
  - **CHIPS:** NBB: results competitive with combined T2K/NOνA sensitivity;
  - **ESSnuSB:** NBB: $L \sim 500$ km; second maximum CPiV search;
  - **Deadalus:** measure δ-dependence of oscillation as function of L using muon-decay at rest.

Supporting experimental programme:

- Coordinated development of hadroproduction and νN scattering programme:
  NA61/SHINE follow-on; conventional νN follow-on, nuSTORM

Steriles:

- New, definitive experiment(s) required to resolve anomalies;
  Proposals: 2-baseline LAr; NESSiE, LSND$'$; nuSTORM

Long term

Objectives of long-term programme:

1. To determine remaining unknown neutrino properties;
2. Elucidate whether SνM is the whole story; and
3. Measure with precision sufficient to allow the physics of neutrino oscillations to be understood.

A new, novel technique will be required to:

- Continue the search for CPiV;
  or measure δ precisely!
- Test the SνM and provide measurements of precision required to elucidate the underlying physics.

Coordinated programme of accelerator and detector R&D required to drive field beyond performance of next generation experiments, e.g.:

- Develop capability to provide neutrino beams from stored muons:
  MICE, nuSTORM, Neutrino Factory.

Initial conclusions [1]

0. **The study of the neutrino is the study of new phenomena that are not described by the Standard Model;**
1. **Accelerator-based programme is vibrant & is international in intellectual interest, engagement and scope;**
2. **The optimal exploitation of the present and approved experiments will benefit from increased cooperation in the development of better s/w & analysis tools;**
3. **LBNE and Hyper-K offer complementary approaches to the search for CPiV;**

   Dedicated programme required to manage systematics;

Initial conclusions [2]

4. **Design studies are underway for LBNO, ESSnuSB & Deadalus potentially attractive alternatives to LBNE and Hyper-K;**
5. **The Neutrino Factory offers the best sensitivity;**

   Incremental implementation of the facility is being studied;
   nuSTORM recognised as an attractive first step;
6. The anomalies in SBL measurements are being investigated energetically;

   SBL programme must also benefit the LBL programme.

Section 4

Observations, next steps and vision

Observations

- To optimise the discovery potential, maximise return on investment:
  - Requires neutrino community to have timely access to a number of complementary, powerful neutrino-beam facilities.
- For the programme to reach its full potential requires a:
  - Programme of measurement by which the systematic errors are made commensurate with the statistical power; and
  - Parallel programme of accelerator and detector R&D.
- To ensure timely access to the required facilities it is necessary to:
  - Exploit the opportunities to develop infrastructures that exist at CERN, KEK/J-PARC and FNAL such that each region makes a unique and critically important contribution.
- To maximise the impact of the expertise, experience, resources and infrastructure that exists in laboratories and institutes worldwide requires active coordination.

Next steps

In its second year the Panel will consult with laboratory Directors, funding-agency representatives, the community and other stakeholders to:

- Develop a road-map for the future accelerator-based neutrino-oscillation programme that exploits the ambitions articulated at CERN, FNAL and KEK/J-PARC and includes the programme of measurement and test-beam exposure that will ensure the programme is able to realise its potential;
- Develop a proposal for a coordinated “Neutrino RD” programme, the accelerator and detector R&D programme required to underpin the next generation of experiments; and
- To explore the opportunities for the international collaboration necessary to realise the Neutrino Factory.

Vision

Taken together, the road-map and Neutrino RD programme will form the basis of the “International accelerator-based Neutrino Programme” (IνP) necessary to deliver the measurements required for the phenomena that explain neutrino oscillations to be discovered.