Vol. 37 (2006) *ACTA PHYSICA POLONICA B* No 7

THE 2006 EPIPHANY CONFERENCE ON NEUTRINOS AND DARK MATTER AS COMPARED TO THE 2000 EPIPHANY CONFERENCE ON NEUTRINOS IN PHYSICS AND ASTROPHYSICS* **

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(Received July 13, 2006)

In 2006, for the second time in the twelve-year history of the Cracow Epiphany conferences, the conference was dedicated to neutrinos. This reflects the very fast development of neutrino physics in recent years. Here the comparison has been made between the 2006 Epiphany Conference on Neutrionos and Dark Matter and the 2000 Epiphany Conference on Neutrinos in Physics and Astrophysics.

PACS numbers: 14.60.Pq, 13.15.+g, 23.40.–s, 95.35.Td

1. At the time of Epiphany 2000

It was less than two years after the famous SuperKamiokande publication on the observation of the neutrino oscillations $\nu_\mu \leftrightarrow \nu_\tau$ for atmospheric neutrinos [1]. Thus the talk by Kiełczewska from the SuperKamiokande and K2K Collaborations [2] was a highlight of the Epiphany 2000 conference. The flavour transformation with maximal mixing and $0.0013\ \mathrm{eV}^2 < \Delta m^2_{23} < 0.0054\ \mathrm{eV}^2$ at 90% C.L. was found and the first three events caused by neutrinos produced at the KEK accelerator during the 1999 runs were observed in the SuperKamiokande detector.

In November 1999 the SNO experiment started to take data and the "solar puzzle" of the missing flux of ν_e solar neutrinos was not yet resolved. The second long baseline accelerator experiment MINOS at the NuMI beam

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[*] Presented at the Cracow Epiphany Conference on Neutrinos and Dark Matter, Cracow, Poland, 5–8 January 2006.

[**] Supported in part by the MNiSW grant 1P03B 041 30.

from Fermilab was under construction [3], while the CNGS experiments awaited a formal approval [4]. The reactor medium baseline experiment CHOOZ was well advanced in determining the new upper limit of the θ_{13} mixing angle [5]. The first long baseline reactor experiment KamLAND was in the construction phase. The antarctic AMANDA experiment looking for the ultra high energy neutrinos was at the initial stage of data analysis.

The observation of the neutrino oscillations revealed non-zero masses of neutrinos and opened the field to many new theoretical ideas. Some of them were presented at the 2000 Epiphany conference [6, 7].

The conference was important for the group of Polish physicists wishing to join the CNGS program. It was a good occasion to meet and to discuss the preferences. The decision was taken to join the ICARUS experiment, which seemed to offer a powerful experimental technique of Liquid Argon TPC's and due to that a variety of interesting measurements [8].

2. Between 2000 and 2006

This period of six years was very important for neutrino physics. Due to the measurements from the SuperKamiokande, K2K, SNO and KamLAND experiments the neutrino oscillations have become a well established experimental fact. Further studies of the atmospheric neutrinos in the SuperKamiokande experiment [9] and of the accelerator neutrinos in the K2K experiment [10] have confirmed that the $\nu_\mu \leftrightarrow \nu_\tau$ oscillations are the dominant mechanism for flavour changing at $L/E \approx 10^3$ km/GeV (L stays for the measurement baseline, E for the neutrino energy). The SNO experiment demonstrated that the total flux of neutrinos agrees with the prediction of the Standard Solar Model with a deficit of the ν_e flux caused by the neutrino oscillations $\nu_e \leftrightarrow \nu_{\mu,\tau}$ on the way from the Sun core to its surface [11]. The spectacular confirmation of the SNO results came from the KamLAND experiment, which observed the reduction of the flux of reactor $\bar{\nu}_e$ and the modulation of their energy spectrum due to the same oscillations [12]. The measurements were based on antineutrinos from more than 30 power stations with an average distance of 180 km between the detector at Kamioka and the most powerful reactors. Finally, both SuperKamiokande for atmospheric neutrinos [13] and KamLAND for reactor neutrinos [14] demonstrated the oscillatory behaviour of neutrino fluxes as functions of L/E.

The experimental data are now well described within the formalism of three neutrino mixing. Three mixing angles form the intriguing set with one angle being maximal within errors (θ_{23} describing the atmospheric oscillations) [13], one being large ($\theta_{12} = 36^\circ$ for solar oscillations) [14] and the third one being small ($\theta_{13} < 10^\circ$) [15]. Is there a new symmetry of nature hidden behind this peculiar triad? The most probable values of the differences of mass squares are $\Delta m^2_{23} \approx 2.5 \times 10^{-3}$ eV^{-2} for atmospheric oscillations and

$\Delta m^2_{12} \approx 8 \times 10^{-5}$ eV^{-2} for solar oscillations. Oscillation fits for the atmospheric and solar regions almost exclude the oscillations $\nu_\mu \leftrightarrow \nu_s$, where ν_s denotes sterile neutrinos. The question about the existence of sterile neutrinos remains because of the observation of the neutrino oscillations at Δm^2 about (0.1–1) eV^{-2} and at very small mixing angles in the LSND experiment [16]. Three regions of Δm^2 mean four neutrinos. The experiments at LEP showed that there are three light neutrinos coupling to Z^0, so the fourth neutrino must be sterile. The effect should be checked by the MiniBooNE experiment which has started in August 2002 [17] and should present its first oscillation results in 2006.

This period was also important for the Polish ICARUS group. There were the successful tests, with cosmics, of the first large TPC module (300 tons of Liquid Argon) in Pavia in 2001. In 2003 the experiment was accepted as CNGS2. In 2005 the collaboration was asked to change the concept of the detector upgrade (from the initial 600 tons of LAr) by replacing the cloning of the existing modules with the construction of a single large TPC.

3. At the time of Epiphany 2006

The K2K experiment was finished in 2005 while other pioneering oscillation experiments of the last decade (SuperKamiokande, SNO, KamLAND) are still active. They have been joined by the MINOS experiment at the beginning of 2005. MINOS presented its first beam results at the Fermilab in March 2006. The OPERA experiment will start data taking in 2006, while the ICARUS T600 detector should be ready at the end of 2007.

The Epiphany 2006 conference was organised during the period of discussions about the best strategy for the future of neutrino physics and, more generally, for the future of particle physics. We tried to make the Epiphany conference part of this discussion in Poland.

The neutrino oscillation physics enters the period of precise measurements, which should answer a few very important questions. Is θ_{23} really maximal? How small is θ_{13}? Is CP violated for neutrinos? Is the neutrino mass hierarchy normal or inverted? The DoubleCHOOZ reactor experiment with two detectors at two distances, should offer the quickest way to improve the measurement of θ_{13}. Answering all the above questions will require very intense neutrino sources as well as huge and rather precise detectors. It means new types of accelerator beams (superbeams, beta beams and beams from muon decays in neutrino factories) and overcoming technological problems due to rescaling the detector mass by more than one order of magnitude. In the case of searches for ultra high energy astrophysical neutrinos it means the construction of the 1 km^3 volume detectors in the antarctic ice (ICECUBE) or in the water of the Mediterranean sea.

A better planning of the future oscillation experiments also requires a careful choice of the detector distance from the neutrino source (the GLOBES program is a very helpful simulation tool for that) and much better measurements and phenomenological descriptions of the neutrino cross sections (the future MINERνA experiment is essential for that).

The most important questions nowadays concern absolute masses of neutrinos. The KATRIN experiment, based on the measurement of the end point of electron spectrum from the Tritium beta decay, should improve the current limit (2.2 eV) for the ν_e mass by an order of magnitude. Mass limit of the order of 10 meV could be achieved by future experiments searching for neutrinoless double beta decays. This, however, requires neutrinos to be Majorana particles. A credible observation of the $\beta\beta0\nu$ decay would be a discovery of similar importance as the discovery of neutrino oscillations. A much better knowledge of nuclear matrix elements is also essential.

The characteristic feature of future neutrino research is the synergy between particle physics, astrophysics, cosmology and nuclear physics. This makes this domain particularly attractive. One can also observe the applications, *e.g.* for dark matter searches, of experimental techniques developed for neutrino physics.

REFERENCES

[1] Y. Fukuda *et al., Phys. Rev. Lett.* **81**, 1562 (1998).

[2] D. Kiełczewska, *Acta Phys. Pol. B* **31**, 1181 (2000).

[3] A. Para, *Acta Phys. Pol. B* **31**, 1313 (2000).

[4] A. Rubbia, *Acta Phys. Pol. B* **31**, 1287 (2000).

[5] M. Apollonio *et al., Phys. Lett.* **B466**, 145 (1999).

[6] H. Fritzsch, Z. Xing, *Acta Phys. Pol. B* **31**, 1349 (2000).

[7] M. Czakon, J. Studnik, M. Zrałek, J. Gluza, *Acta Phys. Pol. B* **31**, 1365 (2000).

[8] S. Amerio *et al., Nucl. Instrum. Methods* **A527**, 329 (2004).

[9] Y. Ashie *et al., Phys. Rev.* **D71**, 112005 (2005).

[10] E. Aliu *et al., Phys. Rev. Lett.* **94**, 081802 (2005).

[11] R. Ahmad *et al., Phys. Rev. Lett.* **87**, 071301 (2001).

[12] K. Eguchi *et al., Phys. Rev. Lett.* **90**,21802 (2002).

[13] Y. Ashie *et al., Phys. Rev. Lett.* **93**, 101801 (2004).

[14] T. Araki *et al., Phys. Rev. Lett.* **94**, 081801 (2005).

[15] M. Apollonio *et al., Eur. Phys. J.* **C27**, 331 (2003).

[16] A. Aquilar *et al., Phys. Rev.* **D64**, 112007 (2001).

[17] I. Stancu, *Nucl. Phys. Proc. Suppl.* **155**, 164 (2006).