Summary of the 2016 Applied Antineutrino Physics Conference

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Abstract. The 2016 Applied Antineutrino Physics Conference was held at the University of Liverpool on December 1-2, 2016, hosted by Dr. Jonathan Coleman and the Liverpool Physics Department. There were forty-five attendees from Europe, Asia, South Asia and the Americas. This is the 12th such conference since the inception of the series in 2004. A recent spate of unexpected experimental and theoretical results on reactor antineutrino spectra were a highlight of the conference, since these deviations from earlier predictions may potentially affect the accuracy of reconstruction of the fissile content of the core based on spectral information. In addition, numerous new detection concepts were introduced, along with analyses of different reactor cycles, and new proposals for reactor monitoring demonstrations.

1. Introduction
Begun in 2004 at University of Hawaii, the Applied Antineutrino Physics conference series has long been a venue for discussion of advances of practical applications of antineutrino detection. The main applications are monitoring of nuclear reactors and nuclear explosions, and measuring the antineutrino signal generated by beta decays in the Earth’s crust and mantle. The last decade has seen remarkable growth in the number of groups pursuing these applications. Over the same period, important advances in fundamental physics have been made using reactor antineutrinos, such as the measurements of the final neutrino mixing angle $\theta_{1-3}$ by the RENO, Double Chooz, and Daya Bay experiments. This diverse activity has resulted in technology developments and experimental insights that advance both fundamental and applied antineutrino physics. Researchers are studying how to monitor new reactor designs, how to reduce or eliminate the overburden requirements for close-in monitoring of reactor corse, how to remotely monitor reactors at ever-increasing distances from the core, and how to pursue Earth tomography by measuring increasing numbers of geo-antineutrinos with larger detectors. In the past year alone, two new initiatives have arisen to perform demonstrations of antineutrino-based reactor monitoring technologies for the first time, in Turkey and in India. While space does not permit a full account, we summarize the conference topical areas and a few highlights.

1.1. New near-field technology advances
The near-field refers to standoff distances shorter than about 1 kilometer from a reactor core. Due to heightened interest in a possible sterile neutrino flavor with a few meter oscillation length, and an interest in improving reactor monitoring applications, a spate of near-field detectors as been developed in the last few years. These detectors attempt to achieve conflicting goals:
increasing spectral precision while reducing the amount of overburden above the detector, and, for the sterile neutrino search the distance from the core to the detector. The energy resolution is required to see the sterile neutrinos oscillatory effect on the detected antineutrino spectrum. The reduction in overburden and is necessary to facilitate deployment, and the reduction in distance to the reactor is done in an attempt to maximize the hoped-for oscillatory effect on rate-based measurements. A significant number of attempts worldwide at improving these detector properties are underway. Inspection of these reveals that segmentation is a common strategy, which has begun to exhibit some initial success in deployments such as PANDA. It is interesting that advances focused on improving practical applications, such as above-ground detection, also benefit the fundamental physics experiments by improving background rejection, while the increased spectral precision needed for the sterile neutrino search can also increase the accuracy of reconstruction of the core fissile content - a key nonproliferation application. Further details and references may be found in the conference presentations and proceedings.

1.2. Recently completed near-field monitoring demonstrations
Numerous dedicated demonstrations of reactor monitoring antineutrino detectors have been put forth over the years, beginning with the pioneering experiments at the Rovno reactor in the Ukraine[1]. Since that time, the U.S., Japan, France, South Korea, England and Italy have all fielded experiments that have explored various approaches to improving deployability and precision. At AAP 2016, results were presented from the VIDARR experiment in England (an effort spearheaded by our Liverpool hosts), by the PANDA experiment in Japan, by the French NUCIFER effort and the recent South Korean NEOS experiment. NEOS presented a new high-statistics measurement of the spectral excess, confirming earlier results.

1.3. Measurements and questions about antineutrino spectra
One important byproduct of the $\theta_{1-3}$ measurements is the measurement of antineutrino spectra at reactors with unprecedented precision. In particular, each of the three $\theta_{1-3}$ experiments have measured a previously unresolved, and still unexplained, excess of antineutrinos in a small energy window, when compared to the reigning theoretical model of reactor antineutrino spectra. Double Chooz, Daya Bay, and RENO showed their most recent, high-statistics antineutrino spectra, among which there is general agreement about the size (2.5 MeV) and spectral location (5-7.5 MeV) of the excess. The RENO experiment presented results that hinted at a correlation of the excess with U235 fraction and total reactor power output. This led into a lively discussion of the theoretical origins of these spectra. While no unambiguous explanation has yet emerged, uncertainties in the underlying beta-spectra that are used for the prediction, fast fission of U-238, and other explanations have been proffered. Patrick Huber’s and the other theoretical talks provided a good overview of the proposed explanations and possible experiments that could help illuminate the answer.

1.4. Far-field monitoring concepts
In nonproliferation contexts, far-field reactor monitoring refers to efforts at monitoring or discovering reactor operations at distances ranging from 1 kilometer, out to an ultimate limit based on flux arguments alone (and anticipated Megaton sized detectors) of roughly 1000 kilometers. The KamLAND liquid scintillator has effectively demonstrated this capability at some 400 kilometers standoff, with sensitivity to reactor antineutrinos arising from (South) Korean power reactors (most conclusively observed during the post-Fukushima shutdown)[2]. A review of progress was presented by the WATCHMAN collaboration, a group formed to pursue a deployment of kiloton-scale gadolinium-doped water Cherenkov detector at some 25 kilometers from a reactor core, to demonstrate sensitivity with what is anticipated to be a more readily scalable medium compared to scintillator. WATCHMAN differs from the recently approved
gadolinium addition to the much larger SuperKamiokande detector, inasmuch as it will aim to track the monthly operations of an individual reactor, rather than integrate the signal of many reactors. Talks described progress on the detector design and simulations, and a new web-based tool was presented for estimating reactor antineutrino spectra at any point on Earth, based on all known reactor positions and up-to-date reported power and operational status derived from International Atomic Energy Agency (IAEA) databases[3].

1.5. Addressing new or different reactor types
Most monitoring demonstrations to date have been made against the most common reactor type worldwide; the Pressurized Water Reactor (PWR). As new reactor types are designed, and as deployments are pursued for a wider set of existing reactor types, both antineutrino detectors, reactor simulations, and analysis methods must adapt. Antineutrino-based monitoring will be confronted by different power output, continuous refueling strategies, and substantial variations in fuel type and the evolution of fuel burnup over the course of the reactor cycle. A set of talks focused on how to understand and accommodate these changes by simulating the evolutions of current and future reactor types, including the British Magnox design, fast reactors, and thorium breeder reactors which utilize $^{233}\text{U}$ as a fission source.

1.6. New proposals
Two new and interesting near-field monitoring proposals were advanced. A team at the Bhabha Atomic Research Centre in Mumbai, India, proposed a first ever deployment at a research reactor at the site, while a group in Turkey is working on a design that can be deployed against planned Turkish reactor complexes. These efforts are welcome addition to the global program and reflect growing interest in the topic worldwide. Indeed, the Indian group will host the 2017 Applied Antineutrino Physics Conference.

References
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