PROCEEDINGS OF SCIENCE

Neutrino Physics at ADS Facilities

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Accelerator Driven System (ADS) subcritical reactors are being developed around the world. The main goals of this kind of facility are to produce energy and, at the same time, to dispose of nuclear waste, which will be used to power nuclear reactors. Since, by itself, used nuclear fuel is not able to sustain a chain reaction, the additional neutrons needed will be supplied by a high-intensity accelerator, where a proton beam will be hitting a spallation target. This accelerator will produce, as a by-product, a large quantity of neutrinos: I will discuss the opportunities offered for the study of neutrino physics. In China the C-ADS program is centered on the design and construction of such a facility: a prototype of the accelerator is already operative, during the course of the project the accelerator energy will be gradually increased up to 1.5 GeV. In the first phases of the project, when the beam energy is low, $\bar{\nu}_e$ can be produced via Isotope Decay At Rest (IsoDAR): they can be detected with liquid scintillators and used to provide competitive bounds on sterile neutrinos in the disappearance channel. In the next phases, when the beam energy is higher, $\bar{\nu}_\mu$ will be produced via muon Decay At Rest (μDAR): in this phase it will be possible to measure the CP-violating phase δ_{CP} and to look for experimental signs of the presence of sterile neutrinos in the appearance channel, testing the LSND and MiniBooNE anomalies.

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1. Introduction

In the last years Decay At Rest (DAR) experiments attracted attention from the neutrino community. The DAEδALUS collaboration [1] suggested that the CP violating phase δ_{CP} can be measured precisely using neutrinos from muon Decay At Rest (μDAR). It is also possible to use Isotope Decay At Rest (IsoDAR) to create $\bar{\nu}_e$, that can be detected via Inverse Beta Decay (IBD) using liquid scintillators, looking for experimental signs of the presence of sterile neutrinos in the disappearance channel; this was first discussed in 1965 [2], recently proposals among these line were presented using KamLAND or JUNO as detectors [3].

All these experiments can be performed at the ADS facilities [4, 5]. The main goals of Accelerator Driven System (ADS) is to recycle used nuclear fuel and, at the same time, to produce energy. Indeed, nuclear waste cannot sustain, by itself, a chain reaction, however in ADS reactors the additional neutrons needed are provided by a high-intensity particle accelerator, where a particle beam collides on spallation target. In China, C-ADS is a project centered on the development and the construction of such a facility: a 26 MeV prototype of the accelerator is already operative in Lanzhou; during the project its energy will be gradually increased up to 1.5 GeV: in Tab 1 it is reported the time schedule for the project.

ADS time-schedule			
R&D: 2017	CIADS: 2022	Demo Facility: 2030	Industrial Facility: 203x
12 mA, 26 MeV	10 mA, 250-500 MeV	10 mA 1GeV	15 mA 1.5 GeV

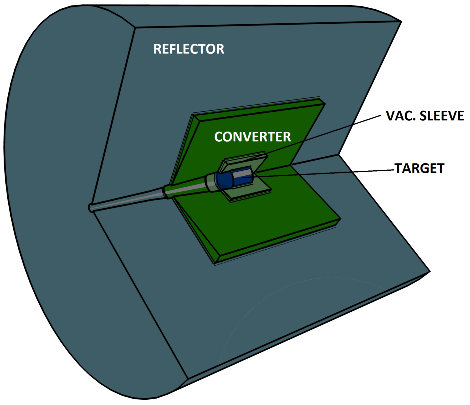
Table 1: Time schedule for the C-ADS project

Even from the first phases of the project, it will be possible to produce neutrinos via IsoDAR by adding a ^{7}Li-based converter around the target: the spallation neutrons will be absorbed in the converter, creating ^{8}Li, its β-decay will then produce $\bar{\nu}_e$. When the energy is higher ($>$ 400 MeV) $\bar{\nu}_\mu$ can be produced via μDAR without adding anything to the target station; it is worth mentioning that since only $\bar{\nu}_e$ can be detected via IBD, in IsoDAR experiments (where $\bar{\nu}_e$ are produced) we are working in the disappearance channel, while in μDAR experiments in the disappearance channel.

2. IsoDAR

In IsoDAR experiments neutrinos are generated exploiting the spallation neutrons produced inside the target: they will be absorbed in a ^{7}Li converter, creating ^{8}Li, that will decay emitting $\bar{\nu}_e$. These neutrinos can be detected via IBD using liquid scintillators, searching for sterile neutrinos.

In [5] we studied the optimization of the target station for an IsoDAR experiment: in Fig. 1 (left panel) it is reported the design of the target station we considered. First we studied the neutron yield from the target, considering different beam energies. While at low energies beryllium target are preferred, when the beam energy is higher than 50 MeV the best performances are achieved using heavy metal targets, such as tungsten, lead or bismuth. However these metals have a very high neutron absorption cross section: if the target is surrounded by a converter or a heavy water sleeve, the neutrons can bounce back and be absorbed inside the target; this effect is particularly relevant for tungsten, where the neutron flux can be reduced up to 60%. It is possible to reduce significantly the neutron loss adding a gap (vacuum sleeve) between the target and the converter, as can be seen from Fig. 1 (right panel), in the case of the tungsten the neutron yield can be increased up to 80% of the initial value using a 20 cm gap.



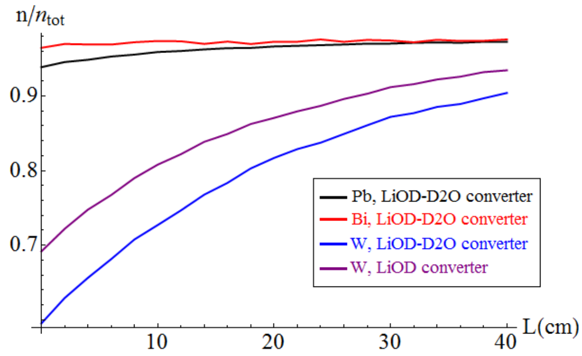


Figure 1: Left Panel: design of the target station. Right panel: fraction of neutrons that are not lost due to the bounce-back, as a function of the dimension of the vacuum sleeve.

We also tested different materials for the converter, comparing their performances. In order to maximize the ^{8}Li yield, the spallation neutrons must be slowed down to thermal energies; in the first designs proposed, a heavy water sleeve, placed between the target and the converter, was acting as a moderator. However we verified that this design is not particularly efficient, because either most of the neutrons will not be thermalized or a significant fraction of them will be absorbed inside the converter. The best performances can be obtained using lithium deuteroxide (either anhydrate, LiOD, or monohydrate LiOD-D_2O), since here the moderator is mixed with the converter. We considered also a solution of LiOD in heavy water and FLiBe, another material which was suggested as converter for IsoDAR@KamLAND [6]. We studied the converter efficiency as a function of the neutron energy and the ^{7}Li mass: as can be seen from Fig 2, when the neutron energy is low lithium deuteroxide offers the best performance, while when it is higher FLiBe has an higher converter efficiency, due to the neutron multiplication effect: indeed, at these energies, a neutron can knock out one or more neutrons from a D or Be atom; this process is more efficient with a FLiBe converter, however if the spallation neutrons are produced using a proton beam, the number of high-energy neutrons is so small that, overall, the optimal converter is LiOD, as can be seen from Fig. 3 (however, this picture could change if, for example, a deuteron beam is considered, since in that case the neutron energy spectrum would be quite different).

3. μDAR

When the beam energy is higher than 400 MeV, neutrinos can be produced via μDAR, via the decay chain

$$\pi^+ \to \mu^+ + \nu_\mu \tag{3.1}$$

$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu \tag{3.2}$$

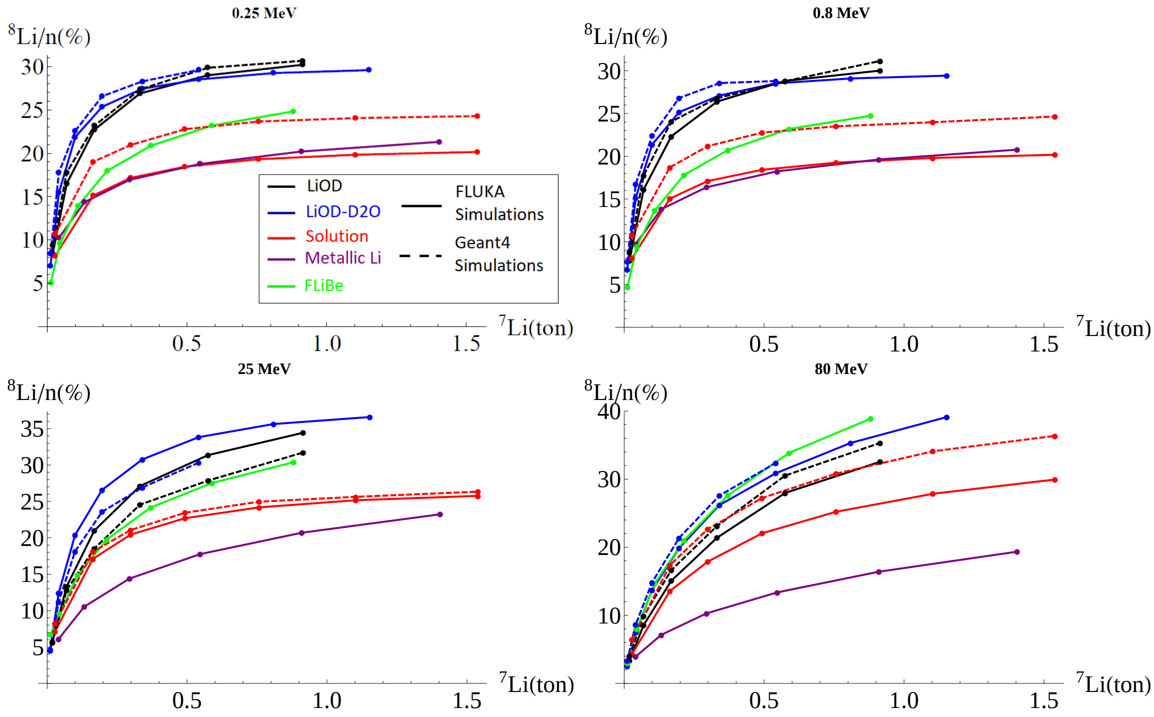


Figure 2: ^{8}Li/n for different neutron energies as a function of the amount of ^{7}Li used

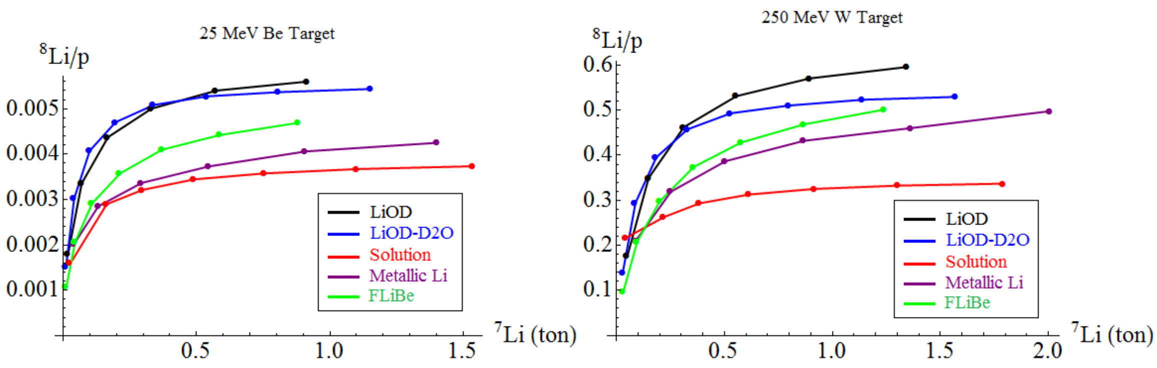


Figure 3: Complete simulations of the ^{8}Li yield for 25 MeV and 250 MeV proton beams

While propagating, $\bar{\nu}_\mu$ will oscillates into $\bar{\nu}_e$, that can be detected via IBD using liquid scintillators. Since only electron antineutrinos can be detected in this way, the other two neutrinos produced in the decay chain do not provide any source of background. Studying the oscillation probability at different baselines it is possible to measure with good precision the CP violating phase δ_{CP}; the first proposal among these line was DAEδALUS [1]: $\bar{\nu}_\mu$ will be produced by three cyclotron complexes and detected using one large liquid scintillator. However, since at these energies it is not possible to reconstruct the direction of the incoming neutrinos, the cyclotrons cannot work at the same time and they will have a duty factor of around 20%. The main difference in our proposal (μ Decay At Rest with Two Scintillators, μDARTS) [4, 7, 8] is that we plan to use only one accelerator for the neutrino production, for example the one that will be build in the course if the C-ADS project, and two large liquid scintillators at different baselines; in this way the duty factor can be increased up to 100%. An additional small detector, near the target station, can be used to constrain the total neutrino flux and, at the same time, to test the LSND anomaly. Some of the advantages of μDAR are that both the emission spectrum and the cross section are known with very good precision, moreover there is no degeneracy between δ_{CP} and $\pi - \delta_{CP}$; finally, there will be a good synergy with long baseline neutrino experiments, like T2K and NOνA; exploiting this synergy it is possible to achieve a reasonable precision (15-35 degrees) even with only one detector. In Fig. 4 it is reported the expected precision that can be achieved using two detectors (see [4] for more details).

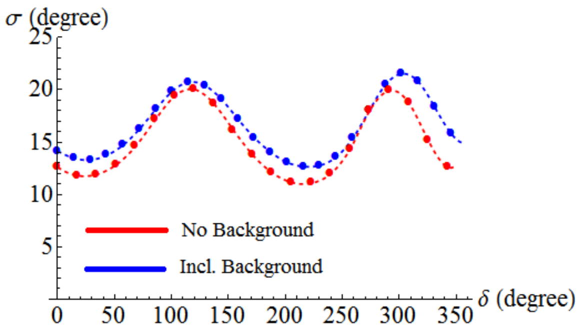


Figure 4: The 1σ precision with which δ_{CP} can be measured, as a function of the tue value of δ_{CP}

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