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Reactor antineutrino detection in Double Chooz experiment: Techniques for background reduction

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Abstract

A crucial task for the Double Chooz reactor antineutrino experiment is the thorough study of the different backgrounds in the detector. Newly developed background reduction techniques minimize the impact of the backgrounds on our sensitivity. Moreover, only a precision and accuracy measurement of the residual background would allow to measure the mixing angle θ_{13} with high precision.

Neutrino coincidence signals are imitated by signals produced in several others physics processes: accidental coincidences of single events (accidental background), as well as correlated events induced by cosmic muons, including stopping muons, fast neutrons and spallation isotopes Li^9/He^8. The Double Chooz collaboration has developed several techniques to reduce these backgrounds without introducing significant signal inefficiency reduction, and has managed to reject 86% of accidental background, more than 50% of Li^9 and He^8 and more than 80% of fast neutrons and stopping muons. Residual backgrounds are quantified with precision: the estimations for their final rates are $0.97^{+0.41}_{-0.16}$ Li^9/He^8 per day, 0.60 ± 0.05 of fast neutrons and stopping muons per day and 0.070 ± 0.005 the accidental background per day. These estimations are used as input for the fit to the measured positron spectrum used to determine θ_{13}. The fit outputs are compatible with the estimated values for all backgrounds.

Keywords: background neutrino oscillation θ_{13} reactor

1. Introduction

Double Chooz is a reactor antineutrino experiment that aims to measure the neutrino mixing angle θ_{13}. Antineutrinos produced in the Chooz nuclear power plant are measured with two detectors. The far detector is located approximately 1050m from the two reactor cores and measures the oscillated neutrino spectrum. The near detector is located approximately 400m from the reactors where neutrino oscillation is mostly negligible. The far detector has been taking data from April 2011 while the near detector will start on November 2014.

The detectors (Figure 1) are composed of four coaxial cylinders[1]. The innermost one is the target where neutrino reactions are observed. The second innermost one is the gamma-catcher, which is used to detect the gamma rays escaping the target. The buffer used to reduce the environment radiation is the next one. There

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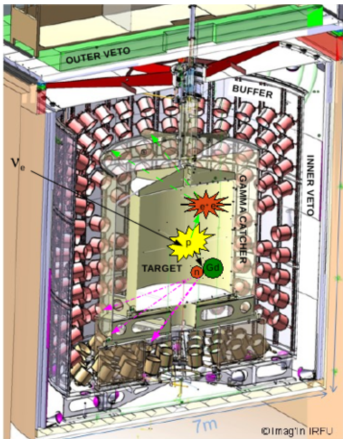

Figure 1: Scheme of the Double Chooz detector

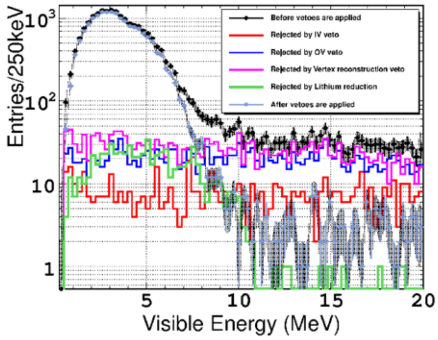

Figure 2: Positron spectra of several distributions. The black spectrum is from all IBD candidates, the grey one is the IBD candidates after vetos and the spectra produced by each veto techniques, except the correlation distance cut, applied are indicated too.

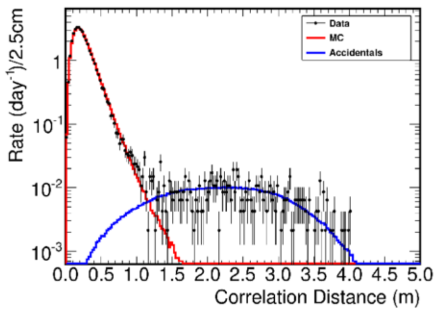

Figure 3: ΔR distributions for data in black, MonteCarlo in red and accidentals in blue.

are 390 photomultipliers (PMTs) in the buffer wall. The outermost one is the inner veto (IV) used as muon-induced background veto. The outer veto system (OV), which is used to identify muons, cover the detector.

Antineutrinos are detected by the inverse beta decay (IBD) that produces a positron and a neutron. The positron is soon annihilated producing a prompt signal in the detector. The neutron is captured by a nucleus of Gd emitting gammas around 30μs after the positron signal. The temporal coincidence between the signals is the reaction signature. Several backgrounds mimic the IBD signature. Long-life spallation isotopes Li^9/He^8 are β-n emitters. Fast neutrons (FN) produce a proton recoil and are later captured. Stopping muons (SM) enter through the veto hole and decay producing a Michel electron which can be mistaken with a neutron capture while the short muon track can be misidentified as a positron. Accidental background are random coincidences between two single events.

Another kind of background (bg) that can be misidentified as neutrino signal is the so-called light-noise: unexpected signals due to sporadic spontaneous flashes from the bases of several PMTs. Most of these signals are rejected from the neutrino sample using their characteristic time pattern: a strong signal from the emitter PMT followed by signals from the neighbourhood ones. However, a small fraction of these events remains.

2. Veto Techniques

The veto techniques developed in Double Chooz reject a significant fraction of the backgrounds while keeping signal inefficiency insignificantly low. Five different techniques are used (Figure 2 and Figure 3):

β-n isotopes veto: A likelihood function based on the muon track-positron distance and the neutron multiplicity is used to reduce the lithium and helium bg. The inefficiency of this veto is 0.54% and the lithium and helium reduction is higher than 50%.

Vertex reconstruction veto: A likelihood fit is used to perform the spatial reconstruction of each event. The value of this likelihood function is used to reject SMs and the remaining light-noise. This cut is energy dependent and produces an inefficiency lower than 0.1%.

IV veto: Veto of positron events that are triggered simultaneously the IV and the signal to reject FNs and SMs. Cuts on the time correlation and on spatial correlation between IV and the signal are applied to get an inefficiency lower than 0.1%

OV veto: Veto of the positron events that are coincident with an OV trigger. This veto removes SMs. The inefficiency produced by this cut is lower than 0.1%. The vertex reconstruction veto, IV veto and OV veto reject more than 80% of all SMs and FNs.

Correlation distance cut: Events with a large distance (>1m) between the positron-like and neutron-like signals are rejected. The inefficiency of this cut is 0.3%. The accidental bg is reduced by 86%.

3. Residual backgrounds

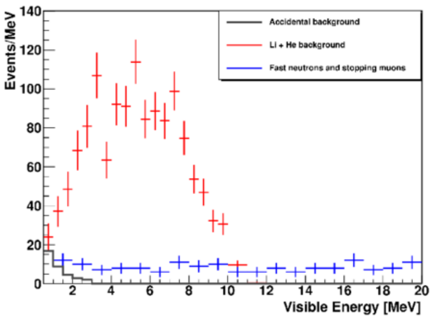

Figure 4: Background specta. The lithium-9 and helium-8 spectrum is in red, the FN and SM one is in blue and the accidental one in black.

Despite the significant background reduction due to the veto techniques described above, residual backgrounds have to be quantified and their spectra obtained (Figure 4)[3].

Accidental background: The estimation of the accidental bg is obtained by applying the neutrino selection cuts, but using a shifted coincidence window (off-time) with 1s shift to avoid all correlated events. Statistics are enhanced by using 2000 windows, each one shifted 800μs from the previous one. The estimated rate is 0.070 ± 0.005 per day.

Li^9/He^8: the rate is estimated from a fit to the Δt distribution of IBD candidates to the previous muons. The prompt spectrum is obtained with a likelihood analysis and its background is subtracted using the off-time muon selection. The estimated rate is: $0.97^{+0.41}_{-0.16}$ per day.

FN and SM: This background has a low fraction of SMs. The spectrum is evaluated based on an IV-tagged sample, and its shape is found to be consistent with a flat distribution. The rate is measured by extrapolating the spectral shape to lower (IBD) positron energy from a high one, where there aren't either neutrinos or β-n isotopes. The estimated rate is: 0.60 ± 0.05 per day.

Besides the above methods, Double Chooz has a way to perform a direct background measurement. Among reactor antineutrino experiments , only Double Chooz has periods of data taking without signal to perform this direct measurement[2]. Up to now, 7.24 days of background data were acquired and 7 background events were found. The measured background is 0.97 ± 0.37 and the total estimated background is $1.58^{+0.42}_{-0.19}$. Both results are in agreement within 1.6σ. The measured background is lower than the estimated one, therefore, an additional unknown background is disfavoured.

4. Contribution to the oscillation fit

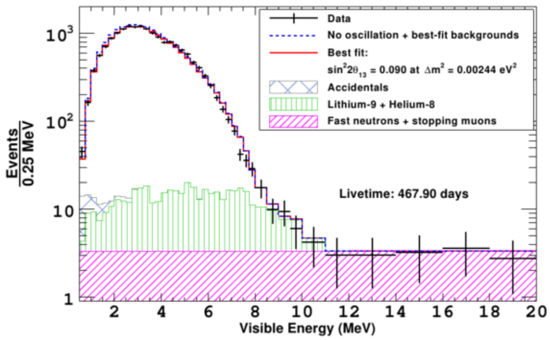

Figure 5: Positron spectrum fit. The experimental data are in black, the best fit in red, the lithium-9 and helium-8 in the green region, the FNs and SMs in the purple region and the accidentals in the light blue region.

The main oscillation analysis in Double Chooz compares observed positron energy spectrum to predicted one (Figure 5). The leverage of this fit comes from distinct positron/positron-like spectrum of signal and backgrounds. The mixing angle θ_{13} isn't the only parameter in the fit, the Li^9/He^8 rate as well as the FN/SM rate are also used as fit parameters. The accidental bg rate isn't used in the fit since the off-time analysis allows for an accurate enough estimation. Uncertainties on dominant background rates constrained the fit. The Li^9 and He^8 rate obtained by the fit is $0.80^{+0.15}_{-0.13}$ per day and the FN and SM rate is 0.56 ± 0.04 per day[3].

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