Determination of the detection systematics in the Double Chooz experiment
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THE DOUBLE CHOOU EXPERIMENT
- Reactor Dβ disappearance is directly related to Dβ.
- Neutrino interactions detected through inverse beta decay, Dβ in Angström.
- Coincidence signal in DChoo leaved liquid scintillator n capture time -300 ps.
- Delayed signal n capture on Ge D1-1500 ns.

DETECTION SYSTEMATICS IN DOUBLE CHOOU
- The inverse beta decay (IBD) events constitute the sought signal.
- The detection rates are estimated so that the efficiency of IBD detection is high while the background contamination remains at a low level.

VEGETS and background neutron cuts are added to this nominal selection.
As a consequence, the contributions to the 0.63% detection systematics consist of the MC uncertainties:
- Monte Carlo normalization factors
- The MC spectrum analysis of the predicted Dβ-1 due to recombination.
  - A Monte Carlo (MC)-MC normalization factor in combination with an uncertainty ensures the detection dependence accuracy of the MC set data.
- The normalization is defined as the ratio of data of MC to MC detection efficiency.
- The predicted detection efficiency contains three contributions:
  - a selection cut dependent efficiency $\epsilon_{sel}$
  - an inherent efficiency $\epsilon_{intrinsic}$
  - a neutrino decay neutron to be captured on Cd
  - A neutron mobility related detection uncertainty.
- The combined total MC normalization factor is then defined as the product of the selection dependent and the inherent Ge capture fraction MC normalization:

NEUTRON SOURCES
- Inverse beta decay (IBD) neutrons
  - Antineutrinos are regarded as a neutron source through IBD.
  - Homogeneous distribution in the detector.
  - Standard neutrino physical oscillation signal.
  - Selection similar to the one for oscillation analysis (inlets of the reactor core).
  - Only non-neutrino decay events are background.
- Veto cuts: energy > 1 MeV, timelag < 500 ns,
- Absolute background rejection is estimated using an off line selection.

CF delayed fission neutrons
- Point-like fission source with $\sim 13$ neutrons per second.
- Deployed at positions along the target symmetry axis.
- Calibration campaigns in the middle of the detector, using a proton beam to achieve high statistics.
- Fission event signature.
  - Prompt neutron cut (30-500 keV).
  - Delayed neutron capture (30-350 keV) with $\delta T$ ~ 2 ns and maximum: $\delta T$ ~ 4 ns.
  - A background-based delayed selection.
- Correlated background reduction by applying a delayed multiplicity of n3.

MUC spallation neutrons
- Event selection in the time range 50 < $\Delta t$ < 150 ps after a muon with $\geq 30$ MeV.
- Background reduction.
  - Muon event selection ($\Delta t$ > 75 ns to next muon).
  - Acquired background selection by off line event selection.
- Fission cut ($E > 0.5$ MeV).

VOLUME-WIDE DETECTION SYSTEMATIC UNCERTAINTY
- The volume-wide MC normalization factor ensures that the cut dependent detection efficiency in the MC reproduces the one in data.
- The normalization factor is determined as the ratio of data and MC predictions only in the efficiency matrix.
- The efficiencies are computed for the whole target volume to include the reduction in their values when approaching the borders.
- The efficiency consists of:
  - Interaction energy passing the delayed energy, correlation time and correlation distance cuts defined for the oscillation analysis.
  - Chromatic events passing the cuts on the same variable.
- All the cuts are evaluated similarly in an inclusive way to account for any possible correlation between them.

IBD neutron volume-wise uncertainty estimation
- The $Dβ$-1 selection is very clean on background.
- The cut dependent efficiency is therefore estimated with wide cuts in the denominator.

Cf fission neutron volume-wise uncertainty estimation
- The systematic uncertainty mainly contributes:
  - Selection cut dependent efficiency $\epsilon_{sel}$
  - Variation of the cut of the detection vertex.
  - Variation of the $\epsilon_{intrinsic}$ due to energy and delayed multiplicity cut.
  - The evaluation of the cut dependent volume-wise MC normalization:

CASCADE-FRACTION SYSTEMATIC UNCERTAINTY
- The $
u$-CC interaction is defined as the ratio of calculated to data.
- It is estimated via the ratio of events counted in the $\nu$-CC and the $\nu$-CC energy spectrum:

MUC spallation neutron-Gd fraction crosscheck
- High neutron energetic for $\nu$ is $\sim 325$ MeV.
- 1.2% systematic uncertainty.
- Compute a $\epsilon_{MC}$ comparison of the spallation neutron-Gd fraction to the antineutrino MC$\nu$ fraction.
- The results of $\epsilon_{MC}$ and $\epsilon_{exp}$ are in agreement within $\sim 0.6%$.

SUMMARY
- The summary of all delayed detection MC normalization factors and their uncertainties is given by the table on the next page.
- The cut dependent and volume-wise normalized factor was measured by two independent analyses. The $\nu$-CC fraction and the IBD CF neutron fraction is in agreement with 1.
- The cross-measurements using IBD and CF result in a good agreement to data as MC expectation.
- The cut dependent normalization uncertainty was estimated using the combined IBD and CF result.
- The Gd fraction normalization was found to be the dominant contribution to the total MC normalization central value and uncertainty of the delayed detection.
- Cross-check measurements using IBD and spallation neutrons could confirm the Gd fraction normalization result.
- The neutron migration systematic uncertainty has been evaluated by MC, MC comparison.
- Since the Gfission as well as the neutron migration MC normalization and uncertainty are created by a MC simulation mismatch, these contributions will be strongly reduced in a two detector measurement of $\epsilon_{MC}$.

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