V 1.00
Herve de Kerret
23th of October 2007

APC scientific council

Double Chooz

1 Overview

1.1 Physics case and experimental context

A reactor antineutrino disappearance experiment with two or more detectors is one of the most cost-effective ways to extend our reach in sensitivity for the neutrino mixing angle θ13 without ambiguities from CP violation and matter effects. The experiment will use the existing neutrino physics facility at the Chooz-B nuclear power station, and is planned to reach a sensitivity to sin2 2θ13 down to 0.03 over a three year run from 2010, with two detectors running simultaneously. This will cover roughly 85% of the currently allowed region. The costs and time to first results for this critical parameter can be minimized since our project takes advantage of an existing laboratory.

The data taking will be divided in two phases: a first one with the Far detector only, and a second phase with both Near and Far detectors running simultaneously. For delta m2 ≈ 2.5 × 10−3eV2, Double Chooz will be sensitive to 0.05 after 1.5 year of data taking in phase, and 0.03 or better after 3 years of operation with two detectors. If θ13 is in this range, long-baseline off-axis neutrino experiments will be able to measure matter effects and search for CP Violation.

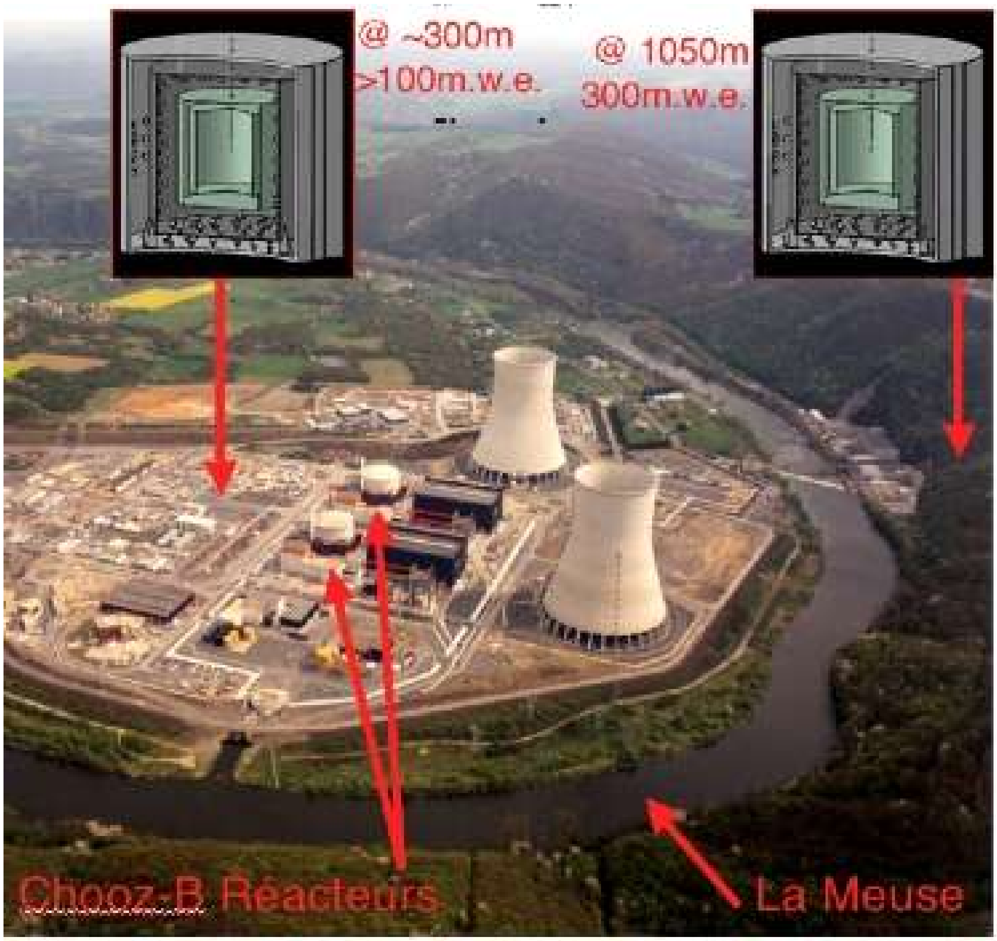

Figure 1: The experimental site of the Double Chooz experiment.

1.2 Experimental site: the Chooz nuclear reactors

The antineutrinos used in the experiment are those produced by the pair of reactors located at the Chooz-B nuclear power station operated by the French company Electricite de France (EdF) in partnership with the Belgian utilities Electrabel. They are located in the Ardennes region, in the northeast of France, very close to the Belgian border, in a meander of the Meuse river. At the Chooz site, there are two nuclear reactors. Both are of the most recent "N4" type (4 steam generators), with a thermal power of 4.27 GWth each. These are pressurized water reactors (PWR) and are fed with UOx type fuel. They are the most powerful type in operation in the world. One unusual characteristic of the N4 reactors is their ability to vary their output from 30% to 95% of full power in less than 30 minutes, using the so-called gray control rods in the reactor core. These rods are referred to as gray because they absorb fewer free neutrons than conventional ("black") rods. One advantage is greater thermal homogeneity. A total of 205 fuel assemblies are contained within each reactor core. The entire reactor vessel is a cylinder 4.27 m tall and 3.47 m diameter. The first reactor started full-power operation in May 1997, and the second one in September of the same year. The average thermal power, taking shutdowns into account, is 7.4 GWth (global load factor is roughly 80%).

The Double Chooz experiment will employ two almost identical detectors of medium size, each containing 10.3 cubic meters of liquid scintillator target doped with 0.1% of gadolinium. The neutrino laboratory of the first CHOOZ experiment,1 located 1.05 km from the two cores of the Chooz nuclear plant, will be used again. We label this site the far detector site or Double Chooz- is shielded by about 300 m.w.e. of 2.8 g/cm3 rock. The first neutrino registered is expected at Double Chooz-far in March- April 2009.

In order to cancel the systematic errors originating from the nuclear reactors (lack of knowledge of the νe flux and spectrum), as well as to reduce the set of systematic errors related to the detector and to the event selection procedure, a second detector will be installed close to the nuclear cores. This is called the near site or Double Chooz-near. An initial study is been completed by the French electric power company Edf to determine the best combination of location and overburden as well as the preliminary cost of the needed civil construction. This study suggested the feasibility of creating a new underground laboratory at 400 m distance from the nuclear reactor cores. The plan is to start taking data at the Double Chooz-near laboratory in 2010.

1.3 The new Double Chooz detector concept

The Double Chooz detector will consist of a target cylinder of 115 cm radius and 246 cm height, providing a volume of 10.3 m3. The near and far detectors will be identical inside the PMT support structure. This will allow a relative normalization systematic error of 0.6%. However, due to the different overburdens (120 vs. 300 m.w.e.), the outer shielding will not be identical, since the cosmic ray background differs by a factor 4 between Double Chooz-near and -far. The overburden of the near detector has been chosen in order to keep a high true-neutrino-signal to background ratio.

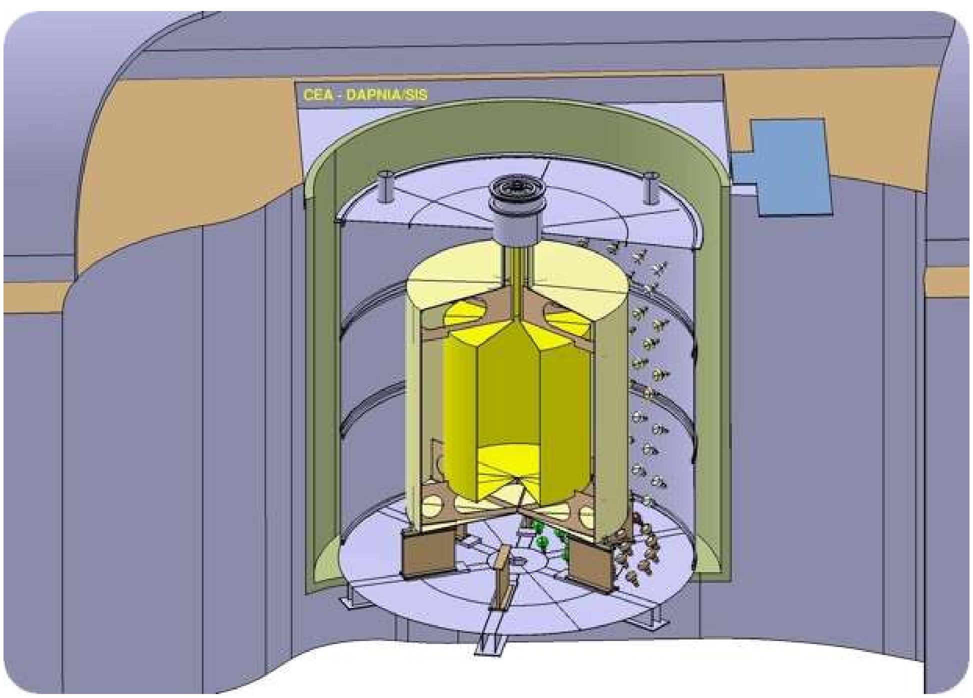

Figure 2: Schematic view of one of the Double Chooz detectors.

Target and γ-catcher

Target and γ-catcher vessels are built from cast acrylic plastic material, transparent to UV and visible photons with wavelengths above 400 nm. The vessels are designed to contain the target and γ-catcher aromatic liquids with long-term hermeticity (no leak for 10 years) and stability. The strongest constraint is the chemical compatibility between the vessel and the scintillating liquids of the target and γ-catcher (chemical stability for a period of at least 5 years).
This compatibility has been tested experimentally in the last 4 years. The γ-catcher vessel must also be chemically compatible with the mineral oil of the buffer region, which is however known to be a weaker constraint. The target vessel is a cylinder of 246 cm height, 230 cm diameter, and 8 mm thickness. It contains a target volume of 10.3 m3. The γ-catcher is a 55-cm-thick buffer of non loaded liquid scintillator (22.6 m3) with the same light yield as the νe target. This scintillating buffer around the target is necessary for efficiently measuring the gammas from neutron capture on Gd and from positron annihilation, and to reject the background from fast neutrons.

Non scintillating buffer

A 105-cm-thick region of non scintillating liquid (114.2 m3) serves to decrease the level of accidental background (mainly the contribution from photomultiplier-tube radioactivity). This region is crucial to keeping the singles rate below 10 Hz in the sensitive region (target+γ-catcher).

Buffer vessel and PMT support structure

This vessel is made of 3-mm-thick stainless steel sheets and stiffeners. A total of 400 phototubes (10 inches) are mounted from the interior surface of the buffer vessel.

Inner veto system

A 50-cm-thick active veto region filled with liquid scintillator for both the near and far detectors. This volume is seen by 80 PMTs.

Outer veto

An outer veto made with scintillating plastic strip will be added over the detector and surrounding rocks, to improve the veto efficiency, to allow a good muon tracking, and to tag near miss muons.

The main uncertainties in the CHOOZ experiment came from the uncertainty in the knowledge of the antineutrino flux coming from the reactor. This systematic error is made to vanish by the addition of a near detector.

The non scintillating buffer will reduce the singles rates in each detector by two orders of magnitude with respect to those in CHOOZ, which had no such buffer. This will allow to reduce the number of analysis cuts, which minimize the systematic errors.

The positron detection threshold will be about 500–700 keV, well below the 1.022 MeV physical threshold of the inverse beta decay reaction. This cut in the rising positron spectrum was an important systematic error in the first CHOOZ experiment.

A summary of key detector parameters is given in Table 1. At the Chooz site, the laboratory previously set by the CHOOZ experiment is vacant and available for use as a far site with minimal reparation. The ventilation and electrical distribution systems have been upgraded a. The relationship between the members of the Chooz collaboration and the reactor company, Electricite de France (EdF), has been very cooperative and cordial. For the Double Chooz experiment, EdF has again shown the same level of close operation and has signed a letter outlining that cooperation.

Table 1: Summary of the some parameters of the proposed Double Chooz experiment.

Thermal power	4.25 GW	each of 2 cores
Electric power	1.5 GWe	each of 2 cores
νe target volume	10.3 m3	Gd loaded LS (0.1%)
γ-catcher thickness	55 cm	Gd-free LS
Buffer thickness	105 cm	non scintillating oil
Total liquid volume	~237 m3	
Number of phototubes per detector	400	8" 13% coverage
Far detector distance	1050 m	averaged
Near detector distance	280 m	averaged
Far detector overburden	300 m.w.e.	hill topology
Near detector overburden	120 m.w.e.	new tunnel
νe far detector events (5 yr)	75,000	with a 60% efficiency
νe near detector events (5 yr)	500,000	with a 55% efficiency
Relative normalization error	0.6%	
Effective bin-to-bin error	1%	background systematics
Running time with far detector only	1–1.5 year	
Running time with far+near detector	3 years	
sin2(2θ13) goal in 3 years with 2 detectors	0.03 (90% CL)	

1.4 Time scale

Construction of the far detector will be completed by the beginning of 2009, and that of the near detector in 2010 (with some uncertainty concerning the schedule of the near laboratory construction). Detector operation will be for 4.5 years, starting with just the far detector, followed by three years of operation with both detectors (2009–2011). Important first results are possible with just the far detector because the luminosity (12 GW-ton-years) of the original CHOOZ experiment will be matched in just a few months. Using both detectors, Double Chooz will reach a sin2 (2θ13) sensitivity of 0.06 in 2010 and 0.03 in 2012. Whether running any longer at that time makes sense will depend on an evaluation of systematic errors and backgrounds achieved, as well as the world situation regarding θ13.

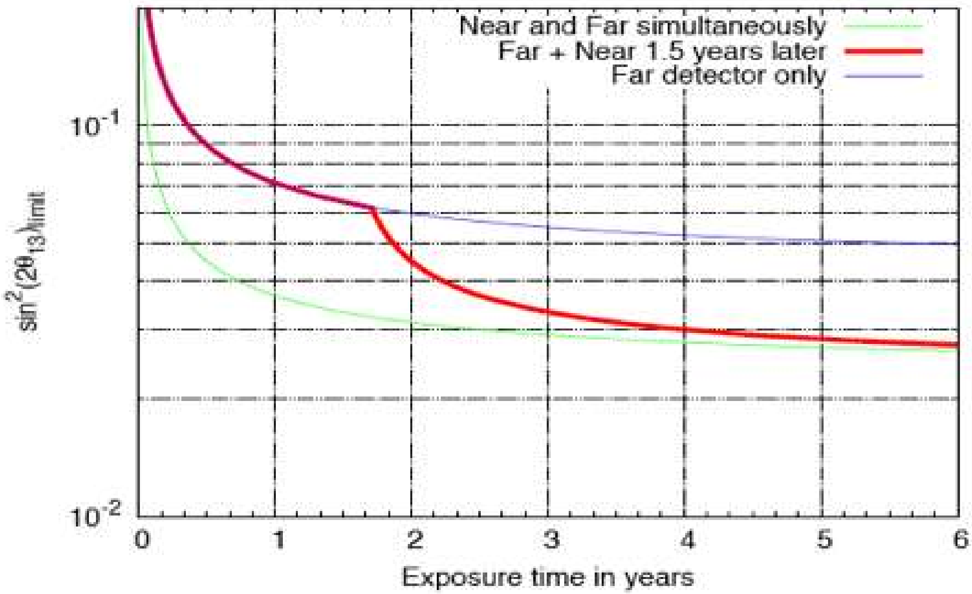

Figure 3: Expected sensitivity to $\sin^2(2\theta_{13})$ (90% C.L. limit) as a function of exposure time.

1.5 the international situation

Since last year, the similar experiment in Japan (KASKA) and US (Braidwood) decided to join Double Chooz. The 8 Japanese universities members of Kaska and the main groups of Braidwood (Columbia and Chicago) entered the collaboration..

The Daya Bay experiment is going on, and is beginning to dig its 3 km tunnel. This is a collaboration US-China. Its near lab will be ready end of 2008, and the full experiment is expected to take data in 2010.

T2K main aim is to measure the same teta13 angle. Accelerator and reactor experiment do not measure the same physical quantity, and a simultaneous measurement of teta 13 would Be complementary

1.6 the collaboration

The collaboration gathers Japon (8 universities), USA (7 universities and 2 national labs), Russia, Brazil, and 4 European countries (England, Germany, Spain, and France). This is more than 100 physicists from about 30 institutions (a full table is given at the end of the document).

The spokesperson is an APC member, and the project manager is an engineer from Saclay. The executive committee has 2 members / country, and meets by phone at least each 2 weeks (and often weekly).

There are ten working groups, covering all areas of the detector construction.

The technical board gathers the main working groups responsible. There are 4 live meetings yearly, and a monthly phone conference.

The experiment cost is about 10 Meuros, to which the cost of the near laboratory has to be added (around 4 Meuros). The funding has been secured in most country. The only difficult can be localized in US, where the experiment has been accepted by NSF, but not by DOE. Some items are only partially funded, but the global funding is more than 90%. France contribution is around 3.9 Meuros (2.4 IN2P3) , to which must be added the near laboratory cost, for which a special funding will be gathered with the help of local autorities.

1.6 APC

1.6.1 the APC group

The group is very tightly linked to the CEA Saclay groups, and two physicists belong to both groups. It has been reinforced by two young physicists during the previous years, and has now a total number of 8 physicists.

1.6.2 commitments

1.6.2.1 mechanics

APC is in charge of the outer shielding and of the main tank of the experiment. This implied to take in charge the old laboratory, and reshape it.

The shielding is necessary to protect the detector against the natural radioactivity of the rocks surrounding it. It is made of a 4 pi layer of 15 cm of iron, which is 250 tons. Buying such an important quantity of iron is now very difficult, and expensive: a first tender was unsuccessful, and a huge work has to be made by APC engineers to modify successfully. This is being prepared in factory, and will be installed at Chooz in March.

This shielding will have to be demagnetized, to lower its magnetic field below the earth magnetic field. A coil is being built on purpose, and each of the 80 iron bars will have to be demagnetized. This is done in close interaction with a speciliazed CNRS laboratory in Grenoble.

The main tank of the detector will house the 200 m3 of liquid scintillator, which implies safety constraints. Moreover, it has to be soldered out of the pit, to avoid remagnetizing the iron shield. Its top lid has to accomodate the path of the 400 PMTs cables, all the filling and calibrating devices. It has an outer fixed part, and a central movable one.

A young engineer was expected to be hired for this project in 2006. A candidate was selected, but the process was cancelled by the agency due to an unexpected funding issue. This year, the process is currently under way, and we hope it to be success full. The actual team of 1.5 persons is not enough for such an important work, in spite of a very high expertise and a great work.

		2006	2007	2008	2009	2010
funding		50	1350		200	

manpower	Needed	3	3.5	3	2	2
	actual	3	1.5 (*)	1.2 (+1? *)	1 (+1? *)	1 (+1? *)

* 3 years contract underway (failed in 2006)

1.6.2.2 Electronics and data acquisition

APC is in charge of the digital electronics and data acquisition. A physicist of the group, D.Kryn is, with C.Lane (Drexel university), leader of the corresponding working group (labelled “electronics and data acquisition”).

The group developed several flash ADC for the Chooz, Borexino, and Double Chooz experiment, in collaboration with CAEN. . The first one was a 200 MHz fastbus board. The Borexino board is a 400 MHz VME. The new Double Chooz board is a 500MHz, and is sold under the name of V1721 by CAEN, within a commercial agreement with CNRS.

The amount of data is reduced by the clever organisation of the board memory, which is split in small areas (called pages) containing one sampling. The trigger allows to keep a full detector digitization of the interesting time gap. The amount of data is further reduced on line: according to the event type, the data are more or less compressed.

Electronics/DACQ			2006	2007	2008	2009	2010	
Funding					366	356		
manpower	ELEC	Needed	1	0.8	0.5	0.2	0.2	Flash ADC system
		actual	0.5 (1)	0.3 (1)	0.1 (1)			
	DACQ	Needed	0		0.5	0	0	Task leader Wi Fi DACQ
		actual						

(2) engineer developing the flash ADC V1721 (CAEN)

1.6.2.3 Data analysis

The group is also involved in the preparation of the future analysis tools, and members of the group are recognized as experts in charge of major responsibilities in the field. Together with the Saclay group, we are present in all areas and able to merge our efforts act as the leading force.

1.6.2.4 thesis

The first Double Chooz thesis was at APC, and studied the physics potential of the experiment. A thesis shared with Saclay starts in 2007

University of Aachen	University of Alabama	AstroParticule et Cosmologie (APC)
Argonne National Laboratory	CIEMAT, Centro de Investigaciones Energeticas MedioAmbientales y Tecnologicas	Drexel University
Universität Hamburg	Max Planck Institut für Kernphysik Heidelberg	Hiroshima Institute of technology
Illinois Institute of Technology	Institute for Nuclear Research RAS	Institute of Physical Chemistry RAS
Kansas State University	Kobe University	RRC Kurchatov Institute
Lawrence Livermore National Laboratory	University of Columbia	Louisiana State University
Miyagi University of Education	Niigata University (KEK collaboration)	University of Notre Dame
DAPNIA CEA/Saclay	Sandia National Laboratories	Subatech Nantes
Tohoku University	Tohoku Gakuin University	Tokyo Institute of Technology
Tokyo Metropolitan University	Eberhard-Karls Universität Tübingen	University of Tennessee
University of Oxford	University of Sussex	University of Chicago