Double-Chooz Neutrino Experiment

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For Double-Chooz Collaboration
Neutrino Oscillation

From $\nu_\mu \rightarrow \nu_\tau$
Atmospheric $\nu_\mu$

$$
\begin{pmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau
\end{pmatrix}
=
\begin{pmatrix}
1 & 0 & 0 \\
0 & c_{23} & s_{23} \\
0 & -s_{23} & c_{23}
\end{pmatrix}
\begin{pmatrix}
c_{13} & 0 & s_{13}e^{-i\delta} \\
0 & 1 & 0 \\
-s_{13}e^{i\delta} & 0 & c_{13}
\end{pmatrix}
\begin{pmatrix}
\nu_1 \\
\nu_2 \\
\nu_3
\end{pmatrix}
$$

where $s_{ij} = \sin \theta_{ij}$, $c_{ij} = \cos \theta_{ij}$

From $\nu_e \rightarrow \nu_x$
Solar $\nu_e$

From nuclear reactor experiments

where $s_{ij} = \sin \theta_{ij}$, $c_{ij} = \cos \theta_{ij}$

3 mixing angles
1 complex phase
2 mass differences
Current knowledge

**SK+K2K+MINOS**
\[ \theta_{23} = 43.3^{+4.3}_{-3.8} \]
\[ |\Delta m_{13}^2| = 2.6 \pm 0.2 \times 10^{-3} \text{eV}^2 \]

**Solar+KamLAND**
\[ \theta_{12} = 33.7 \pm 1.3 \]
\[ |\Delta m_{12}^2| = 7.9^{+0.27}_{-0.28} \times 10^{-5} \text{eV}^2 \]

Limit at 90% CL:

(\text{CHOOZ} + \text{atm} + \text{LBL} + \text{solar} + \text{KamLAND})

\[ \sin^2 2\theta_{13} < 0.11 \]

arXiv:0710.5027

The main goal of upcoming experiments is the determination of \( \theta_{13} \)

$\theta_{13}$ at nuclear reactors experiments

$\bar{\nu}_e$ disappearance searches

$P(\bar{\nu}_e \rightarrow \bar{\nu}_e)$ Independent of $\delta$-CP, weak dependence on $\Delta m_{12}$

Matter effects negligible due to the small distances and the $\nu$ energy $O$(MeV)

- Unambiguous measurement of $\theta_{13}$ complementary to beams
- The only limitation comes from statistical and systematic errors
- These experiments must be carried out on a short time scale to provide an input for future beams
Neutrino detection at nuclear reactor experiments

Detection by inverse $\beta$-decay

$$\bar{V}_e + p \rightarrow e^+ + n$$

**Signature** Delayed coincidence of:

Prompt $e^+$ annihilation $E_{e^+} = E_\nu - (M_n - M_p)$

Photons from $n$ capture on H $E_\gamma = 2$ MeV
on dedicated nuclei (Gd) $E_\gamma = 8$ MeV
Backgrounds

Accidental:
- $e^+$-like signal: radioactivity from materials and surrounding rock.
- n signal: n from cosmic $\mu$ spallation, thermalized and captured on Gd.

Or another radioactivity event

Correlated:
- fast n (by cosmic $\mu$) recoil on p (low energy) and captured on Gd
- long-lived ($^9$Li, $^8$He) $\beta$-decaying isotopes induced by $\mu$
To look for non-zero values of $\theta_{13}$

Beyond the previous systematic limitations:

1. **Two detectors** to reduce uncertainties to the reactor flux
2. **Identical detectors** to reduce errors due to detector acceptance
Improving CHOOZ

\[
\text{CHOOZ: } R = \frac{N_{\text{meas}}}{N_{\text{exp}}} = 1.01 \pm 2.8\% \text{ (stat)} \pm 2.7\% \text{ (sys)}
\]

### Statistical error

<table>
<thead>
<tr>
<th></th>
<th>CHOOZ</th>
<th>Double Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target volume</td>
<td>5.55 m³</td>
<td>10.3 m³</td>
</tr>
<tr>
<td>Data taking period</td>
<td>Few months</td>
<td>3-5 years</td>
</tr>
<tr>
<td>Event rate</td>
<td>2700</td>
<td>Chooz-far 40000/3y Chooz-near &gt; 1 106/3y</td>
</tr>
<tr>
<td>Statistical error</td>
<td>2.8%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

### Systematic errors

- Improve detector design and knowledge
- Large S/B detector design (shielding and radiopurity materials) and increasing overburden

<table>
<thead>
<tr>
<th></th>
<th>CHOOZ</th>
<th>Double Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor uncertainties</td>
<td>2.1%</td>
<td>----</td>
</tr>
<tr>
<td>Number of protons</td>
<td>0.8%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Detector Efficiency</td>
<td>1.5%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>
The Double Chooz Collaboration

Spokesman: Hervé de Kerret (APC)

**France:** APC Paris, CEA/Dapnia Saclay, Subatech Nantes, Strasburg

**Germany:** Aachen, MPIK Heidelberg, TU München, EKU Tübingen, Hamburg

**Spain:** CIEMAT Madrid

**UK:** Sussex

**Japan:** HIT, Kobe, MUE, Niigata, TGU, TIT, TMU, Tohoku

**Russia:** RAS, RRC Kurchatov Institute

**USA:** Alabama, ANL, Chicago, Columbia, Drexel, Illinois, Kansas, LLNL, LSU, Notre Dame, Sandia, Tennessee, UCD

**Brazil:** CBPF, UNICAMP
The Chooz site:

Chooz-B reactors
8.4 GWth
Placed in the Ardennes (France)
The Detector(s)

**Target**: 10.3m$^3$ Gd doped LS
(Acrylic) $R=1.15m$
$H=2.47m$
$th=8mm$

**γ-Catcher**: 22.6m$^3$ LS
(Acrylic) $R=1.70m$
$H=3.55m$
$th=12mm$

**Buffer**: 114.2m$^3$ mineral oil
(Stainless Steel) 390 10” PMTs
$R=2.76m$
$H=5.67m$
$th=3mm$

**Inner Veto**: 80m$^3$ LS
(Steel) 78 8” PMTs
$R=3.27m$
$H=7 m$
$th=10mm$

**Outer muon Veto**: Scintillator panels

**Shielding**: 15cm Steel
Current Status

Current Activity: Far Detector Construction and Integration

- Civil engineering work completed.
- Pit refurbished and access adapted.

Near detector:
- Location defined
- Preliminary study completed
- Lab ready end of 2009
Current Status

Liquid Scintillator
- Delivery Gd-complex completed
- PXE arrived in MPIK (Heidelberg) tests and purification going on
- Scintillator hall ready, filling up with equipment

Vessels and mechanical components:
- Design approved
- The fabrication is on-going
Current Status

**PMT 10” Hamamatsu R7081**

- PMT geometry baseline
- 390 PMTs/detector
- PMT mechanical support
- & magnetic shield

First 100 PMT batch delivered.
Test benches ready
Schedule

- Far detector assembly 2008—Summer 2009
- Far detector commissioning Summer 2009
- Near detector civil work complete End 2009
- Near detector assembly 2010
- Near detector start Beginning 2011
Expected Sensitivity

Current limit @90%CL
\( \sin^2 2\theta_{13} < 0.11 \)

Limit from Far Chooz (~2010)
\( \sin^2 2\theta_{13} < 0.06 \)

Limit from Double Chooz (~2012)
\( \sin^2 2\theta_{13} < 0.035 \)

Far detector alone
\( \sigma_{\text{sys}} = 2.5\% \)

Both detectors
\( \sigma_{\text{sys}} = 0.6\% \)
Summary

- **Double Chooz** will be the first of a new generation of neutrino experiments using identical detectors at different distances from a reactor to measure $\Theta_{13}$.

- We will measure or set a strong limit in $\Theta_{13}$ within a few years.
Backup
Neutrino oscillations: present status
$\theta_{13}$ Determination

$\sin^2 \theta_{13} - \delta$ plane for the true values $\sin^2 \theta_{13} = 0.1$ and $\delta = 90^\circ$

arXiv:0710.5027

Super beams

Reactors

90% CL

3σ

- Best fit normal hierarchy
- Best fit inverted hierarchy

Combination:
- A relative good determination of $\theta_{13}$
- Some information on $\delta$ (corrupted by the ambiguity in the mass hierarchy)
- CP violation cannot be established
$\theta_{13}$ Determination

Evolution of the $3\sigma$ discovery potential of a non-zero value of $\theta_{13}$ of upcoming experiments

Lowest true value for which $\sin^22\theta_{13}=0$ excluded at $\geq3\sigma$
Reactor experiments proposals
Reactor experiments proposals

![Graph showing neutrino oscillations]

G. Mention et al. (in preparation)
## Double-Chooz: Systematic errors

<table>
<thead>
<tr>
<th>Source</th>
<th>Chooz</th>
<th>Double-Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reactor-induced</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\nu$ flux and $\sigma$</td>
<td>1.9 %</td>
<td>$&lt; 0.1 %$</td>
</tr>
<tr>
<td>Reactor power</td>
<td>0.7 %</td>
<td>$&lt; 0.1 %$</td>
</tr>
<tr>
<td>Energy per fission</td>
<td>0.6 %</td>
<td>$&lt; 0.1 %$</td>
</tr>
<tr>
<td><strong>Detector-induced</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid angle</td>
<td>0.3 %</td>
<td>$&lt; 0.1 %$</td>
</tr>
<tr>
<td>Target Mass</td>
<td>0.3 %</td>
<td>0.2 %</td>
</tr>
<tr>
<td>Density</td>
<td>0.3 %</td>
<td>$&lt; 0.1 %$</td>
</tr>
<tr>
<td>H/C ratio &amp; Gd concentration</td>
<td>1.2 %</td>
<td>$&lt; 0.2 %$</td>
</tr>
<tr>
<td>Spatial effects</td>
<td>1.0 %</td>
<td>$&lt; 0.1 %$</td>
</tr>
<tr>
<td>Live time</td>
<td>few %</td>
<td>0.25 %</td>
</tr>
<tr>
<td><strong>Analysis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From 7 to 3 cuts</td>
<td>1.5 %</td>
<td>0.2 - 0.3 %</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2.7 %</td>
<td>$&lt; 0.6 %$</td>
</tr>
</tbody>
</table>

- Two “identical” detectors, Low bkg
- Distance measured @ 10 cm + monitor core barycenter
- Same weight sensor for both det.
- Accurate T control (near/far)
- Same scintillator batch + Stability
- “identical” Target geometry & LS
- Measured with several methods
- (see next slide)
- (Total ~0.45% without contingency ....)