Double Chooz and RENO

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International Workshop on
Next Nucleon Decay and Neutrino Detectors,
Paris 11-13 September 2008
Current knowledge

**Global**: $\sin^2(2\theta_{13}) < 0.14$ or $\theta_{13} < 11^\circ$ (90% CL) for $\Delta m^2 = 2.5 \cdot 10^{-3}$ eV$^2$

**CHOOZ**

$R = 1.01 \pm 2.8\% \text{(stat)} \pm 2.7\% \text{(syst)}$

$\nu_e \rightarrow \nu_x$


$R = 1.01 \pm 2.8\% \text{(stat)} \pm 2.7\% \text{(syst)}$

in 1 km distance to reactors

T. Schwetz, arXiv:0710.5027
Measuring $\theta_{13}$ with reactor neutrinos

- $\bar{\nu}_e$ disappearance experiment with a second, identical detector near to the source to measure the full flux and spectrum
- Uncertainties of reactor power, burnup effects, neutrino spectrum, cross section and detector efficiency (almost) cancel.
- Clean $\theta_{13}$ measurement, independent of $\delta$-CP, independent of $\text{sgn}(\Delta m_{31}^2)$
- Complementary to neutrino beams, can break correlations and degeneracies

\[ P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2 \left( \frac{\Delta m_{31}^2 L}{4 E_\nu} \right) - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \left( \frac{\Delta m_{21}^2 L}{4 E_\nu} \right) \]
Chooz-B nuclear power plant
• in the Ardennes, France
• Electricité de France
• two PW reactors of type N4
• thermal power \(8.5 \text{ GW}_{\text{th}}\)

**NEAR** detector lab with 351 m/465 m to reactors, 115 m.w.e., access tunnel with 12% slope, available end of 2009

**FAR** detector lab with 1115 m/998 m to reactors, 300 m.w.e., old tank dismantled, lab updated, install. started 05/08
Detector layout

10m³ Target:
LS: 80% oil + 20% PXE + 1 g/l Gd + PPO + Bis-MSB in acrylic vessel

γ Catcher:
LS: 80% oil + 20% PXE + PPO + Bis-MSB in acrylic vessel

Non scintillating Buffer:
non-scintillating mineral oil

Buffer vessel with 390 10” PMTs:
Stainless steel 3 mm

Inner Muon Veto:
Scintillator + 78 8” PMTs

Steel Shielding:
15 cm demagnetized steel

Target density for all liquids: 0.800 g/cm$^3$
Signal and Background

**e⁻ antineutrino Signature**
- Prompt $e^+$ (1-8 MeV)
- Delayed $n$ Gd-capture (8 MeV)
- Time correlation: $\tau \sim 30 \mu s$
- Space correlation: $< 1$ m

<table>
<thead>
<tr>
<th>Distance</th>
<th>Neutrinos d⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Far</td>
<td>70</td>
</tr>
<tr>
<td>Near</td>
<td>500</td>
</tr>
</tbody>
</table>

**Accidental Background**
- $\gamma$
- $E_\gamma > 1$ MeV
- $\Sigma \gamma \sim 8$ MeV

<table>
<thead>
<tr>
<th>Distance</th>
<th>Neutrinos d⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Far</td>
<td>2</td>
</tr>
<tr>
<td>Near</td>
<td>11</td>
</tr>
</tbody>
</table>

**Correlated Background**
- Neutron slowing/thermalisation
  - $\Sigma \gamma \sim 8$ MeV

<table>
<thead>
<tr>
<th>Distance</th>
<th>Neutrinos d⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Far</td>
<td>1.6</td>
</tr>
<tr>
<td>Near</td>
<td>5.2</td>
</tr>
</tbody>
</table>
Collaboration

June 2006: Double Chooz proposal:
119 authors from 26 institutions
(hep-ex/0606025)

October 2007: TDR

June 2008
Far detector site status

Installation in the Liquid Handling Building has started (6 large storage tanks from TUM)

Civil engineering work has been finished (detector pit refurbished, doors enlarged, new ventilation system, safety system).

Shielding steel bars have been mounted in the pit.
Site has been chosen with >45m overburden, almost flat topology.

Inner detector components

Scintillators

Target solvent: 20% PXE – 80% Dodecane
PPO / bis-MSB (γ spectroscopy, NAA)
1 g/l Gd loading: developed @MPIK
100 kg Gd(dpm)_3 compound delivered

New building at MPIK for production, storage and purification of scintillators

Buffer vessel and acrylics:
Design completed, suitable material has been chosen in discussion with manufacturer, now production.
Photodetection system

15% coverage with 390 10“ PM tubes
Energy resolution goal: 7% @ 1MeV
PMT radiopurity: single rate < 5 Hz/detector
PMTs have been shipped to Japan & Germany for tests and assembly.

390 Hamamatsu R7081 10“ PMTs per detector
µ metal shields
PMT mechanics
HVsplitters
**Inner and Outer Muon Veto**

**Inner Veto**
- to tag efficiently cosmic rays, muons, and secondaries
- LAB and tetradeconane, 50 cm thickness
- 78 8" PMTs (encapsulated IMB tubes)
- Reflective walls (painted and foil)
- PMTs, almost all parts ready for Chooz

**Outer Veto**
- Tag “near-miss” \( \mu \)
- Redundancy for high rejection power

**Prototype cut view**
- Panels of strips
- Coextruded scintillator + TiO\(_2\) reflector
- 1.2 mm Ø wavelength-shifting fibre

completed first prototype module
Detector Calibration

Schematic overview of calibration source deployment

- Fish line (z-axis)
- Articulated arm
- Wire source in guide tube
- Wire source in buffer tube
- Fixed fibers for light injection in buffer

- Scintillator Energy Scale
- Light Transport
- PMT Light Collection/QE
- PMT Gain
- PMT Timing
- γ Detection Efficiency
- n Detection Efficiency
- Deadtime
- Stability Monitoring

- γ Sources
- n Sources
- Light Flashers
- Cosmics
- Multi-Wavelength Laser System
- Multi-Wavelength LED System
- Muons
- Spallation Neutrons
- Cosmogenics
- Hg-203
- Cs-137
- Ge-68
- Co-60
- PoC
- tagged Cf-252
- Cf-252
- Am-Be
### Sensitivity & schedule

- **Double Chooz Far integration** Started in May 08
  - 2008-09 → Far Detector construction & integration
  - Mid-2009 → Start of phase I: Far 1 km detector alone
    \[ \sin^2(2\theta_{13}) < 0.06 \text{ after 1.5 year (90% C.L.) if no-oscil.} \]
  - 2008-10 → Near Lab Escavation & Near Detector Integration
  - 2011 → Start of phase II: Both near and far detectors
    \[ \sin^2(2\theta_{13}) < 0.03 \text{ after 3 years (90% C.L.) if no-oscil.} \]
Current Status of RENO

Slides/pictures by Soo-Bong Kim
Schematic Setup of RENO at YeongGwang
Summary of Construction Status

• 03~10, 2007 : Geological survey and tunnel design are completed.
• 07~12, 2008 : Tunnel construction
• Hamamatsu 10” PMTs are considered to be purchased. (expect to be delivered from March 2009)
• 09, 2008 : SK new electronics are adopted and electronic modules are delivered.
• 09, 2008 : A mock-up detector (~1/10 in volume) is assembled.
• 10~12, 2008 : Steel/acrylic containers and mechanical structure will be ordered soon.
• Liquid scintillator handling system will be prepared.
Tunnel Construction

Far detector site

Near detector site
Summary of RENO

- RENO is suitable for measuring $\theta_{13}$ \((\sin^2(2\theta_{13}) > 0.02)\)

- Geological survey and design of access tunnels & detector cavities are completed → Civil construction began in July, 2008.

- RENO is under construction phase.

- Data–taking is expected to start in early 2010.

- International collaborators are being invited.
Several experiments aim at being the first of a new generation of reactor neutrino experiments using identical detectors at different distances from a reactor to measure $\theta_{13}$.

R&D phase is far advanced, we are in the construction phase, with detector installation started in Chooz in May 2008. Data taking with far detector is scheduled for mid-2009.

Era of precision measurements with reactor neutrinos will improve knowledge on $\theta_{13}$, in a complementary way to long baseline experiment.
Nuclear reactors are a strong, pure source of electron antineutrinos

\[ \sim 2 \cdot 10^{20} \bar{\nu}_e \left( \text{s}.GW_{\text{th}} \right)^{-1} \]
\[ \bar{\nu}_e + p \rightarrow e^+ + n \]
\[ n + p \rightarrow d + \gamma \text{ (2.2 MeV)} \]
\[ n + \text{Gd} \rightarrow \text{Gd} + \gamma's \text{ (8 MeV)} \]

**Antineutrino detection**

Threshold \( E_v > 1.8 \text{ MeV} \)

\( E_v \approx E_{\text{vis}} + 0.8 \text{ MeV} \)

\( \tau = (30.7 \pm 0.5) \mu\text{s} \) with 0.1% Gd

\( \tau = 180 \mu\text{s} \) for capture on H
Accidental coincidences between:

- **e⁺-like signal** (radioactivity from materials, PMT, surrounding rock) $R_e$

- **neutron signal** (induced by cosmic $\mu$, $\gamma$’s mimicking neutron) $R_n$

$$R_{\text{acc}} = R_e \times R_n \times \Delta t$$

→ reduce gamma background
→ rate & shape of accidental background can be measured in situ and subtracted from the spectrum

Fast neutrons (induced by cosmic $\mu$) scatter on protons and are captured by Gd.

Long-lived isotopes ($^9\text{Li}$, $^8\text{He}$) with $\beta$-n-cascades (induced by cosmic $\mu$).
Gamma background

Double Chooz improvement!
Cosmogenic background: $^9\text{Li}$ example

- Cosmic muons produce $^9\text{Li}$, $^8\text{He}$, $^{11}\text{Li}$ on scintillator $^{12}\text{C}$
- "Long" half-life (~200ms)
- $\sigma_{\text{prod}}$ measured at $\langle E_\mu \rangle = 190$ GeV (CERN/SPS)
  

- Data from CHOOZ, CTF and KamLAND (+ Borexino)

$\beta$-$n$ cascade

178 ms: would lead to unacceptable dead-time
Start of construction
Reactor Experiment for Neutrino Oscillation

Korean/Russian collaboration
6 reactors with total $17.3\,\text{GW}_{\text{th}}$

Goal:
$\sin^2 2\theta_{13} \sim 0.02 \, @ \, 90\% \, \text{CL in 3 years}$
Larger Detectors

**Angra dos Reis, Brazil:**
- Goal: $\sin^2 2\theta_{13} \sim 0.006$
- very large target mass (~ 200t)
- 30 researchers from 11 institutions
- very near prototype detector approved by FINEP in March 2007
- participation of the Brazilian group in Double Chooz
- full experiment in Angra around 2013?

**Triple Chooz:**
- just an idea yet...
- larger cavity available in 2011
- 200t target (possible to observe spectral distortions)
A small hint for non-zero $\theta_{13}$

slight preference for $\sin^2\theta_{13} \sim 0.013$
from the combination of solar+reactor 2008 data
<table>
<thead>
<tr>
<th>Systematics</th>
<th>Chooz</th>
<th>Double-Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>2.7 %</td>
<td>&lt; 0.6 %</td>
</tr>
<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>Volume</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; 0.1 %</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 2-3 cuts</td>
<td>1.5 %</td>
<td>0.2 - 0.3 %</td>
</tr>
</tbody>
</table>

- two "identical" detectors, monitor flux with near det.
- distance measured @ 10 cm + monitor core barycenter
- same weight sensor for both det.
- accurate T control (near/far)
- same scintillator + stability of scintillator
- "identical" target geometry & LS
- measured with several methods
- Low backgr., reduction of accidentals
The detector(s)

- Electronics racks
- Other systems:
  - Outer Muon Veto: Plastic scintillator strips with X/Y meas
  - Calibration Systems
  - Glove Boxes