Double Chooz

NNN 2009
08/10/2009
Thierry Lasserre
Saclay
Double Chooz underlying physics

\[ P(\bar{\nu}_e \rightarrow \nu_e) = \sum_i \text{Ampl} \]

\[ = \sin^2(2\theta_{13}) \left[ 1 - \sin^2(2\theta_{13}) \right] \left[ \sin \left( 1.27 \frac{\Delta m^2_{\text{atm}} (\text{eV}^2) L (\text{m})}{E (\text{MeV})} \right) + O\left( \frac{\Delta m^2_{\text{sol}}}{\Delta m^2_{\text{atm}}} \right) \right] \]

- Simple oscillation formula
  - depends \( \sin^2(2\theta_{13}) \) & \( \Delta m^2_{\text{atm}} \), weakly on \( \Delta m^2_{\text{sol}} \)

- MeV electron antineutrinos \( \Rightarrow \) only disappearance experiments
  - \( \sin^2(2\theta_{13}) \) measurement independent of \( \delta\text{-CP} \)

- MeV neutrinos + 1 km baseline \( \Rightarrow \) negligible matter effects \( O[10^{-4}] \)
  - \( \sin^2(2\theta_{13}) \) measurement independent of sign(\( \Delta m^2_{13} \))
The - new - concept

Lev Mikaelyan (Kurchatov, 2000)

\[ P(\nu_e \rightarrow \nu_e) = 1 - \sin^2(2\theta_{13})\sin^2(\Delta m^2_{31}L/4E) \]

\[ \sin^2(2\theta_{13}) = 0.12 \]

\[ \Delta m^2_{\text{atm}} = 3.0 \times 10^{-3} \text{ eV}^2 \]

Chooz Nuclear Power Station
2 cores of 4.27 GW\textsubscript{th} each
Ardellier et. al, hep-ex/0405032

Lev Mikaelyan (Kurchatov, 2000)

\[ e^+ \text{ spectrum} \]
Far Detetector
Stat. Errors

Far/Near ratio

Ardellier et. al, hep-ex/0405032
Double Chooz

130 physicists from 35 institutes

http://doublechooz.org/
Improving CHOOZ: key facts

Best Sensitivity @CHOOZ: \( R = 1.01 \pm 2.8\% \text{(stat)} \pm 2.7\% \text{(syst)} \)

- **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>Target composition</td>
<td>( 6,77 \times 10^{28} \text{ H/m}^3 )</td>
<td>( 6,55 \times 10^{28} \text{ H/m}^3 )</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>Far: 40000 / Near: 500000 (3 y)</td>
</tr>
<tr>
<td>Statistical error</td>
<td>2,7%</td>
<td>0,5%</td>
</tr>
</tbody>
</table>

- **Systematic & Background errors**

- **Two Detector Concept**
- **Improved detector design:**
  Lower threshold, e+ and n Efficiencies, Calibration System
- **Lower Background:** Shielding, Radiopurity

<table>
<thead>
<tr>
<th></th>
<th>Chooz</th>
<th>Double-Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor cross section</td>
<td>1.9 %</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>
<tr>
<td>Reactor power</td>
<td>0.7 %</td>
<td>—</td>
</tr>
<tr>
<td>Energy per fission</td>
<td>0.6 %</td>
<td>—</td>
</tr>
</tbody>
</table>

T. Lasserre 08/10/2009
The site in French Ardennes

- **300 mwe**
  - Hill topology

- **115 mwe**
  - Flat topology

- **1115 m**
  - Iso - Near/Far flux

- **351 m**

- **465 m**
Far Site Status

- **Laboratory status:**
  - Site of the CHOOZ experiment
  - Integration ongoing

- **Features:**
  - 1 km baseline (15 000 y⁻¹)
  - 300 m.w.e. (hill topology)
  - \( \mu \)-Rate: ~20 Hz @IV
  - ISO 6 Clean Room

- **Liquid storage building:**
  - Liquids delivery in Nov/Dec

Safety files accepted by French authorities (ASN)

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Near Site Status

- **Status:**
  - Fully Funded (7 partners)
  - Site Engineering Study Completed
  - Complementary bore hole study in Oct.
  - Construction: 07/2010 → 07/2011

- **Features:**
  - 400 m from nuclear cores (150 000 y⁻¹)
  - A 155 m tunnel to access the new lab
  - 115 m.w.e (almost flat topology)
  - $\mu$-Rate: ~250 Hz @IV

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Background & Design

**e⁻ antineutrino Signature**

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

**Background & Design**

**Accidental Background**

- Neutron slowing/thermalisation
- $E_\gamma > \sim 1 \, MeV$
- $\Sigma \gamma \sim 8 \, MeV$
- Far: 2 neutrinos $d^{-1}$
- Near: 11 neutrinos $d^{-1}$

**Correlated Background**

- $\Sigma \gamma \sim 8 \, MeV$
- Far: 1.6 neutrinos $d^{-1}$
- Near: 5.2 neutrinos $d^{-1}$

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Outer Veto: plastic scintillator strips (400 mm)

ν-Target: 10.3 m$^3$ scintillator doped with 0.1 g/l of Gd compound in an acrylic vessel (8 mm)

γ-Catcher: 22.3 m$^3$ scintillator in an acrylic vessel (12 mm)

Buffer: 110 m$^3$ of mineral oil in a stainless steel vessel (3 mm) viewed by 390 PMTs

Inner Veto: 90 m$^3$ of scintillator in a steel vessel equipped with 78 PMTs

Veto Vessel (10 mm) & Steel Shielding (150 mm)

(4 liquid densities adjusted at 0.800 ± 0.005)
γ ray shielding & Veto vessel

- γ’s from rock (2 ppm U, 5 ppm Th, 14000 ppm K)
- 15 cm steel shielding low radioactive
  (250 tons of steel installed, $10^{-9}$ g/g U/Th)
- Construction & integration Completed
- 1 cm thick steel vessel for tightness

Bar demagnetization test bench at Chooz

80 x 8 m long bars
250 ton Steel Shielding

T. Lasserre 08/10/2009
Inner Veto: tag efficiently cosmic ray muons & external fast neutrons entering the detector

- 50 cm, scintillating LAB oil (ready for mix)
- ~78 IMB PMTs (8“) **installed**
- Reflective walls (ext. paint + int. VM2000)

IMB PMT (R1408) + encapsulation

T. Lasserre 08/10/2009
- **10" Hamamatsu tubes** + 1 HV channel/PMT
  - 390 PMTs \(\rightarrow\) \(~13\%\) coverage
  - Energy Resolution goal: 7% at 1 MeV
  - New Low Background Glass Production
    \(\rightarrow\) PMT Singles 3,5 Bq/det (>0.7 MeV)
  - PMT delivered and soon integrated

- **Mu-metal Magnetic shielding** ready
- **PMT supporting structure** ready
- **Customized PMT** based + FEE designed
- **Full PMT characterisation & Testing** done
  \(\rightarrow\) Integration in May 2009

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Inner Detector Phototubes

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5/6 PMT Integration Completed

T. Lasserre 08/10/2009
10 tons Plexiglas material (5 vessels)

- Design based on GEANT4 simulation
  - dead material (spectral distortion)
  - detector optics

- Novel plexiglass:
  - Non standard thicknesses
  - Improved material compatibility with LS
  - No fluorescence & UV transparent
  - Production in clean room
  - Radiopurity: a few $10^{-11}$ g/g U/Th/^{40}K
    - Ge Spectroscopy @LNGS
    - NAA @Munich FRM
Acrylic Vessels

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Integration Ongoing

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Cleanliness & Radiopurity

- Radiopurity
Use of underground germanium counters for material qualification: Heidelberg, Munich, LNGS, Modane, Oroville, Saclay

<table>
<thead>
<tr>
<th>Material</th>
<th>$^{40}K$</th>
<th>$^{238}U$</th>
<th>$^{232}Th$</th>
<th>$^{60}Co$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target LS</td>
<td>$10^{-10}$</td>
<td>$10^{-13}$</td>
<td>$10^{-13}$</td>
<td>—</td>
</tr>
<tr>
<td>Target Acrylics</td>
<td>$10^{-8}$</td>
<td>$10^{-11}$</td>
<td>$10^{-11}$</td>
<td>—</td>
</tr>
<tr>
<td>GC LS</td>
<td>$10^{-10}$</td>
<td>$10^{-13}$</td>
<td>$10^{-13}$</td>
<td>—</td>
</tr>
<tr>
<td>GC Acrylics</td>
<td>$10^{-8}$</td>
<td>$10^{-11}$</td>
<td>$10^{-11}$</td>
<td>—</td>
</tr>
<tr>
<td>Buffer Oil</td>
<td>—</td>
<td>$10^{-12}$</td>
<td>$10^{-12}$</td>
<td>—</td>
</tr>
<tr>
<td>Buffer Vessel</td>
<td>—</td>
<td>$10^{-9}$</td>
<td>$10^{-9}$</td>
<td>15</td>
</tr>
<tr>
<td>Veto LS</td>
<td>—</td>
<td>$10^{-10}$</td>
<td>$10^{-10}$</td>
<td>—</td>
</tr>
</tbody>
</table>

- Cleanliness
The Chooz lab. is being transformed – step-by-step- to an ISO 6 clean room during detector integration

- Material compatibility:
All materials in contact with liquid being exposed to liquids for validation with high exposure (time \times surface)
Detector Calibration Systems

- **Articulated Arm**
- **Embedded LED calibration system** 385, 420, 470 nm
- **Fish-line**
- **Glove Box**
- **GC guide Tube**
- **Buffer guide Tube**

T. Lasserre 08/10/2009
Tag “near miss” μ. Redundancy for higher rejection power
- IV calibration
- Fast Neutrons rejection

Technology: Panels of strips of coextruded plastic scintillator +TiO$_2$
reflector with 1.2 mm diameter wavelength shifting fiber

Far detector: 2 x 6.4x6.4 m$^2$
+ umbrella

Near detector: 4 x 6.4 m$^2$

Status: Prototype under test at Chooz. Material production for both detector started

T. Lasserre 08/10/2009
- A SINGLE Batch LS for both detectors
- Target Solvant: 20% PXE – 80% Dodecane
- GC Solvant: 4 % PXE – 46% Dod. - 50% Oil
- 100 Kg pure Gd compound delivered
- PVDF coated Target Transport Tank (6m³)
- Buffer/Veto Oil delivered soon on site

MPIK new building for LS storage, mixing and purification

T. Lasserre 08/10/2009
- 250 m³ of liquid scintillator & mineral oil
- 22 m³ Gd-Scintillator ready to be mixed
- Complex filling system to be installed by January 2010
- Target Weighing measurement @0.2% to control the number of free H
$\Delta m_{\text{atm}}^2 = 2.5 \times 10^{-3} \text{ eV}^2$ (20% uncertainty)

- Efficiencies included
- 1% ‘bin-bin’ uncorrelated error on background subtraction.
- Systematics 1Det = CHOOZ
- Systematics 2Det:
  - $\sigma_{\text{abs}} = 2.0\%$
  - $\sigma_{\text{rel}} = 0.6\%$
  - $\sigma_{\text{scl}} = 0.5\%$
  - $\sigma_{\text{shp}} = 2.0\%$
  - $\sigma_{\Delta m^2} = 20\%$
- **Chi² Analysis**
  - 2 detectors simulateously
  - Account for neutrino spectrum
  - Known backgrounds & systematics and their uncertainties

- **Assumptions**
  - 3 years of data (50 000 evt/far)
  - $\Delta m_{31}^2 = 2.5 \times 10^{-3} \text{ eV}^2$

- **Nominal sensitivity**
  90% C.L. limit if no-oscillation: $\sin^2(2\theta_{13}) < 0.032$

- **Robustess (pulls method)**

<table>
<thead>
<tr>
<th>Best</th>
<th>Central</th>
<th>Worst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>1.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Rel. Norm.</td>
<td>0.4%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Spectrum</td>
<td>1.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Background rates</td>
<td>X 0</td>
<td>X 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reactor-induced</th>
<th>Chooz</th>
<th>Double Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu$ flux and spectrum</td>
<td>1.9 %</td>
<td>&lt;0.1 %</td>
</tr>
<tr>
<td>Reactor power</td>
<td>0.7-2 %</td>
<td>&lt;0.1 %</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]</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>-</td>
<td>&lt;0.2 %</td>
</tr>
</tbody>
</table>

| Detector-induced | From 7 to 3 cuts | 1.5% | 0.2 - 0.3% |

| Analysis | Total | 2.7% | <0.6% |

Depth of near detector 120 m.w.e.
Double Chooz Status

- **2009** → Far detector construction & intégration

- **04/2010** → Start of phase I: Far 1 km detector alone
  \[ \sin^2(2\theta_{13}) < 0.06 \text{ after 1.5 y (90\% C.L.) if no-oscillation} \]

- **2010/11** → Near Lab Excavation
  → Near Detector Integration

- **2011** → Start of phase II: both near and far detectors
  \[ \sin^2(2\theta_{13}) < 0.03 \text{ after 3 y (90\% C.L.) if no-oscillation} \]