News from the
Sudbury Neutrino Observatory (SNO)

Christine Kraus
TAUP conference, Sendai, Japan
September 12th, 2007

> SNO experiment
> Phase III analysis - Status
> What to expect
 (next few Month)
The SNO detector

located: INCO Creighton mine, Sudbury, Ontario, Canada

2039 m underground (6000 mwe)

DCR = Deck Clean Room

1000 tonnes D2O

12 m acrylic vessel

1700 t H2O (inner)

18 m PSUP

5300 t H2O (outer)

~9500 PMTs

54% coverage

The SNO detector is located in the INCO Creighton mine, Sudbury, Ontario, Canada. It is 2039 meters underground (6000 mwe). The detector consists of a 1000-tonne D2O core, surrounded by a 12-meter acrylic vessel, a 1700-tonne H2O inner layer, an 18-meter PSUP, and a 5300-tonne H2O outer layer. The detector contains approximately 9500 PMTs with 54% coverage.
Reactions in the SNO detector

Charged Current (CC)
\[ \nu_e + d \rightarrow p + p + e^- \]

Neutral Current (NC)
\[ \nu_x + d \rightarrow \nu_x + p + n \]

Elastic Scattering (ES)
\[ \nu_x + e^- \rightarrow \nu_x + e^- \]

Some directional info
\[ (1-1/3\cos^2\theta_{\text{sun}}) \]
only sensitive to \( \nu_e \)
good \( E_{\nu} \) sensitivity

equally sensitive to all active flavours
detect neutron capture
directional sensitivity
mostly \( \nu_e \) (factor 6.5)
smaller cross section
3 phases with different ways to detect neutrons

- **phase I**: 306 d
  - Commissioning
  - Pure D\textsubscript{2}O
  - Add 2t salt

- **phase II**: 391 d
  - Remove salt
  - Install counter array

- **phase III**: ~396 d
  - D\textsubscript{2}O back
  - Production data

**Time line**

- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007

Determine CC, ES flux --> compare to other exp., find deficit
Determine NC flux --> measure total flux from \(^{8}\text{B}\) ν’s, compare to calculations

\[\text{n captures on deuterium}\]
\[\sigma = 0.0005\text{b}\]
\[6.25 \text{ MeV } \gamma\]

\[\text{n captures on chlorine}\]
\[\sigma = 44\text{b}\]
\[8.6 \text{ MeV multiple } \gamma\text{s}\]

\[\text{n captures on } ^{3}\text{He prop. counter array}\]
\[\sigma = 5330\text{b}\]
\[0.764 \text{ MeV}\]
391 days salt data - in numbers

\[
\begin{align*}
\phi_{CC} &= 1.68^{+0.06}_{-0.06} \text{ (stat.)}^{+0.08}_{-0.09} \text{ (syst.)} \\
\phi_{NC} &= 4.94^{+0.21}_{-0.21} \text{ (stat.)}^{+0.38}_{-0.34} \text{ (syst.)} \\
\phi_{ES} &= 2.35^{+0.22}_{-0.22} \text{ (stat.)}^{+0.15}_{-0.15} \text{ (syst.)}
\end{align*}
\]

(In units of \(10^6 \text{ cm}^{-2} \text{s}^{-1}\))

\[
\frac{\phi_{CC}}{\phi_{NC}} = 0.340 \pm 0.023 \text{ (stat.)}^{+0.029}_{-0.031}
\]

\(\mu, \tau\) neutrinos

electron \(\nu\)

SNO solves the solar neutrino problem

fluxes for all neutrinos
Physics Motivation

Event-by-event separation. Measure NC and CC in separate data streams.

Different systematic uncertainties than neutron capture on NaCl.

3He Proportional Counters were installed (april 2004)

Detection Principle

\[ ^2\text{H} + \nu_x \rightarrow p + n + \nu_x - 2.22 \text{ MeV} \quad \text{(NC)} \]

NCD: \[ ^3\text{He} + n \rightarrow p + ^3\text{H} + 0.76 \text{ MeV} \]
SNO neutral current detection array (NCDs)

NCD Specifications:
- Neutron detection: \( ^3\text{He} + n \rightarrow ^3\text{H} + p \)
- Active gas: \(^3\text{He}-\text{CF}_4\) [85:15] at 2.5 atm.
- Operating voltage: 1950 V (gain \(~\text{200}\) )
- Radiopurity: <10 ppt U, Th (<4% SSM)

Radius of Acrylic Vessel

3D layout of the NCD strings:

Cu anode wire (50 \(\mu\)m)

\(^3\text{He}-\text{CF}_4\) gas mix

Fused silica insulator

CVD nickel counter body (0.36 mm thick)

Delay line termination (80 ns)

Vectran braid

Acrylic ROV ball

Acrylic anchor ball

Length of NCD Strings: 9-11 m

Whoever: 5 cm
Energy spectrum from a single deployed $^3$He proportional counter. The main peak corresponds to the 764-keV Q-value of the $^3$He(n, p)$^3$H reaction.
NCD pulse shapes
Pre-amplifiers digitize pulse shapes for particle identification

neutron with p-t track || wire

α track || wire

Entries 15000
Mean 3096
RMS 1589

neutron with p-t track ⊥ wire

α track ⊥ wire

Time (microseconds)
Calibration - neutrons - 24Na (example)

determine total neutron efficiency of array

add 2l of activated 24NaCl-D2O brine into SNO and mix until uniformly distributed

several methods used for source strength determination

NCD neutron capture efficiency: (26.7 +/- 0.7)%

array eff.: 64% (2.5% rel. err.)
Analysis scheme for NCD data

- Do energy fit
- Subtract background
- Use pulse shape discrimination
- Use neutron calibration data to determine eff. and capture and neutron shape

Collaboration has developed 4 pulse shape discrimination methods
Determination of systematic uncertainties well under way
MC efforts for NCD pulse shapes well under way
Fit of final spectral form will determine number of neutrons detected in the NCD array, after all corrections (measured with help of calibration data) have been applied.
SNO pdf* fit method

- Each physics process has typical signature in energy, radial profile and angle towards the sun

- This allows statistical separation of events

- In third phase the NC events in D$_2$O are largely suppressed by $^3$He neutron capture. That allows charged current measurement with lower uncertainty (goal 3.3% instead of 5.3% phase I and 4.5% phase II)

*probability density function
NCD phase PRL: SOON

- including: NCD NC flux measurement
- including: CC flux (PMTs)
- including: ES (PMTs)
- including: external backgrounds

very close to projected systematic uncertainties (~5-6% for NC, ~3-4% in CC)

complete data set processed (close), systematic studies well under way
Other ongoing analysis: LETA

LETA = Low Energy Threshold Analysis

- Combining phase I and II (D2O and SALT)

- Pushing energy threshold as low as possible (3.5 MeV instead of 5.5 MeV before)

- Increase statistics, improve analysis, include background PDFs, decrease systematic uncertainty

- Final systematic uncertainty studies ongoing (substantial improvement), expect publication in the next few months
Since end of data taking

data taking ended Nov. 28th, 2006

40 NCD's removed
D2O removed
D2O shipped
H2O removed
empty vessel
boating expeditions

systematic studies:
determine radioactivity (NCDs, AV), …