From SNO to SNOLAB

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On behalf of the SNO Collaboration

The 10th ICATPP Conference
Villa Como, 8-12 October, 2007
Outline

- Introduction – Solar Neutrinos
- Sudbury Neutrino Observatory (SNO)
- Results and prospect
  - SNO Phases I (pure D$_2$O)
  - SNO Phase II (salt)
  - SNO Phase III (NCD)
- SNOLAB
  - Low energy solar neutrinos (SNO+)
  - Dark Matter (Picasso & DEAP)
  - Double beta decay (EXO)
- Summary and Conclusion
SNO Collaboration
--- Sudbury Neutrino Observatory

- Carleton University
- Laurentian University
- Queen’s University
- TRIUMF Laboratory
- University of British Columbia
- University of Guelph
- Oxford University
- Brookhaven National Laboratory
- Lawrence Berkeley National Laboratory
- Los Alamos National Laboratory
- University of Pennsylvania
- University of Texas at Austin
- University of Washington
- Massachusetts Institute of Technology
- LIP, Lisbon, Portugal
Solar Neutrinos

Neutrino Flux

Neutrino Energy (MeV)
Solar Neutrino Problem (SNP)

Measured ≠ predicted

### Neutrino reactions

\[
\begin{align*}
\nu_e + ^{37}\text{Cl} & \rightarrow e^- + ^{37}\text{Ar} \\
\nu_e + ^{71}\text{Ga} & \rightarrow e^- + ^{71}\text{Ge} \\
\nu_l + e^- & \rightarrow \nu_l + e^- 
\end{align*}
\]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Medium</th>
<th>Threshold (MeV)</th>
<th>Measured/SSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homestake</td>
<td>Cl</td>
<td>0.814</td>
<td>[CC]=0.34±0.03</td>
</tr>
<tr>
<td>SAGE+GALLEX/GNO</td>
<td>Ga</td>
<td>0.2332</td>
<td>[CC]=0.52±0.03</td>
</tr>
<tr>
<td>SuperK</td>
<td>H_2O</td>
<td>7.0</td>
<td>[ES]=0.406±0.013</td>
</tr>
</tbody>
</table>


A. Bellerive: Villa como, Oct. 2007
1,000 tons D2O.
6 m radius acrylic vessel.
9 m radius steel support structure
9,500 PMTs, 54% coverage.
7,000 tonnes H2O shielding.
Urylon liner and radon seal
Low radioactive backgrounds materials are selected (e.g. U, Th).
depth: 2092 m (~6010 m.w.e.) ~70 muons/day
The SNO Detector

View from the bottom of the SNO acrylic vessel and PMT array with a fish-eye lens

View of the SNO detector

A.Bellerive: Villa como, Oct. 2007
### Three methods to detect the neutrons from the NC reaction in SNO

<table>
<thead>
<tr>
<th>Phase I ((D_2O))</th>
<th>Phase II ((\text{Salt}+D_2O))</th>
<th>Phase III ((^3\text{He}+D_2O))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov. 99 - May 01</td>
<td>July 01 - Sep. 03</td>
<td>Nov. 04 - Nov. 06</td>
</tr>
</tbody>
</table>

#### Phase I \((D_2O)\)

- n captures on Deuterium
  \[ ^2\text{H}(n,\gamma)^3\text{H} \]
  \[ \sigma = 0.0005\text{b} \]
  - 6.25 MeV single \(\gamma\)
  - PMT array readout

#### Phase II \((\text{Salt}+D_2O)\)

- 2t NaCl added
- n captures on Chlorine
  \[ ^{35}\text{Cl}(n,\gamma)^{36}\text{Cl} \]
  \[ \sigma = 44\text{b} \]
  - 8.6 MeV multiple \(\gamma\)s
  - PMT array readout

#### Phase III \((^3\text{He}+D_2O)\)

- n captures on \(^3\text{He}\) counters
  \[ ^{3}\text{He}(n,\gamma)^4\text{He} \]
  \[ \sigma = 5330\text{b} \]
  - 0.764 MeV \((p,^3\text{H})\)
  - Independent readout
  - Event by event separation

\[ n + ^3\text{He} \rightarrow p + ^3\text{H} \]
SNO timeline


Phase I
306 days
Commissioning

D₂O

Phase II
391 days
D₂O + Salt

D₂O

Phase III
396 days
D₂O + ³He counters

³He counters: Install & Commission

PRL 87, 071301, 2001
PRL 89, 011301, 2002
PRL 89, 011302, 2002
PRC 75, 045502, 2007

PRL 92, 181301, 2004
PRC 72, 055502, 2005

Total of ~1100 live days

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Calibration of SNO detector


Calibration source | Details | Calibration
--- | --- | ---
Pulsed nitrogen laser | 337, 369, 385, 420, 505, 619 nm | Optical & timing calibration
\(^{16}\text{N}\) | 6.13-MeV \(\gamma\)-rays | Energy & reconstruction
\(^{8}\text{Li}\) | \(\beta\) spectrum | Energy & reconstruction
\(^{252}\text{Cf}\) | neutrons | Neutron response
Am-Be | neutrons | Neutron response
\(^{3}\text{H}(p, \gamma)\text{He} ("pT")\) | 19.8-MeV \(\gamma\)-rays | Energy linearity
U, Th | \(\beta - \gamma\) | Backgrounds
\(^{88}\text{Y}\) | \(\beta - \gamma\) | Backgrounds
Dissolved Rn spike | \(\beta - \gamma\) | Backgrounds
In-situ \(^{24}\text{Na}\) activation | \(\beta - \gamma\) | Backgrounds
Neutrino detection

PMT array measurement:

- $e^-$ from CC or ES reaction
- Compton-scattered $e^-$ of $\gamma$s from $n$-capture (NC reaction) in the detector

Čerenkov photons

$e^-$ vertex direction energy

Position
Time
Charge

PMT hits

PMT charge

0 20 40 60 80 100

0 200 400 600 800 1000 1200 1400

$2 \times 10^3$

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Neutrino reactions in SNO detector

**ES**  \[ \nu_x + e^- \rightarrow \nu_x + e^- \]
- Mostly sensitive to \( \nu_e \), some \( \nu_\mu, \nu_\tau \)
- Strong directional sensitivity

**CC**  \[ \nu_e + d \rightarrow p + p + e^- \]
- \( Q = 1.44 \) MeV
- Measure \( \nu_e \) energy spectrum
- Sensitive to \( \nu_e \) only

**NC**  \[ \nu_x + d \rightarrow \nu_x + p + n \]
- \( Q = 2.22 \) MeV
- Equally sensitive to 3 active \( \nu \) flavors
- Measures total \( ^8B \) \( \nu \) flux (SNO only)
Key signatures for $\nu$ oscillations of SNO

flavor change?

\[
\frac{\Phi_{CC}}{\Phi_{ES}} = \frac{\nu_e}{\nu_e + 0.154(\nu_\mu + \nu_\tau)}
\]

ES:
- Strong directional sensitivity, $\theta_{\text{sun}}$
- Super-K precision measurement

\[
\frac{\Phi_{CC}}{\Phi_{NC}} = \frac{\nu_e}{\nu_e + \nu_\mu + \nu_\tau}
\]

NC:
- Equally sensitive to 3 flavors
- Cross section uncertainties cancel

\[\Phi_{\text{day}} \text{ vs } \Phi_{\text{night}}\]
Neutrino Signal Extraction from PMT Data

Energy Distribution

Radial Distribution \((R^3, R_{AV}=1)\)

Solar Direction Distribution

The energy (top row), radial (middle row), and directional (bottom row) distributions used to build pdfs to fit the SNO signal data.

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D2O Phase
Results of the SNO Experiment

Phase I

Pure D$_2$O

Nov. 1999 - May 2001
Shape Constrained Neutrino Fluxes (D$_2$O)

Signal Extraction in $\Phi_{cc}$, $\Phi_{nc}$, $\Phi_{es}$ with $E_{\text{Threshold}} > 5$ MeV

$\Phi_{cc}(\nu_e) = 1.76^{+0.06}_{-0.05} (\text{stat.})^{+0.09}_{-0.09} (\text{syst.}) \times 10^6$ cm$^{-2}$s$^{-1}$

$\Phi_{es}(\nu_x) = 2.39^{+0.24}_{-0.23} (\text{stat.})^{+0.12}_{-0.12} (\text{syst.}) \times 10^6$ cm$^{-2}$s$^{-1}$

$\Phi_{nc}(\nu_x) = 5.09^{+0.44}_{-0.43} (\text{stat.})^{+0.46}_{-0.43} (\text{syst.}) \times 10^6$ cm$^{-2}$s$^{-1}$

Signal Extraction in $\Phi_e$, $\Phi_{\mu\tau}$

$\Phi_e = 1.76^{+0.06}_{-0.05} (\text{stat.})^{+0.09}_{-0.09} (\text{syst.}) \times 10^6$ cm$^{-2}$s$^{-1}$

$\Phi_{\mu\tau} = 3.41^{+0.45}_{-0.45} (\text{stat.})^{+0.48}_{-0.45} (\text{syst.}) \times 10^6$ cm$^{-2}$s$^{-1}$
Results from the SNO Experiment

Phase II

2 tons NaCl added in D$_2$O

July 2001 - Sep. 2003
Phase II (SALT)

2 tons NaCl added into the D2O

- Higher neutron capture cross section
- Higher energy release (totally 8.6 MeV)
- Multiple gammas (averagely 2.5 γs)

\[ \sigma = 44 \text{ b} \]
\[ \sigma = 0.0005 \text{ b} \]

Pure d2o

Salt added

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Advantages of Salt: more sensitive

- Neutrons capturing on $^{35}\text{Cl}$ provide higher neutron energy above threshold.
- Higher capture efficiency
- Gamma cascade changes the angular profile.
Advantages of salt: event isotropy

Isotropy variable, $\beta_{14}$, function of angles between each pair of hit PMTs ($\theta_{ij}$) in event [similar to thrust in collider physics]

$\beta_{14}$ powerful discriminating variable between NC and CC/ES events
Salt phase (July 2001 – September 2003)

\[ n + ^{35}\text{Cl} \rightarrow ^{36}\text{Cl}^* \rightarrow ^{36}\text{Cl} + \gamma' s \]

- **Radial Distribution** (\( R^3, R_{AV}=1 \))
- **Energy Distribution** (MeV)
- **Solar Direction Distribution**
- **Isotropy Distribution**

- NC changed due to larger \( \sigma_{n\gamma} \)
- NC shifted to higher energy
- Unchanged
- All new due to multiple \( \gamma' \)’s

Model dependent

\( ^{35}\text{Cl} \rightarrow ^{36}\text{Cl}^* \rightarrow ^{36}\text{Cl} + \gamma' s \)
Charged Current (CC=\(\nu_e\)) Spectrum
Salt results & comparison to SSM

More precise salt results confirm D$_2$O results
Day/Night Asymmetries

\[ A_x = \frac{(\Phi_{\text{night}} - \Phi_{\text{day}})}{(\Phi_{\text{night}} + \Phi_{\text{day}}) / 2} \]

\[ A_{CC} = -0.056 \pm 0.074 \text{(stat.)} \pm 0.051 \text{(syst.)} \]
\[ A_{NC} = 0.042 \pm 0.086 \text{(stat.)} \pm 0.067 \text{(syst.)} \]
\[ A_{ES} = 0.146 \pm 0.198 \text{(stat.)} \pm 0.032 \text{(syst.)} \]

\[ A_{CC} \text{ and } A_{NC} \text{ are correlated } (\rho = -0.532) \]

In standard neutrino oscillations, \( A_{NC} \) should be zero…
Oscillation analysis

SNO-only neutrino oscillation analysis, including pure D2O and salt phase dataset.

The $^8$B flux was free in the fit; hep solar neutrinos were fixed at $9.3 \times 10^3$ cm$^{-2}$ s$^{-1}$.

<table>
<thead>
<tr>
<th>Oscillation analysis</th>
<th>$\Delta m^2$ ($10^{-5}$ eV$^2$)</th>
<th>$\tan^2 \theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNO-only</td>
<td>$5.0^{+6.2}_{-1.8}$</td>
<td>$0.45^{+0.11}_{-0.10}$</td>
</tr>
<tr>
<td>Global solar</td>
<td>$6.5^{+4.4}_{-2.3}$</td>
<td>$0.45^{+0.09}_{-0.08}$</td>
</tr>
<tr>
<td>Solar plus KamLAND</td>
<td>$8.0^{+0.6}_{-0.4}$</td>
<td>$0.45^{+0.09}_{-0.07}$</td>
</tr>
</tbody>
</table>

Contains Cl, Sage, Gallex/GNO and SK-1 zenith data
8B flux free in fit, hep flux fixed to $9.3 \times 10^3$ cm$^{-1}$s$^{-1}$
SNO hep Solar Neutrino analysis

Pure D$_2$O dataset

**hep reaction in the pp chain:**

$$\begin{align*}
^3\text{He} + p & \rightarrow ^4\text{He} + e^+ + \nu_e
\end{align*}$$

Graph showing neutrino fluxes and energies with labels for various reactions.

**SSM: BS2005**

$$(7.97 \pm 1.24) \times 10^3 \text{ cm}^2 \text{ s}^{-1}$$

18.77 MeV
SNO hep and DSNB $\nu$ analysis

**DSNB: Diffuse Supernova Neutrinos**

- Both signals lie in the region between $^8$B solar neutrinos and atmospheric neutrinos
- Search by counting number of events within a predefined energy window or signal box …

**hep neutrinos**
- Dominant background is $^8$B solar neutrinos
- Normalize with low-energy fit with account for neutrino oscillations ($6 < T_{\text{eff}} < 12$ MeV)

**DSNB neutrinos**
- Dominant background is atmospheric neutrinos
- Signal region $21 < T_{\text{eff}} < 35$ MeV

---

Pure D2O dataset

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SNO hep and DSNB $\nu$ analysis

**Pure D2O dataset**

**hep neutrinos**
- 2 events in signal box
- consistent with expected backgrounds
- $\Phi_{hep} < 2.3 \times 10^4 \text{ cm}^{-2}$
  - 90% confidence level upper
  - 2.9 times SSM prediction
  - 6.5 times better than SK limit

**DSNB neutrinos**
- 0 events in signal box
- 0.18 background events expected
- $\Phi_{DSNB} < 70 \text{ cm}^{-2}$ for $22.9 < E_\nu < 36.9 \text{ MeV}$
  - 90% confidence level upper limit
  - average of 5 models
  - $10^2$ better than previous MB limit
A periodicity analysis on the D$_2$O and salt data sets was performed using both a Lomb-Scargle periodogram and an unbinned maximum likelihood fit (PRD 72 052010, 2005).

For the combined data sets, the largest peak occurs at a period of 2.4 days, with a statistical significance of $S=8.8$.

Monte Carlo shows that 35% of simulated data sets give a peak at least this large.

No statistically significant periodicity was found.

Results from the SNO Experiment

Phase III

$^3$He Proportional Counters

Nov. 2004 - Nov. 2006:
SNO Phase III ($^3$He Proportional Counters)

$^3$He Proportional Counters ("NC Detectors")

Detection Principle

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

\[ ^3\text{He} + n \rightarrow p + ^3\text{H} + 0.76 \text{ MeV} \]

40 Strings on 1-m grid
398 m total active length

Physics Motivation

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

Different systematic uncertainties than neutron capture on NaCl.
### Correlation Coefficients between the CC, ES, and NC events

<table>
<thead>
<tr>
<th></th>
<th>$\text{D}_2\text{O unconstrained}$</th>
<th>$\text{D}_2\text{O constrained}$</th>
<th>$\text{Salt unconstrained}$</th>
<th>$\text{}^3\text{He}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NC,CC</strong></td>
<td>-0.950</td>
<td>-0.520</td>
<td>-0.521</td>
<td>~0</td>
</tr>
<tr>
<td><strong>CC,ES</strong></td>
<td>-0.208</td>
<td>-0.162</td>
<td>-0.156</td>
<td>~-0.2</td>
</tr>
<tr>
<td><strong>ES,NC</strong></td>
<td>-0.297</td>
<td>-0.105</td>
<td>-0.064</td>
<td>~0</td>
</tr>
</tbody>
</table>
SNO Phase III ($^3$He Proportional Counters)

The positions of the NCD strings projected onto the plane of the AV equator

$^3$He

Installation of the NCD strings

40 Strings on 1-m grid
398 m total active length

$^3$He Strings and 4 $^4$He strings for determination of $\alpha$ background

NIM A 579 (2007) 1054–1080
SNO Phase III ($^3$He Proportional Counters)

- Proportional counters detect neutrons via: $n + ^3$He $\rightarrow$ p + $^3$H
- Low radioactivity CVD nickel, 5 cm diameter, 0.36 mm thick
- Gas is 85% $^3$He and 15% CF$_4$, at $\sim$ 2.5 atm
- Anchored to the bottom of SNO on a 1-meter square grid
- 40 strings, each 9 to 11 meters long, 398 meters total length
- 50 $\mu$m copper anode wire at 1950 V
Neutron Capture in the NCDs

~ 1200 n captures per year in NCDs from solar ν

\[ n + ^3\text{He} \rightarrow p + ^3\text{H} \quad (Q = 764 \text{ keV}) \]

End view of an NCD with representative ionization tracks.

Idealized energy spectrum in a $^3\text{He}$ proportional counter.
SNO Phase III ($^{3}$He Proportional Counters)

Blind data set of the NCD events

- Data from $^{3}$He NCD-Strings
- Alpha Background
- Characteristic $^{3}$He(n,p)$t$
  Spectrum from Calibration

- Improve Separation
  - Pulse-Shape-Disc.
  - String-by-String
  - Ring-by-Ring Symmetry
- Pulse-Evolution & MC Model

Counts vs. Energy (MeV)
SNO Sensitivity

Future
Ratio CC/NC
Day-night
Combination of information from three phases!

SNO-D$_2$O Day/Night Spectra
Sep 14/07, AGlobalFit
$\chi^2_{\text{min}} = 25.94$ at (4.47e-01, 5.01e-05), P-value = 0.7663
Scales: $^8\text{B} = 0.903$, hep = 1.001
What SNO might tell us in the future...

- LMA Allowed
- SNO Day-Night
  (3% abs. uncertainty)
- SNO CC/NC
  (7% uncertainty)

CC/NC
Contours

Day – Night
Contours (%)

hep-ph/0212270
hep-ph/0204253
Summary

What we have:

- $^8$B neutrino results from first two phases, including fluxes, spectrum, D/N asymmetry
- search for periodicity in data
- hep and diffuse SN neutrino results

What is next:

- First results from NCD phase
- Low energy threshold analysis for phase I and II
- muon and atmospheric analysis
- other results
- COMBINATION OF ALL THREE PHASES!
SNOLAB

Surface Facility

Underground Laboratory

2km overburden (6000mwe)
SNOLAB

Phase I

Existing SNO Facility

Relocate
-Lab Entry
-Personnel Facilities

Utility Area
- Chiller
- Generator
Existing SNO Facility

**Phase I**
* Excavation began Fall 2004, completed May 2007
* Outfitting began June 2007

**Phase II**
* Funding announced yesterday.

Utility Area
- Chiller
- Generator

Relocate
- Lab Entry
- Personnel Facilities
## Laboratory Space

<table>
<thead>
<tr>
<th></th>
<th>Area</th>
<th>Volume</th>
<th>Area</th>
<th>Volume</th>
<th>Area</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Excavation</strong></td>
<td></td>
<td></td>
<td><strong>Clean Rm</strong></td>
<td></td>
<td><strong>Laboratory</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Area</strong></td>
<td></td>
<td></td>
<td><strong>Area</strong></td>
<td></td>
<td><strong>Area</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td></td>
<td></td>
<td><strong>Volume</strong></td>
<td></td>
<td><strong>Volume</strong></td>
<td></td>
</tr>
<tr>
<td>Existing</td>
<td>20,049 ft²</td>
<td>582,993 ft³</td>
<td>12,196 ft²</td>
<td>470,360 ft³</td>
<td>8,095 ft²</td>
<td>412,390 ft³</td>
</tr>
<tr>
<td></td>
<td>1,863 m²</td>
<td>16,511 m³</td>
<td>1,133 m²</td>
<td>13,321 m³</td>
<td>752 m²</td>
<td>11,679 m³</td>
</tr>
<tr>
<td>Existing + Phase I</td>
<td>65,340 ft²</td>
<td>1,367,488 ft³</td>
<td>41,955 ft²</td>
<td>1,049,393 ft³</td>
<td>26,117 ft²</td>
<td>837,604 ft³</td>
</tr>
<tr>
<td></td>
<td>6,072 m²</td>
<td>38,728 m³</td>
<td>3,899 m²</td>
<td>29,719 m³</td>
<td>2,427 m²</td>
<td>23,721 m³</td>
</tr>
<tr>
<td>Existing + Phase I&amp;II</td>
<td>77,636 ft²</td>
<td>1,647,134 ft³</td>
<td>53,180 ft²</td>
<td>1,314,973 ft³</td>
<td>32,877 ft²</td>
<td>1,043,579 ft³</td>
</tr>
<tr>
<td></td>
<td>7,215 m²</td>
<td>46,648 m³</td>
<td>4,942 m²</td>
<td>37,241 m³</td>
<td>3,055 m²</td>
<td>29,555 m³</td>
</tr>
</tbody>
</table>

CLASS 2000 Clean Room Laboratory Space
August 2006
- Phase I excavation 76% complete
Excavation Status: August 2006

Cube Hall
Excavation Status: August 2006

Ladder Labs
Excavation Status: Today

- September 2007
- Phase I excavation complete
- Phase I outfitting underway
- Phase II excavation underway
Phase II

Cryopit
- Ended data taking 28 Nov 2006
- Most heavy water returned June 2007
- Finish decommissioning end of 2007
Surface Facilities

- Site: 4,700 ft² CLASS 1000 Clean Room Laboratories, IT Infrastructure (high speed off site), Office, Meeting Rms, Control Rms, Material handling.
- Laurentian Water Facility: Intended for spike work not appropriate for site. Will have Ultra Pure Water facility, Low BG counting
Material Screening

Ge Gamma Counter

- Low Background Counting available for the experiments.
- 1 liter sample sizes
- Presently being used by SNO, EXO, DEAP/CLEAN, PICASSO

<table>
<thead>
<tr>
<th>Element</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>0.5 ppm</td>
</tr>
<tr>
<td>Th</td>
<td>1.4 ppb</td>
</tr>
<tr>
<td>U</td>
<td>0.28 ppb</td>
</tr>
</tbody>
</table>
Material Screening

ESC (Electrostatic Counter)

- 8 counters on site.
- Self contained samples connected directly to the recirculating loop. Other samples placed in polypropylene cylinders with N₂ or Ar gas recirculated through chamber.
- Turnaround time 1 month (3 months notice recommended)
  - 2 weeks/sample + 2 weeks for background.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>²²²Rn (U)</td>
<td>20 atoms/day</td>
</tr>
<tr>
<td>²²⁰Rn (Th)</td>
<td>10 atoms/day</td>
</tr>
<tr>
<td>²¹⁹Rn (Ac)</td>
<td>50 atoms/day</td>
</tr>
</tbody>
</table>
Material Screening

- Radon Emanation Chambers
  - Used extensively for counting materials used in the SNO experiment.
  - sensitivity ~50 decays per day.
- ICP-MS
  - Association with facility at NRC (National Research Council) ICP-MS facility in Ottawa.
  - Tuned to maximize sensitivity to U and Th at sub ppt levels. K limits to > 100 ppb.
Scientific Program

Low Energy Neutrinos

- SNO+ (SNO filled with liquid scintillator)

Search for Cold Dark Matter

- Picasso
- DEAP

Investigation of Double-Beta Decay

- Enriched Xenon Observatory (EXO)
- SNO+ (upgrade Nd loaded)
SNO++: Survival Probability

**pep flux:**

Uncertainty ±1.5%

Allows precision test of the Solar Standard Model & the LMA matter enhanced oscillation scenario

Real-time low energy ν’s experiments are the ultimate probe of the Sun

\[ \Delta m^2 = 7.9 \times 10^{-5} \text{ eV}^2 \]

\[ \tan^2 \theta = 0.4 \]

\[ P^0 \]
SNO+ liquid scintillator
The Cosmic Connections

Energy budget of Universe

- Atoms: 4%
- Dark matter: 23%
- Dark energy: 73%

SEARCH FOR WIMP !!!

96% is a mystery!
WIMP Direct Detection Tools

**DM**

**CHARGE**

- Semiconductors: Ge, Si
- TPC

**LIGHT**

- NaI, CsI, CaF<sub>2</sub>, Liq. Ar & Xe

**HEAT**

- Cryogenic detectors: Al<sub>2</sub>O<sub>3</sub>, LiF

**Active Background Rejection**

- NaI, Liq.Xe: UK/NAIAD, DAMA, ZEPLIN-I, DEAP/CLEAN
- Ge, Si: CDMS, EDELWEISS
- CaWO<sub>4</sub>, BGO: CRESST, Rosebud
- Freon: PICASSO, SIMPLE
- Xe: DRIFT

**Superheat**

**Freon**
Spin dependent interaction – axial coupling

Neutralino Interaction with Matter

- Small freon droplets in polymerized gel at room T° droplets overheat
- A particle hit vaporizes the droplet: - phase transition event - an acoustic shock wave detected with piezoelectric transducers

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Spin</th>
<th>Unpaired</th>
<th>$\lambda^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^7$Li</td>
<td>$3/2$</td>
<td>p</td>
<td>0.11</td>
</tr>
<tr>
<td>$^{19}$F</td>
<td>$1/2$</td>
<td>p</td>
<td>0.863</td>
</tr>
<tr>
<td>$^{23}$Na</td>
<td>$3/2$</td>
<td>p</td>
<td>0.011</td>
</tr>
<tr>
<td>$^{29}$Si</td>
<td>$1/2$</td>
<td>n</td>
<td>0.084</td>
</tr>
<tr>
<td>$^{73}$Ge</td>
<td>$9/2$</td>
<td>n</td>
<td>0.0026</td>
</tr>
<tr>
<td>$^{127}$I</td>
<td>$5/2$</td>
<td>p</td>
<td>0.0026</td>
</tr>
<tr>
<td>$^{131}$Xe</td>
<td>$3/2$</td>
<td>n</td>
<td>0.0147</td>
</tr>
</tbody>
</table>
Picasso at SNOLAB

Remotely controled from U de Montréal
Neutralino Interaction with Matter

Spin independent interaction \textendash{} scalar coupling

$\Rightarrow$ heavy nuclei

- Require Low-E Threshold
- Require Large Target Mass
- Ultra-Low Background

$M_{\text{WIMP}} \sim 100$ GeV

$M_{\text{Recoil}} < 100$ keV

DEAP/CLEAN… sensitivity
ββ decay proposals at SNOLAB

Enriched Xenon Observatory
EXO
Background due to SM $2\nu\beta\beta$ decay

$2\nu\beta\beta$ spectrum (normalized to 1)

$0\nu\beta\beta$ peak (5% FWHM) (normalized to $10^{-6}$)

Summed electron energy in units of the kinematic endpoint ($Q$)


The only effective tool here is energy resolution

A.Bellerive: Villa como, Oct. 2007
Conclusion

What we have:

Great Physics out of SNO

What is next:

Exciting future for SNOLAB
Thanks