Initial Operation of SNO

The Sudbury Neutrino Observatory

Introduction:
- Detector specifics
- Physics goals
- Backgrounds
- Calibrations

The First 3 months (May 99 - present)

The Future

A.A. Hamian for the SNO collaboration

SUDBURY NEUTRINO OBSERVATORY COLLABORATION

A Collaboration of 11 institutions, ~80 physicists.

Canada:

- Queen's University
- Guelph University
- Laurentian University
- University of British Columbia
- Center for Research in Particle Physics

USA:

- Lawrence Berkeley National Lab.
- University of Washington
- University of Pennsylvania
- Los Alamos National Lab.
- Brookhaven National Lab.

UK:

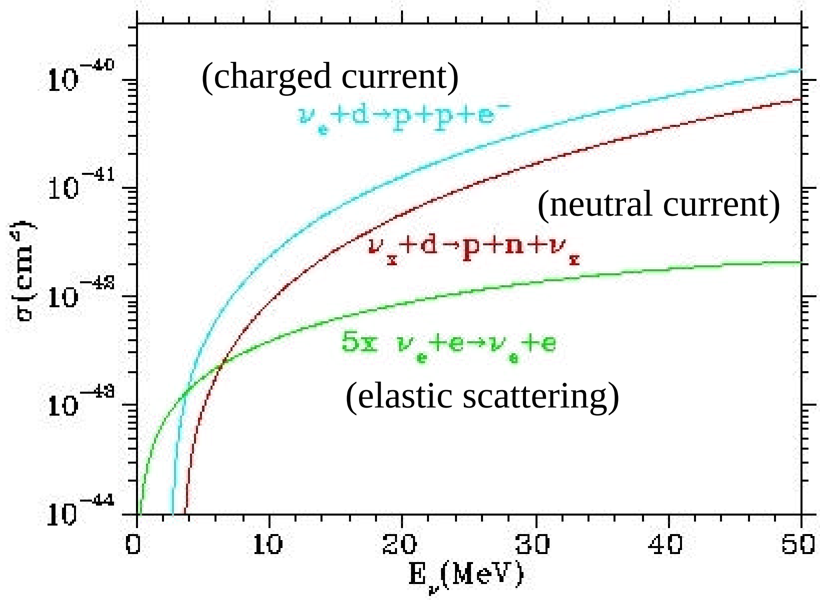
- University of Oxford

The Sudbury Neutrino Observatory:

A Heavy Water Cerenkov Detector for Neutrinos

- Use deuterium (D_2O) as neutrino target.
- Sensitive to ν_e, ν_μ, ν_τ.

IDEAL!



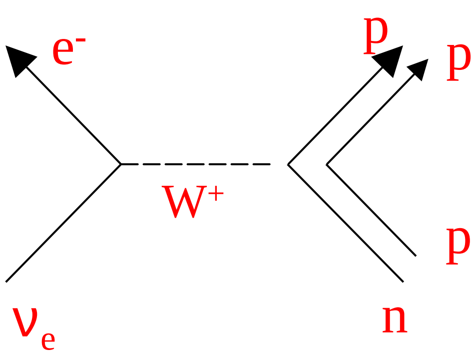
Features:

- High cross section; 1kT D_2O = 10 kT H_2O equiv.
- Detect ν_e flux, $\Phi(\nu_e)$,

  and $\nu_e + \nu_\mu + \nu_\tau$ flux, $\Phi(\nu_{Tot})$.
- Find ratio $R = \Phi(\nu_e)/\ \Phi(\nu_{Tot})$ → "smoking gun"?
- Plus other interesting physics...

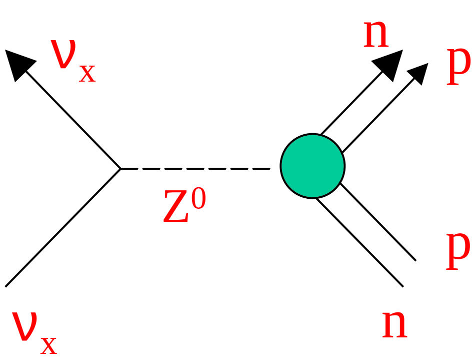
Detecting Neutrinos with Deuterium

1) Charged Current (CC) $\nu_e + d \rightarrow p + p + e^-$



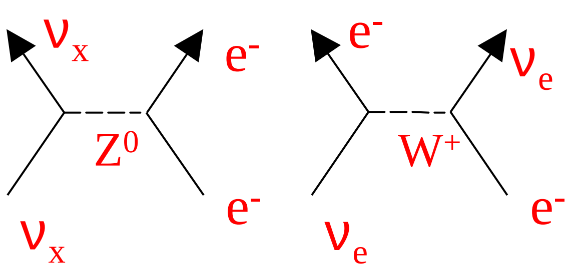
- Spectral shape (~20% resolution).
- Spectral distortion → MSW effect.
- Angular distribution:
  $W(\theta_e) = 1 - 1/3 \cos \theta_e.$

2) Neutral Current (NC) $\nu_x + d \rightarrow p + n$



- Sensitive to all ν above 2.2 MeV.
- Total ^{8}B solar ν flux.
- ν oscillations from CC/NC ratio.

3) Elastic Scattering (ES) $\nu_x + e^- \rightarrow \nu_x + e^-$



- Directional sensitivity.

SNO Physics Goals

Search for ν flavor change (ν oscillations):

ratio of CC to NC events.

Distortion of energy spectrum (ν oscillations; MSW):

CC ^{8}B energy spectrum.

^{8}B total flux (test of solar models):

NC ^{8}B measurement.

Time dependent solar ν flux:

regeneration in Earth (MSW);
7% orbital eccentricity;
solar magnetic field effects.

Search for Supernova ν's:

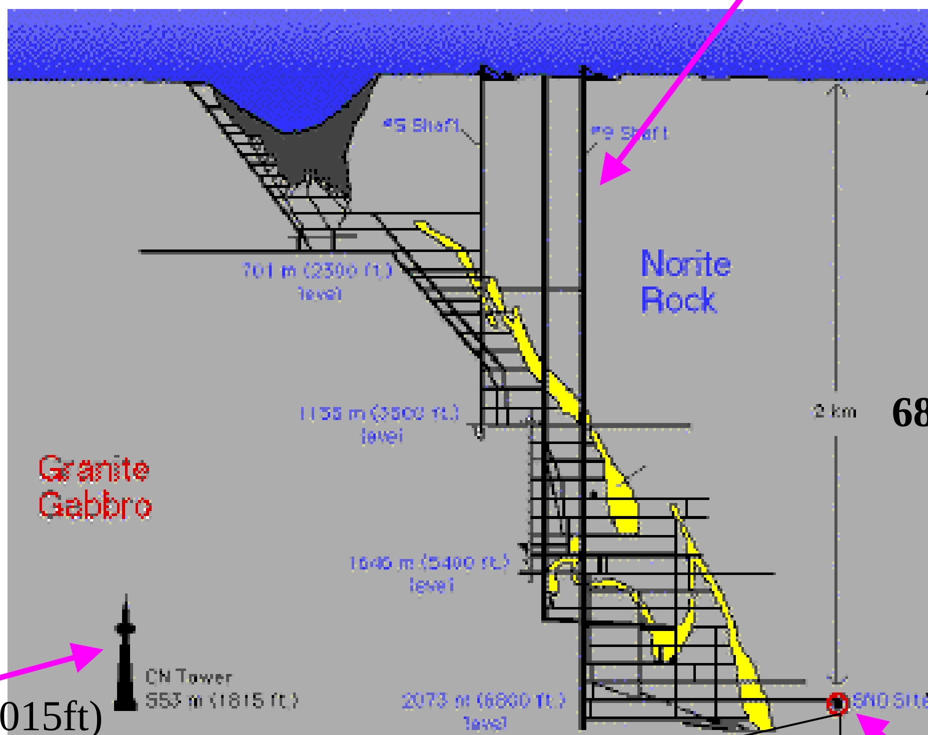
ν_x.

Good signature for antineutrinos:

$^{2}H + \overline{\nu}_e \rightarrow n + n + e^+$

SNO: Detector Specifics

INCO’s Creighton Shaft #9 (Lively, ON)

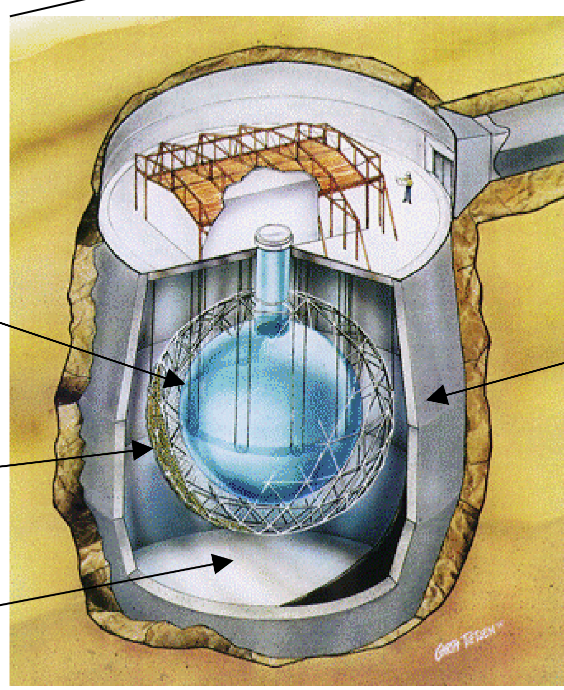


6800ft

CN Tower (1015ft)
(Space Needle: 605ft)

SNO

12m diameter acrylic vessel



Urylon liner

9450 PMTs and reflectors

25m diam. cavity filled with H_2O

Neutral Current Detection in SNO

Neutral current interaction: $\nu_x + d \rightarrow p + n + \nu_x$

Detect neutron either directly or by capture on deuterium or ^{35}Cl.

Detection Methods:

1) Capture on deuterium: $n + d \rightarrow t + \gamma$ **(6.26 MeV)**

- Low cross section, 24% capture efficiency.

2) Capture on ^{35}Cl: $n + {}^{35}Cl \rightarrow {}^{36}Cl + \gamma$ **cascade (8.58 MeV)**

- Add 2.5 Tonnes $MgCl_2$ to D_2O.
- 83% capture efficiency.
- Subtract "no salt" signal from "salt" signal.

3) Add Neutral Current Detectors (T. Steiger's talk follows)

- ^3He proportional counters: $n + {}^3He \rightarrow p + {}^3H + 0.76$ **MeV**
- Neutral current detector materials must be ultra-clean.
- Distinct event-by-event neutron signature.
- Always ready for supernovae.

SNO Anticipated Event Rates

Assuming flux-reduced Standard Solar Model: 1/3 SSM(BP98)

Charged current: ~ 9 events/day
Neutral current: ~ 3 events/day
Elastic scattering: ~ 1 event/day

Typical solar ν event has only ~50 detected photons.

Reduction of backgrounds drives the design of the detector.

Suppression of Physics Backgrounds

Cosmic Rays: high energy events & spallation products.
→Detector is located 2km (~6km w.e.) underground.

Cavity wall radioactivity: neutrons and high energy γ's.
→Light water shields active volume.

Phototube radioactivity:
→Custom made Schott glass has 5 times lower Radioactivity than standard phototube glass.
→Light water shield extends 2.5m between D_2O and phototubes.

D_2O vessel:
→12m diameter vessel constructed from very low radioactivity acrylic and glue.

D_2O and H_2O:
→Uranium and Thorium are the greatest danger, and are found in mine dust.
→Operate entire underground laboratory as full clean room.
→Continually purify water with hyperfiltration and reverse osmosis techniques.

Rejection of Backgrounds

Energy:

→Radioactive backgrounds are below energy regime where neutrinos interact.

Charge:

→Phototube charge measurements allow identification of anomalous events.

→In general, expect only 1 photon/PMT.

Reconstruction: Event position and direction.

→Requires high precision phototube timing measurements.

→Charge-dependent timing correction requires high precision charge measurements (<< 1 pe)

→Elastic scattering reaction produces forward-scattered electron.

→Charged current reaction produces angular distribution that falls as 1 - 1/3cosθ.

Detector Calibrations

•Optical Calibration: determine reflectivity and absorption of detector components.

√ Laser source: photons of 337-700 nm, 0-45 Hz, variable intensity, variable geometry, into 4π..

√ LEDs: photons, 480 nm, 0-1 kHz, variable intensity, fixed & known geometry, into 30 deg. cone.

→Sonoluminescence: fast photon source.

•Energy Calibration: determine energy scale (tubes/MeV) and resolution.

√ ^{16}N: β, 6.1 MeV γ, energy near threshold, efficiency (triggered source), gain, angular response.

→$^{3}H(p,\gamma)^{4}He$: 19.8 MeV γ, high energy effects (multiphotoelectron, charge response).

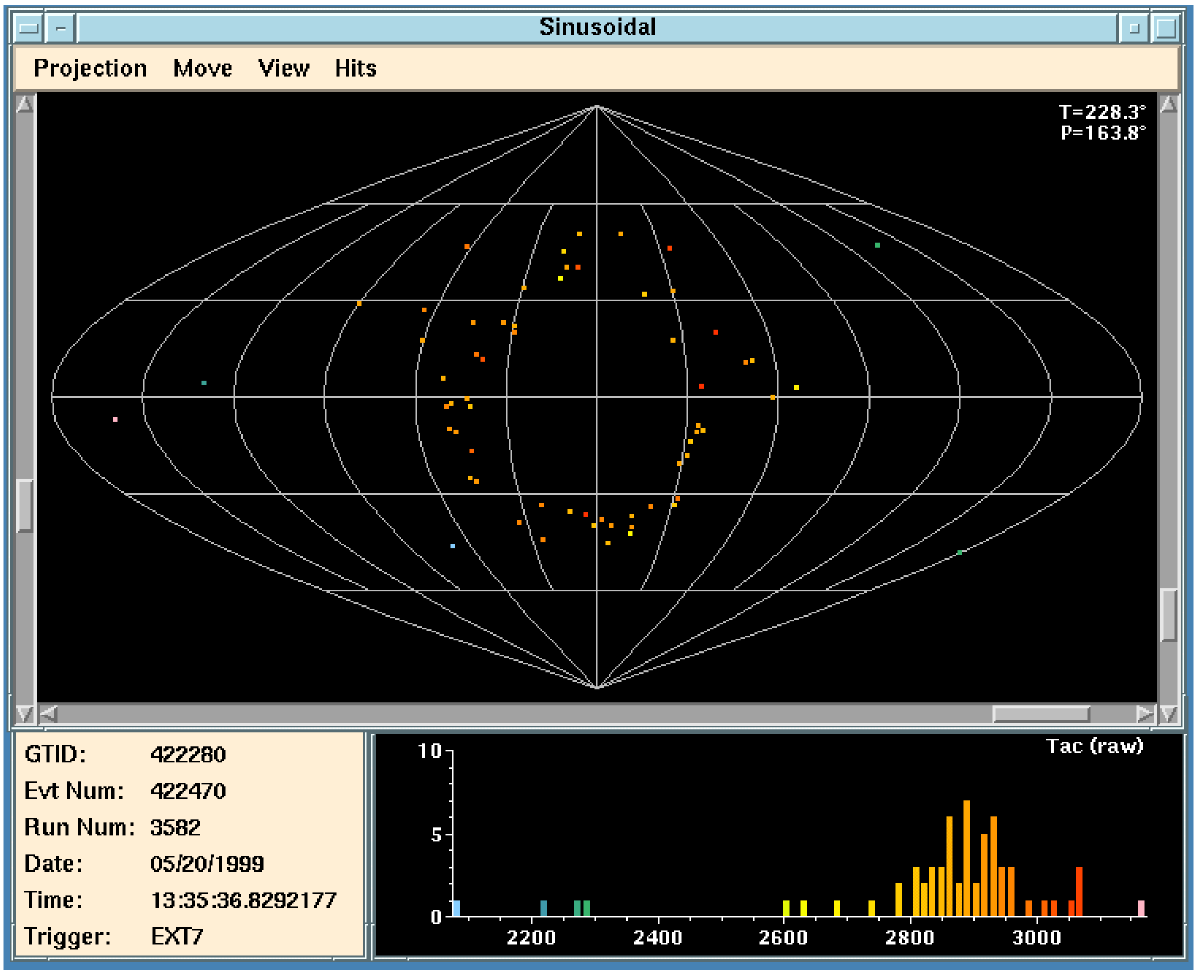
•Reconstruction: determine position and angular resolution, efficiency.

√Laser.
√^{16}N.

•Neutron Detection Efficiency: neutral current measurement.

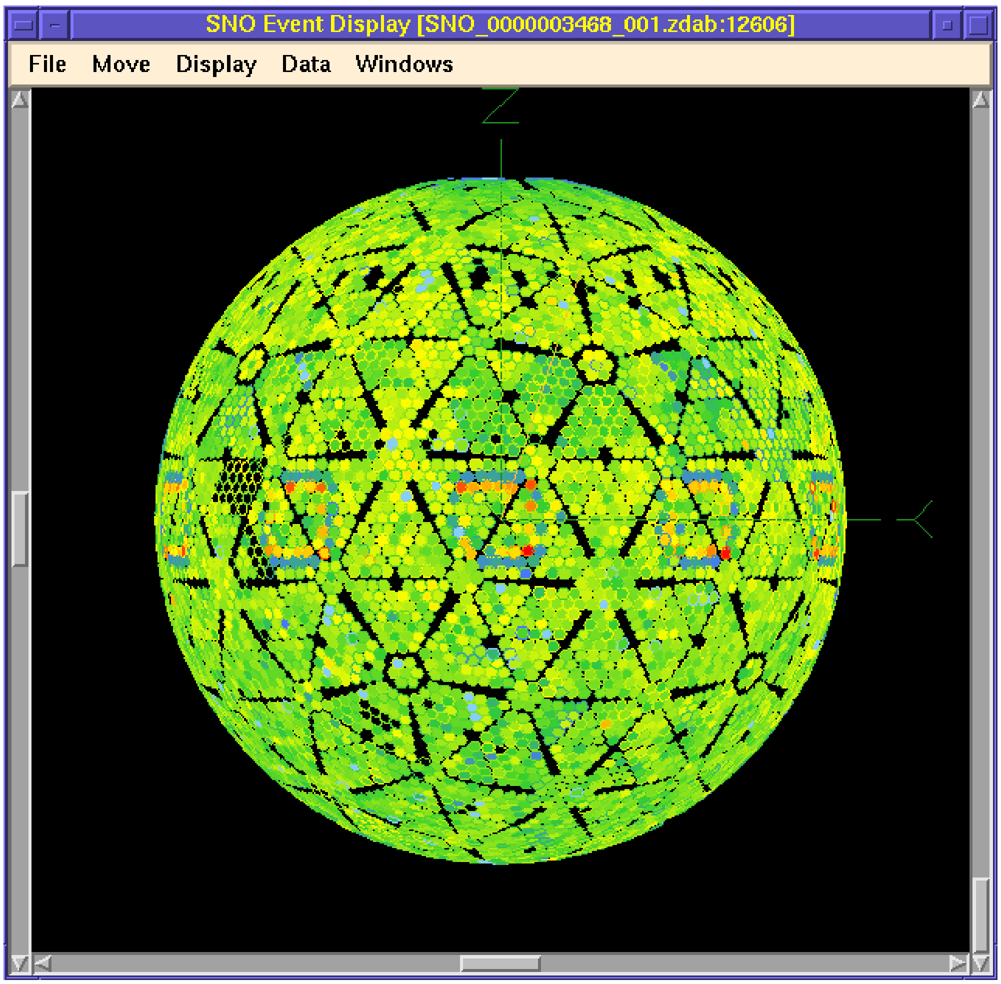
→ ^{252}Cf fission neutron source.
→^{17}N triggered neutron source.

16N Ring



Sinusoidal
Projection
Move
View
Hits
T=228.3°
P=163.8°
GTID: 422280
Evt Num: 422470
Run Num: 3582
Date: 05/20/1999
Time: 13:35:36.8292177
Trigger: EXT7
Tac (raw)
10
5
0
2200
2400
2600
2800
3000

Laser Source, summed events.



SNO Turn-On

The past year has seen the detector brought up and water fill completed.

- April 98 - September 98: Air fill data

→Ran calibration sources: laser, sono, ^{16}N.
→Tube timing looks good.
→Saw ‘acrylic’ muons.
→Saw flashing PMTs.

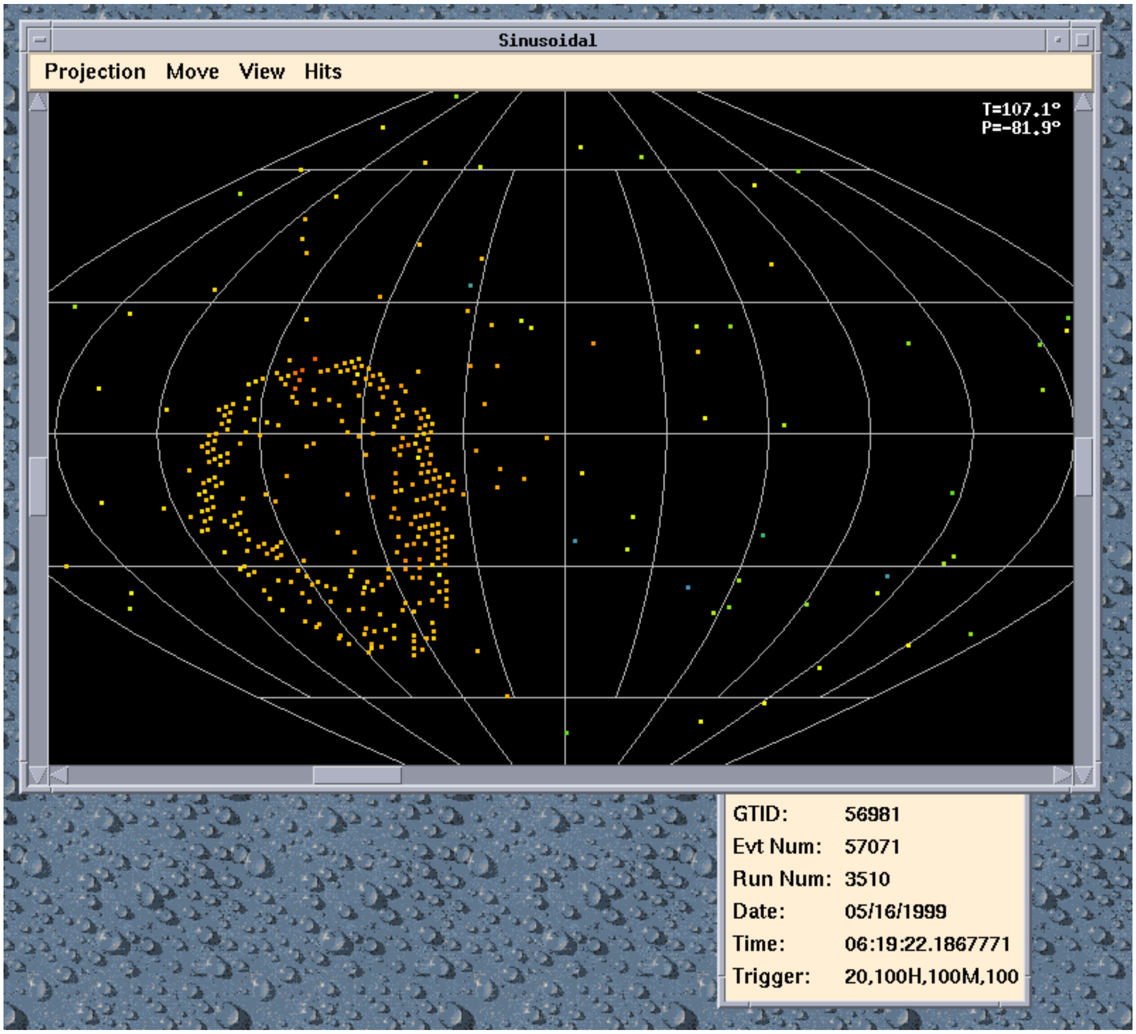
- September 98 - April 99: Partial fill data

→Saw muons.
→Radon studies.
→γ’s & neutrons from rock.
→Laser, sono runs.
→High voltage breakdown (wet end).

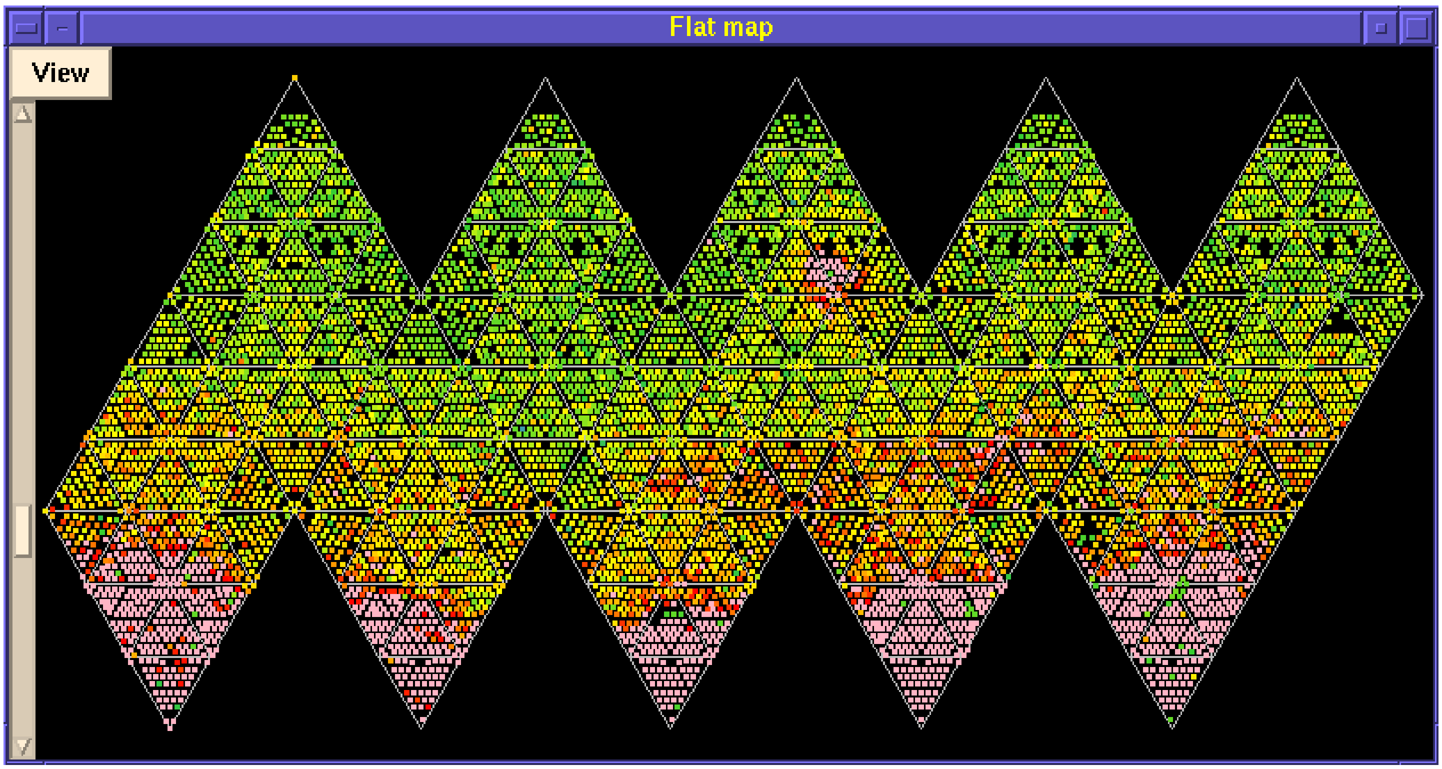
- April 30, 99: Water fill complete

- May 1, 99: Detector turned on!

Contained Muon. # of hit tubes >> expected ν signal.

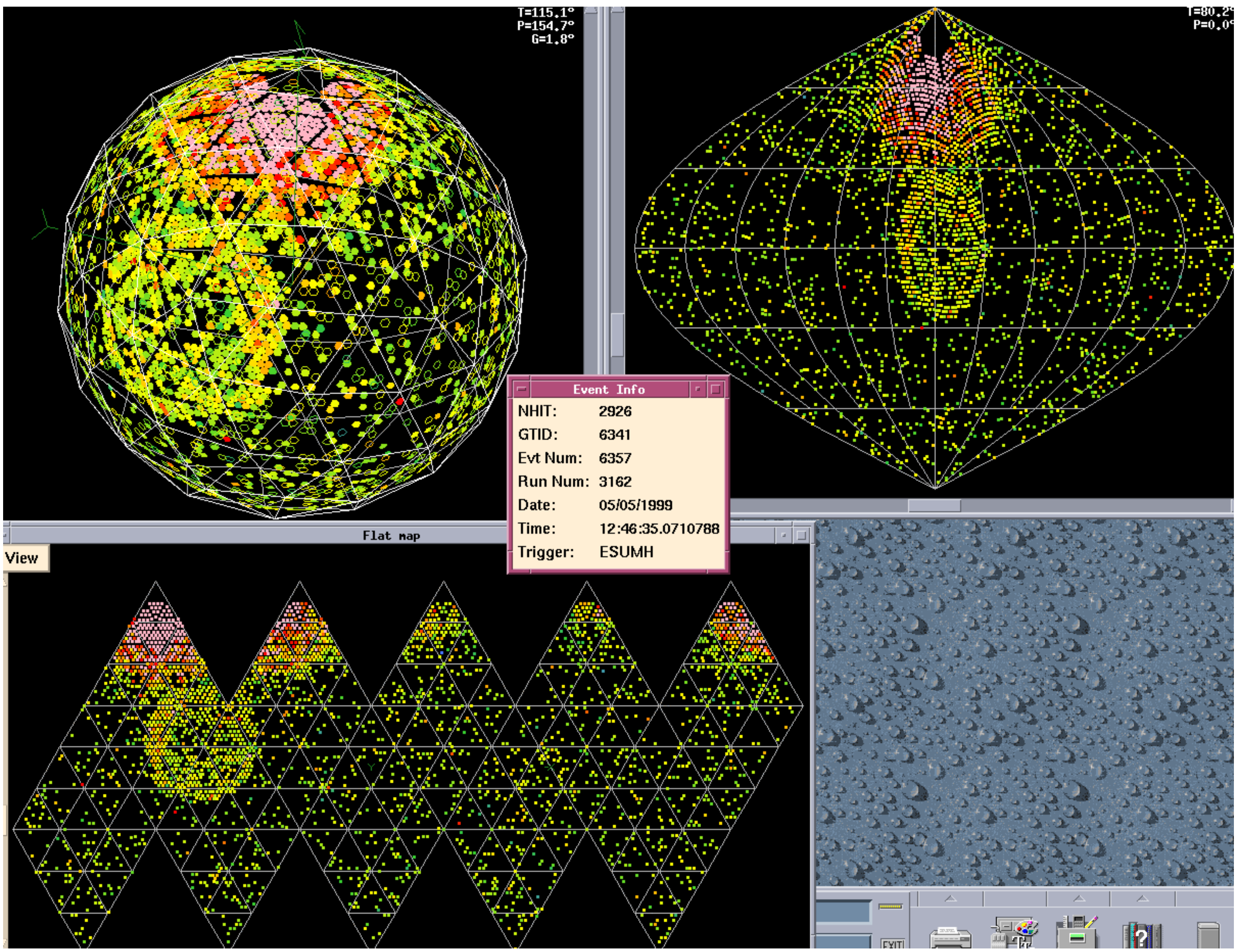


Through-going Muon.



First "Detector Full' Experience (May 99 - present)

- HV breakdown: only one connector seen to exhibit significant breakdown, plus a handful of breakdown events from other connectors.
- Livetime: has been ~65% for this period, dominated by 1 week shutdown for installation of radon barrier. Working towards 100% live within a month or so.
- Optics/Timing: first calibration runs with laser done.
- Energy: first energy calibration runs done using ^{16}N.


T=115.1°
P=154.7°
G=1.8°
T=80.2°
P=0.0°
Event Info
NHIT: 2926
GTID: 6341
Evt Num: 6357
Run Num: 3162
Date: 05/05/1999
Time: 12:46:35.0710788
Trigger: ESUMH
Flat map
View

Detector Performance: The First 3 Months

Very quiet!

- Current channel thresholds < 0.5 pe;
- Tube rates < 800Hz.
- Overall trigger rate (all trigger types) ~ 10 - 15 Hz.

Trigger rates by type:

Trigger	Threshold	Rate (Hz)
Pulsed trigger	zero bias	5
100 ns coincidence	17 PMTs	3-5
20 ns coincidence	17 PMTs	3-5
Energy sum	~300 pe	<1
Prescaled (1:10000)	11 PMTs	<1

With current thresholds, could run at sustained rate 25 times higher than current rate.

- >98% of all channels fully operational and taking data.
- Water already looks clean:
  - H_2O levels within factor of 10 of goal including Radon levels.
  - D_2O levels within factor of 10 of final goal.
- Rate of “flasher” PMTs dropped by ~ factor of 5 compared to air fill data.

The Future

- Two week mine shutdown started this week; detector is on, will give us longest uninterrupted data set so far.
- Production calibration data taking started (timing, optics, energy), continue after shutdown.
- New sources coming online over next few months.
- Work towards 100% livetime ASAP.
- Production physics data taking to start when radon levels are below final goal and detector is stable (thresholds optimized etc).
- Assess background levels, decide on neutral current detection method(s).

Summary and Conclusion

•Initial operation of the SNO detector has been very promising; quieter at turn-on than had been anticipated. SNO is in good shape!

•Poised to start physics programme in a month or so.

•SNO will soon provide:
→Measurement of solar ν_e flux.
→First high-resolution measurement of solar ν_e ^{8}B spectrum.
→First measurement of fraction of non-electron type neutrinos from the Sun.

… stay tuned!