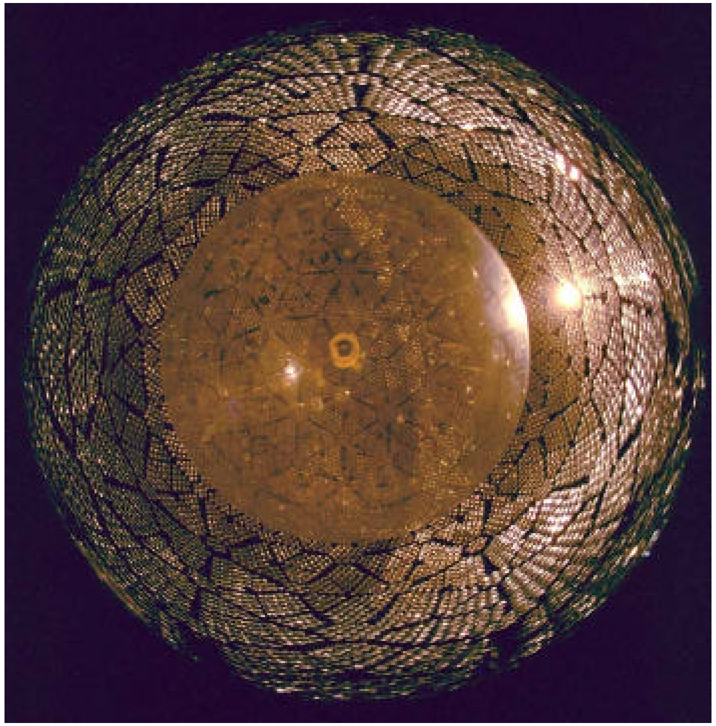

Results from the Sudbury Neutrino Observatory

Karsten M. Heeger

For the SNO Collaboration
CENPA, Seattle

- Design and Physics Objectives
- Detector Operations
- Calibration and Detector Response
- Data Analysis
- First Results

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Sudbury Neutrino Observatory

2092 m to Surface (6010 m w.e.)

17.8 m Diameter Support Structure for
9456 20 cm PMTs
~55% coverage within 7 m

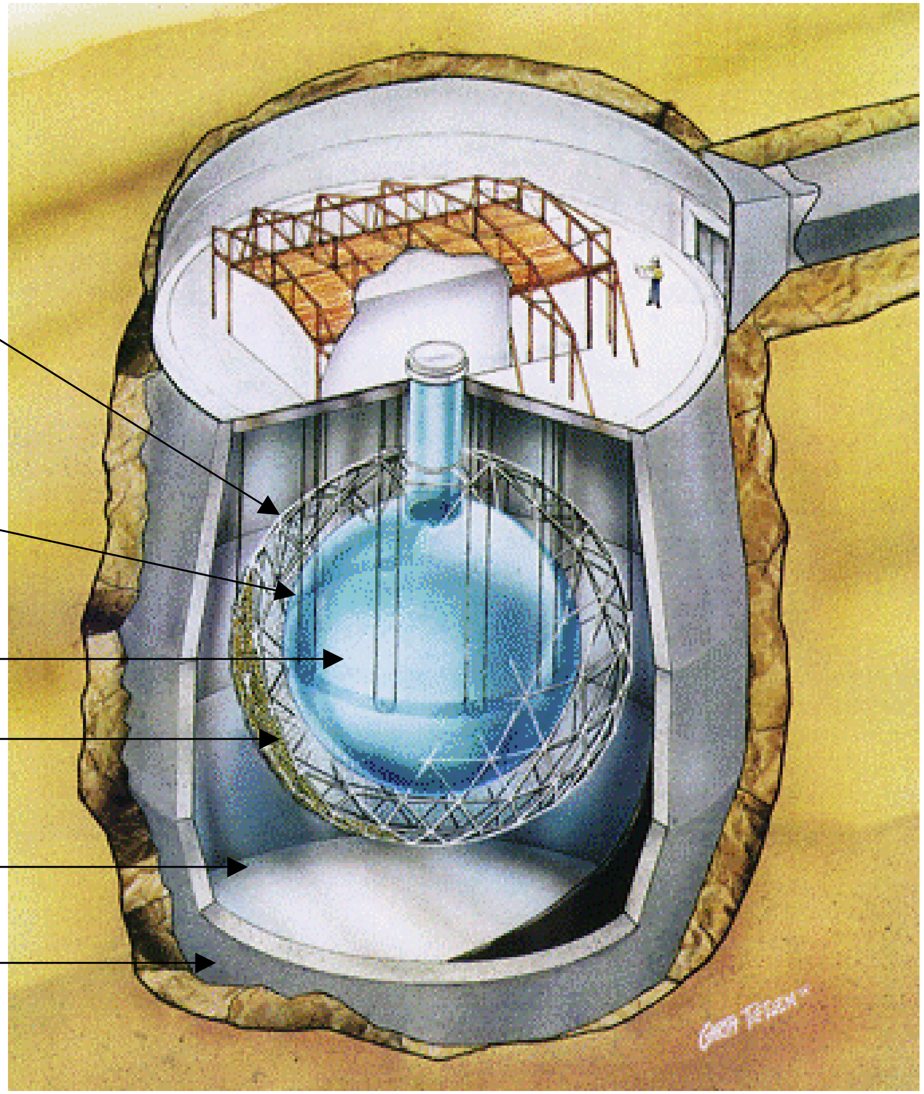
12 m Diameter Acrylic Vessel

1000 Tonnes D_2O

1700 Tonnes Inner
Shielding H_2O

5300 Tonnes Outer Shield H_2O

Urylon Liner and Radon Seal



Neutrino Detection in SNO

Neutrino Interactions in D_2O and H_2O and their Flavor Sensitivity

Charged-Current (CC)	ν_e only
$\nu_e + d \rightarrow e^- + p + p$	Measurement of energy spectrum
$E_{thresh} = 1.4$ MeV	

Elastic Scattering (ES)	ν_x, but enhanced for ν_e
$\nu_x + e^- \rightarrow \nu_x + e^-$	Strong directional sensitivity

Neutral-Current (NC)	ν_x
$\nu_x + d \rightarrow \nu_x + n + p$	Measures total ^8B flux from Sun
$E_{thresh} = 2.2$ MeV	

SNO Physics Program

Solar Neutrinos	• Search for ν flavor change
	CC/ES, CC/NC
	• ^{8}B Total Flux (test of solar models)
	• Spectral distortions
	• Time Dependences
	diurnal
	annual
	solar cycle
	• Measurement of hep flux

Supernova watch, relic SN neutrinos

Antineutrinos

Atmospheric Neutrinos

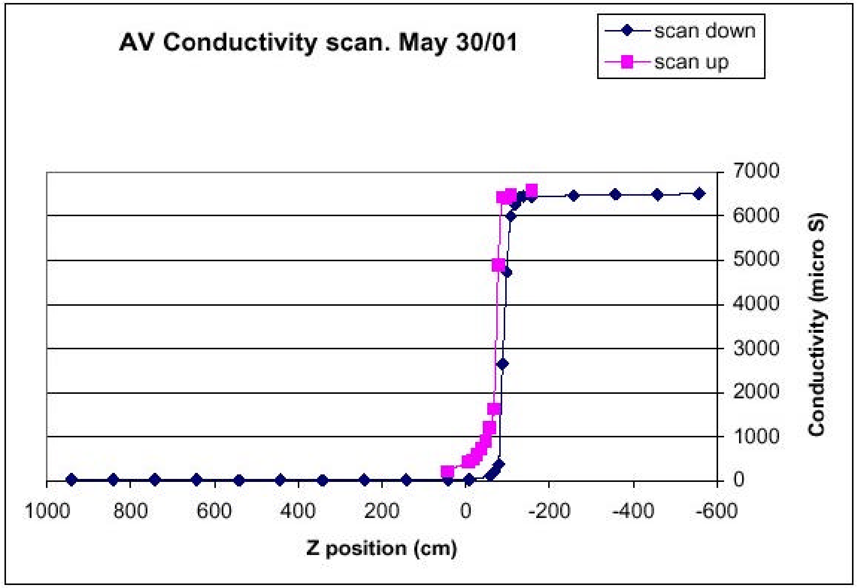
SNO Run Sequence

I. Pure D_2O	CC, ES some NC $n+d \rightarrow t+\gamma$... ($E\gamma = 6.25$ MeV, $\varepsilon_n \sim 24\%$)
II. $D_2O+NaCl$ (added salt)	CC, ES enhanced NC $n+{}^{35}Cl \rightarrow {}^{36}Cl+$ □γ (E □$_{\gamma} = 8.6$ MeV, $\varepsilon_n \sim 45\%$ above threshold)
III. $D_2O+NCDs$ (${}^{3}He$ proportional counters)	Concurrent CC, NC, ES $n+{}^{3}He \rightarrow p+t$ → event by event separation ($\varepsilon_n \sim 37\%$)

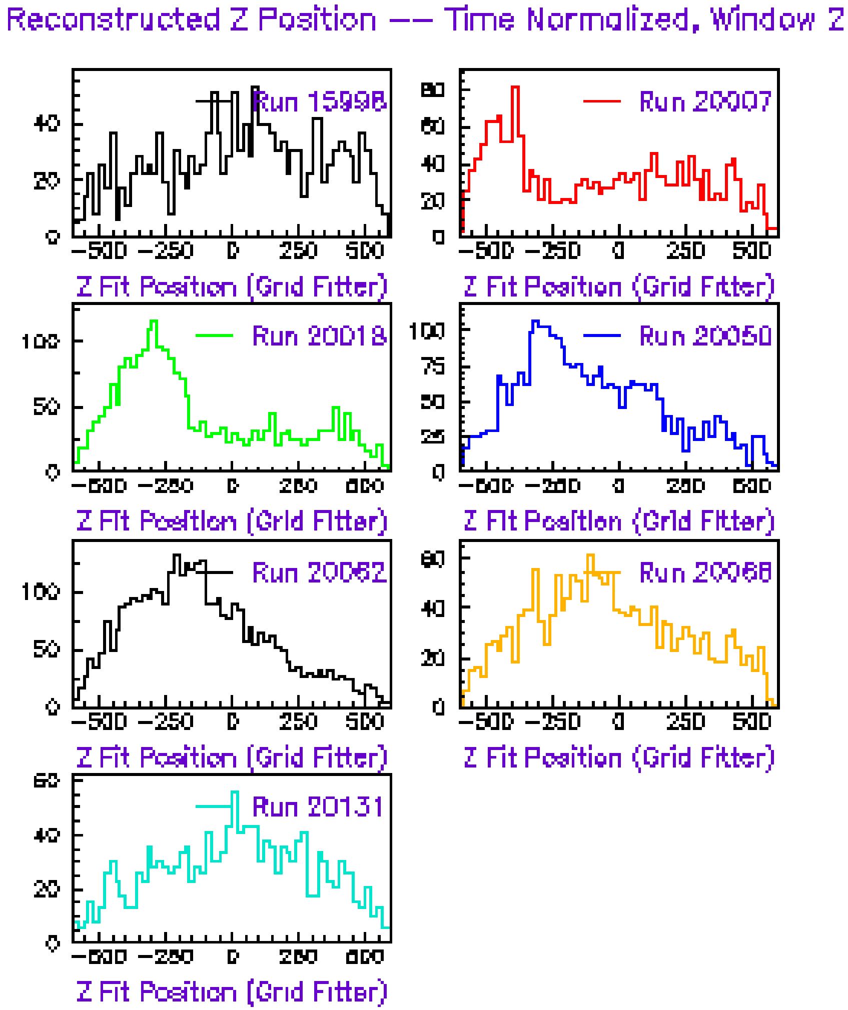
SNO Phase II - Addition of Salt

SNO Phase II: D_2O+NaCL
- Runtime about 8 months
- Enhances neutron capture efficiency:
  ε_n~83% (~45% above threshold)

May 28 - June 5, 2001
- Salt introduced at bottom of detector
- Addition of NaCL completed



Event Rate vs z Position During Addition of Salt

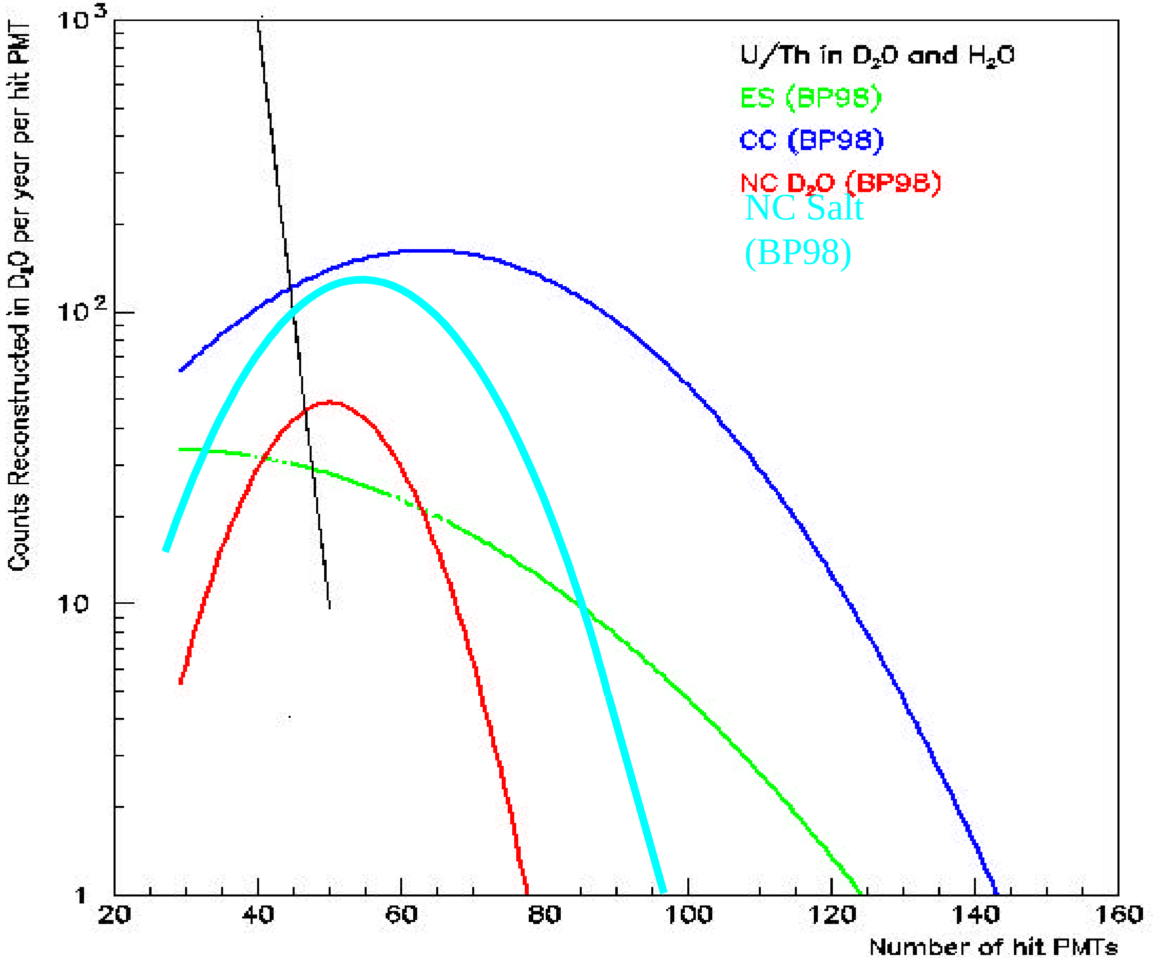


SNO Phase II - Physics with Salt

- **Enhanced NC sensitivity**
ε_n~45% above threshold

- **Systematic check of**
energy scale
E_γ=8.6 MeV

- **NC and CC separation by**
event isotropy



Preparations for Phase III - Neutral Current Detectors

NCD Array

NC Detection: $n+{}^3He \rightarrow p+t$
Total Length: 775 m
Counters: 292 (300)
Vertical Strings: 96
n capture efficiency: $\varepsilon_n \sim 45\%$

Neutron Background Estimates from Radioassay

uniform+near vessel: <4.4% SSM

Status of NCD Project

First deployment of NCD into D_2O Sep 2000
Counter construction complete April 2001
Electronics Commissioning Summer 2001
DAQ partially complete
Analysis of cooldown data
Development of pulse shape analysis techniques

Schedule

Pre-deployment welding: Winter 2001
Deployment of NCD array: Summer 2002

Calibration and Detector Response

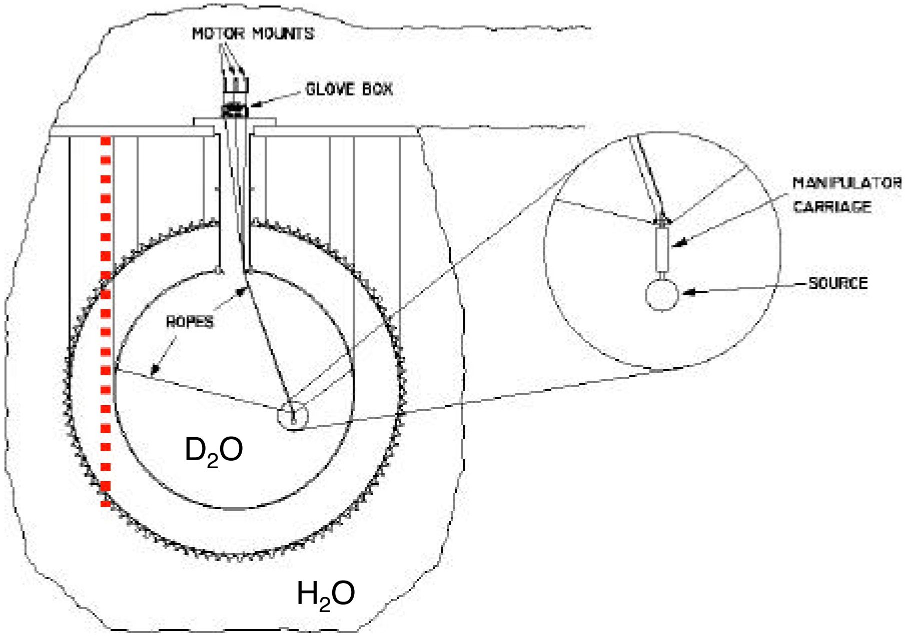
Calibration Issues

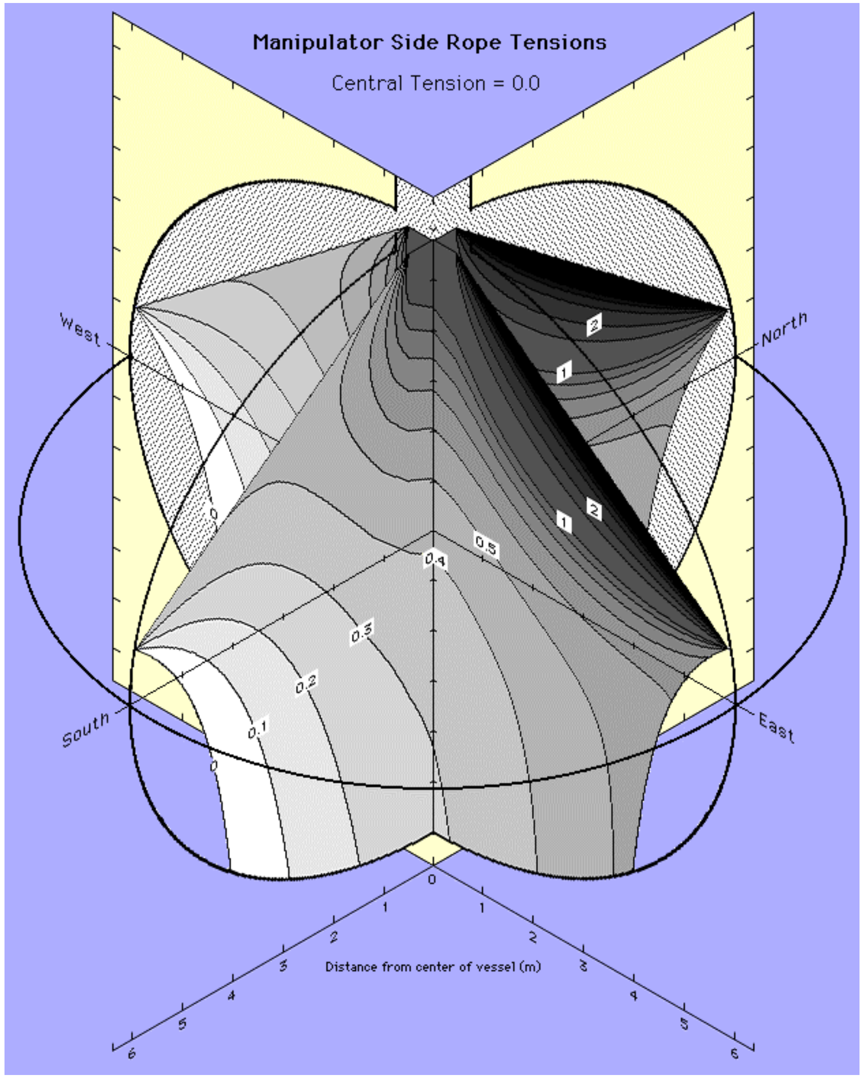
- Photon Generation, transport, and detection
  - different media: D_2O, acrylic, H_2O, PMT
  - attenuation, reflection, scattering
- Detector geometry
- Detector status and conditions

Calibration Techniques

Electronics	electronic pulsers, pulsed light sources	
Optical Response	pulsed laser at λ=337, 365, 386, 420, 500, and 620 nm, ~2 ns resolution	
Energy response	^{16}N	6.13 MeV γ, tagged
	p,t	19.8 MeV γ
	neutrons	6.25 MeV γ
	^{8}Li β spectrum	13 MeV endpoint
	^{8}B β spectrum	15 MeV endpoint

Calibration Systems





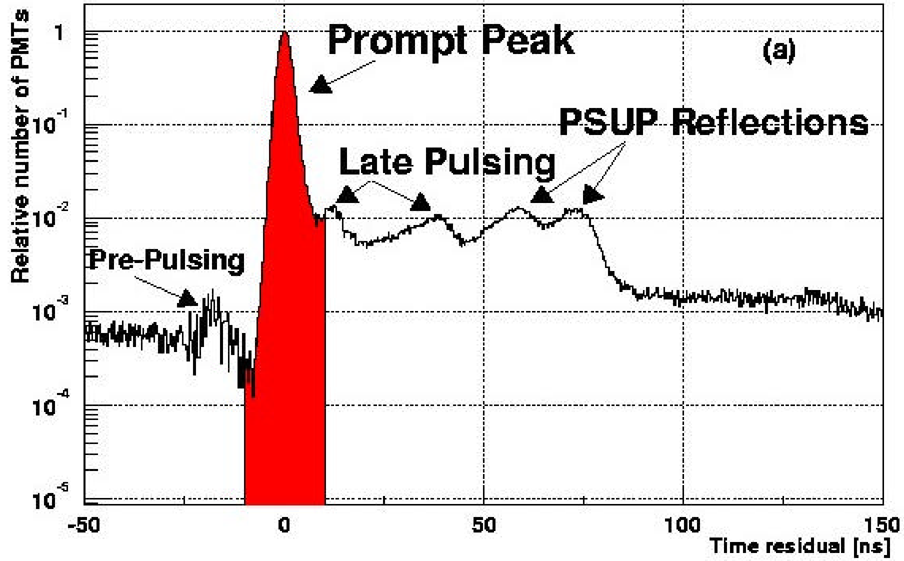
Source Deployment

- In two planes in D_2O
- One line in H_2O (so far)
- Positioning accuracy: $\pm$ 2-5 cm

Optical Response - Timing Residuals

Timing Residuals
Difference in time between hit and direct flight time from vertex

Source at Center



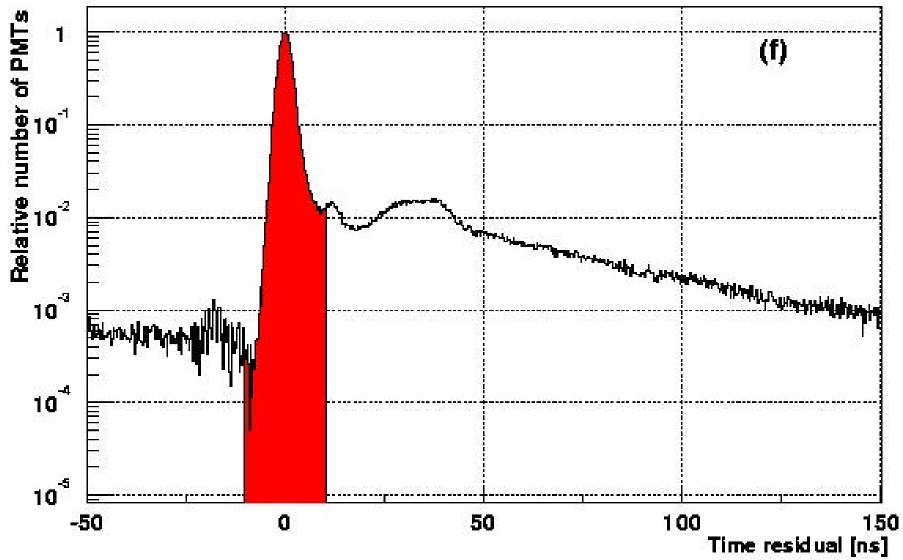
Event Energy Estimators

I. Prompt light

with position and direction correction

II. Total light (Nhit)
without position and direction correction

Source at z=500 cm



Time Since Last Hit Dependence

Effect
• Variation in ADC pedestal with time since last hit (TSLH)
• Variation in ADC slope with time since last hit (TSLH)

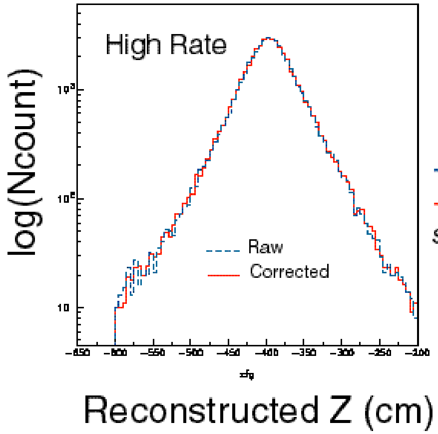
Observation
Timing residuals depend on data rate

Software Solution
Calibrated out in reconstruction of neutrino data

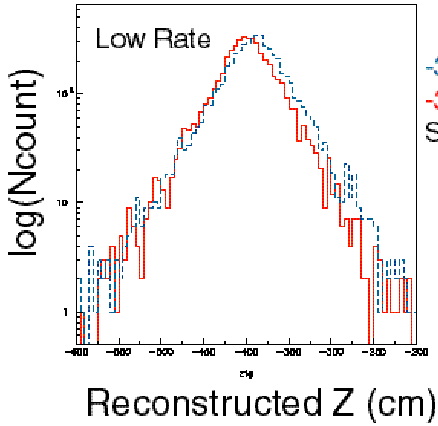
Effect on Reconstruction

N16 source at Z=-400cm

Low Rate vs High Rate Data & Corrections



-395.9 (0.5) w/o correction
-395.5 (0.5) w correction
source at -400 cm

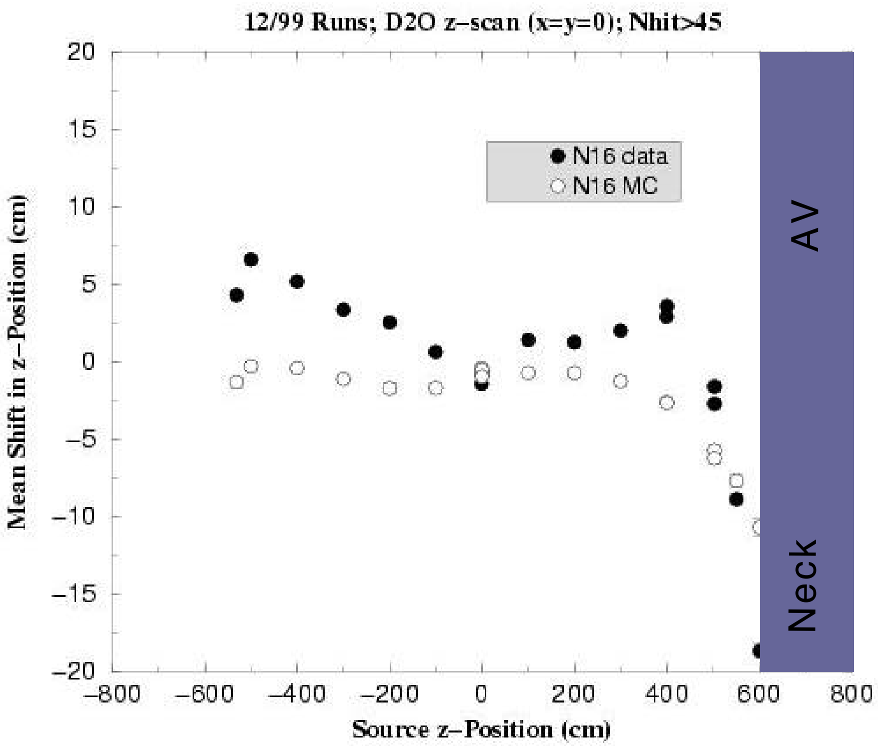


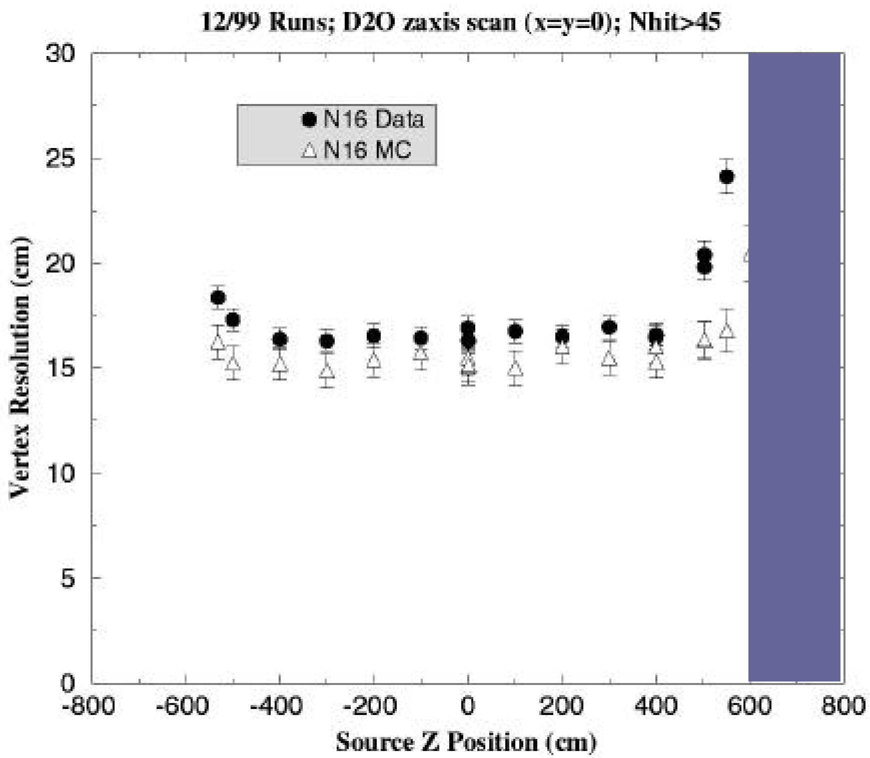
-389.7 (0.5) w/o correction
-398.5 (0.5) w/ correction
Source at -400 cm

Event Reconstruction

Calibration Sources in D_2O ^{16}N γ's and ^{8}Li β's
in H_2O ^{16}N γ's

Vertex resolution: ~16 cm



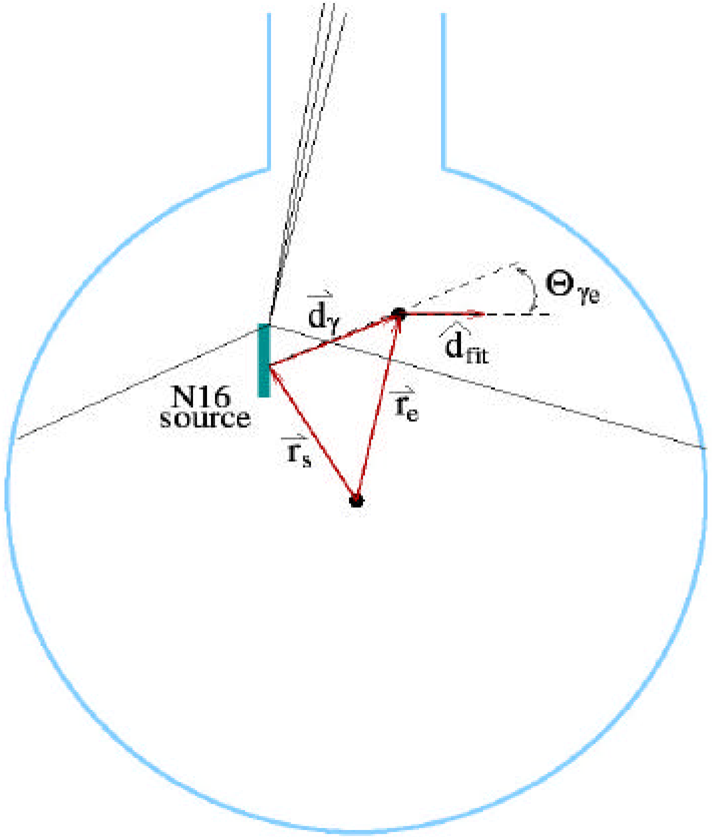


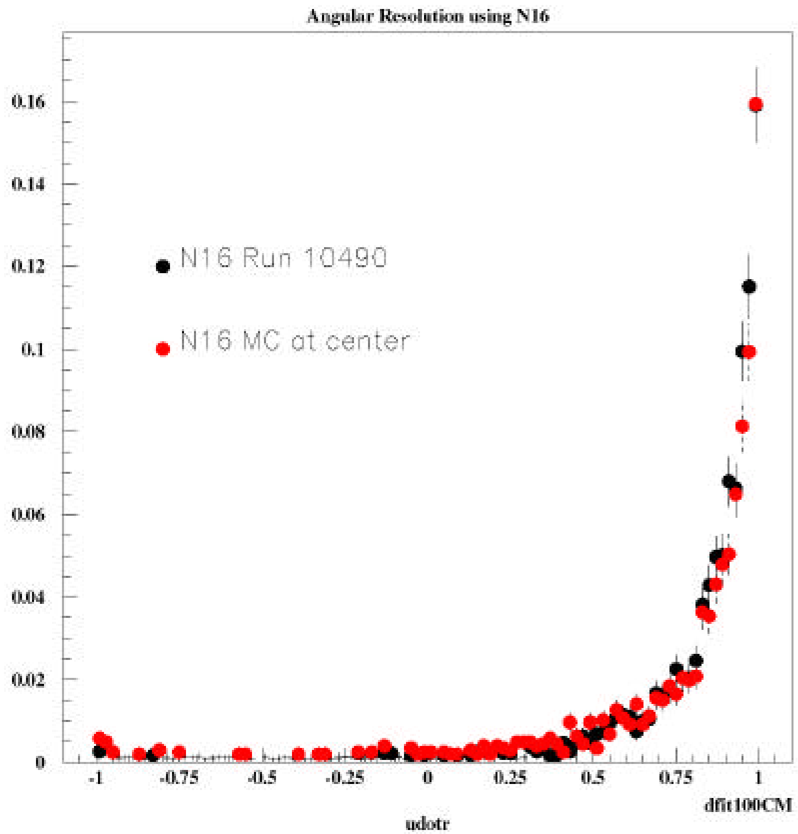
Angular Resolution

Error in reconstructed event direction: $\theta_e = \vec{u}_{fit} \bullet \vec{u}_e$

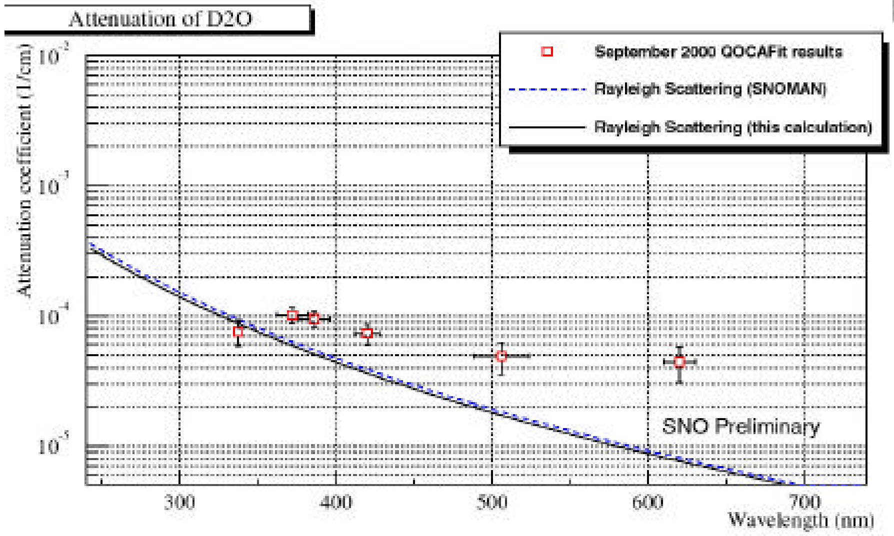
Resolution function: true angular resolution + multiple scattering of e^-

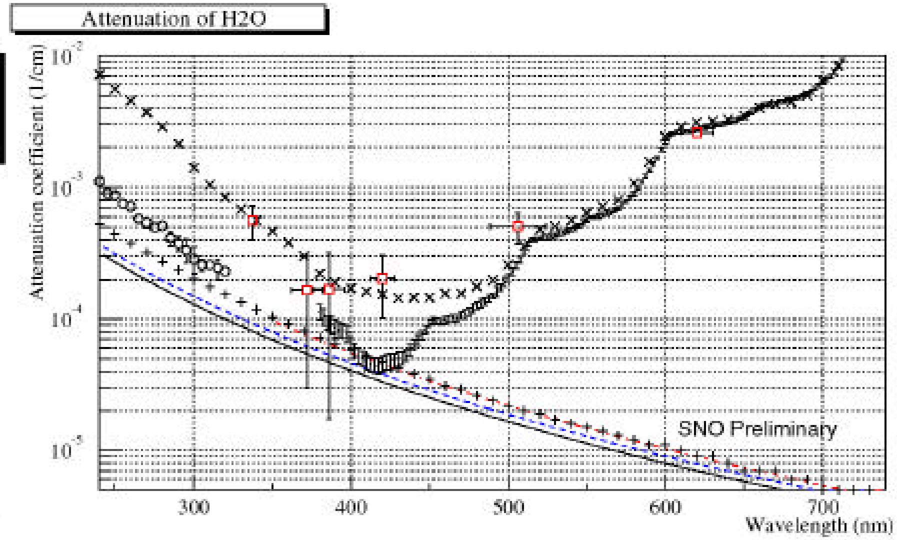
Angular resolution: 26.7° → small effect on flux determination

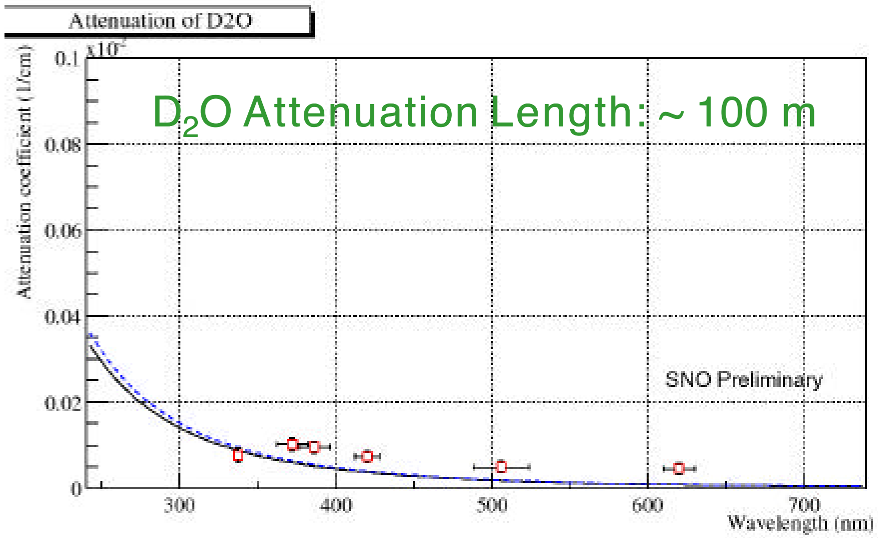


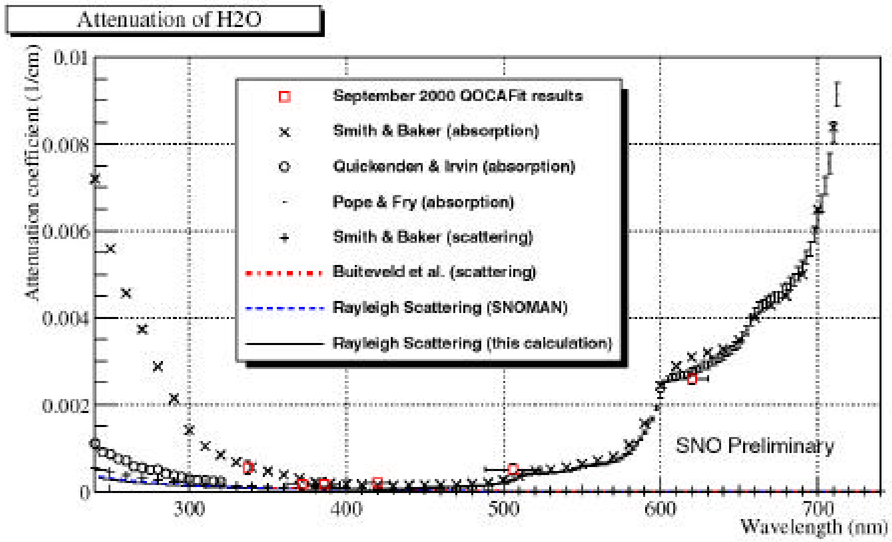


Optical Response: D_2O and H_2O Attenuation









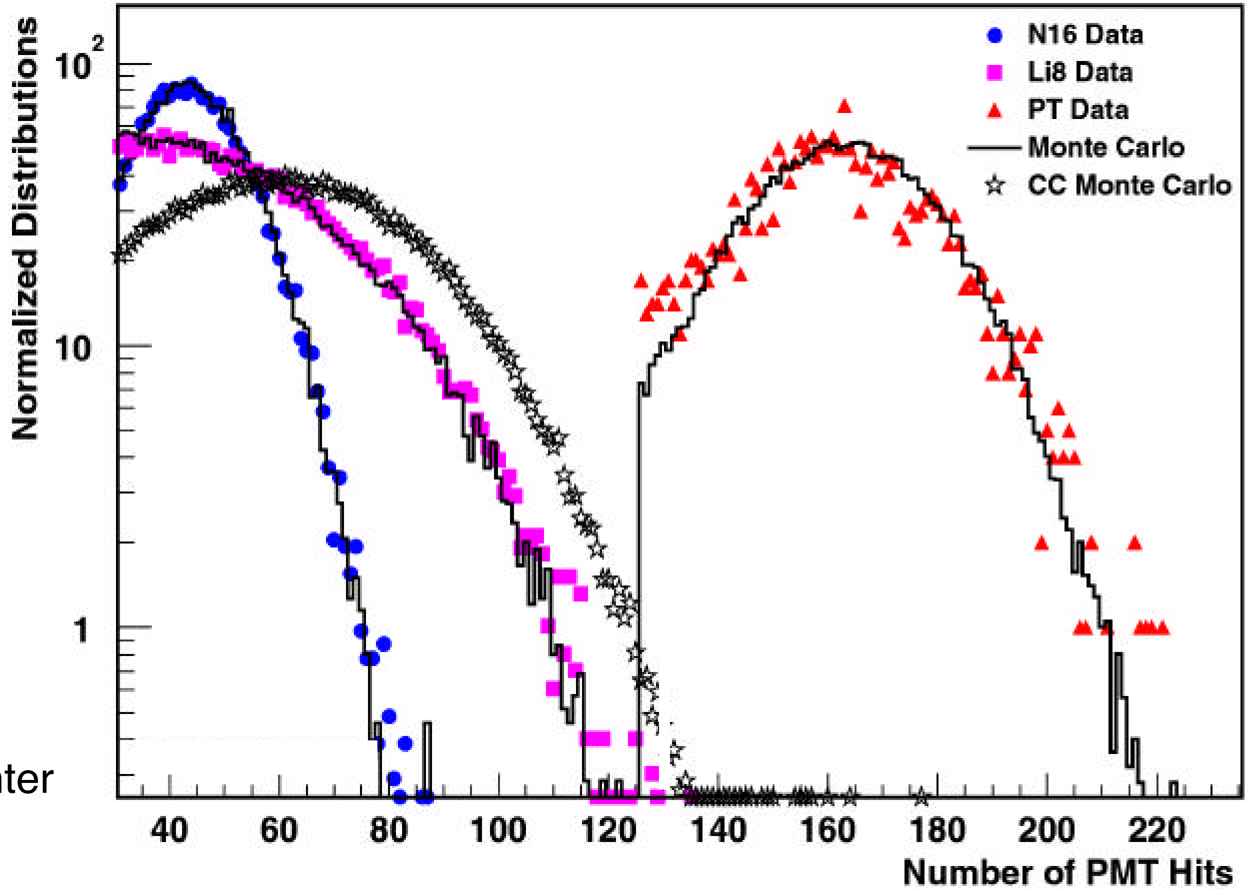
SNO Energy Response - Absolute Energy Scale

- established with triggered ^{16}N (E_γ=6.13 MeV)
- tested against ^{8}Li, ^{252}Cf, and (p,t) source

^{8}Li
13 MeV endpoint
(n,α) on ^{11}B

(p,t)
$E\gamma$=19.8 MeV
from $^{3}H(p,\gamma)^{4}He$

^{252}Cf
$E\gamma$=6.25 MeV
from n capture



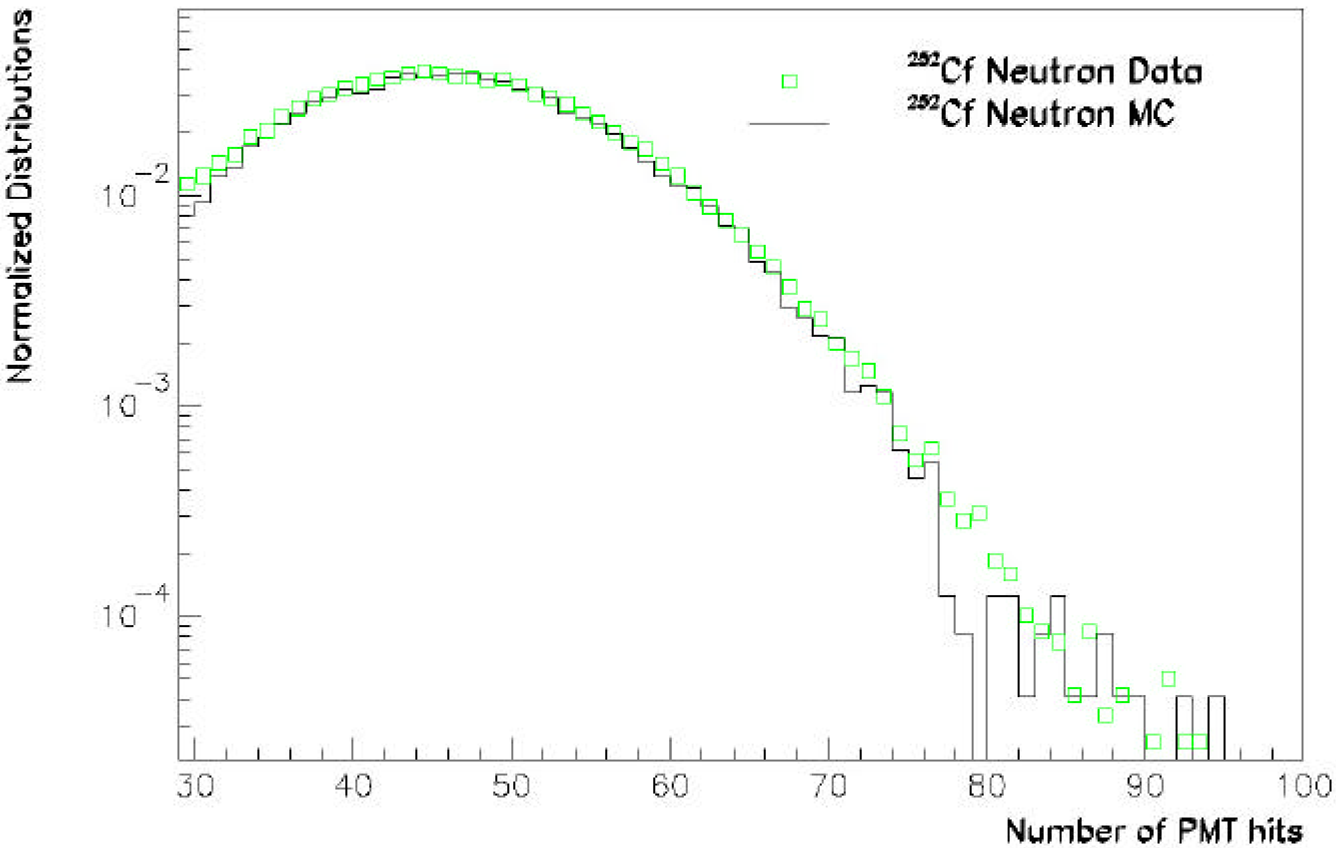
Sources at Center

SNO Energy Response - Spatial Dependence

• various ^{16}N positions inside D_2O
• Monte-Carlo prediction tested against extended distribution of 6.25-MeV γ from ^{252}Cf neutrons

→ more difficult to analyze passive neutron source

→ tagged neutron source under development

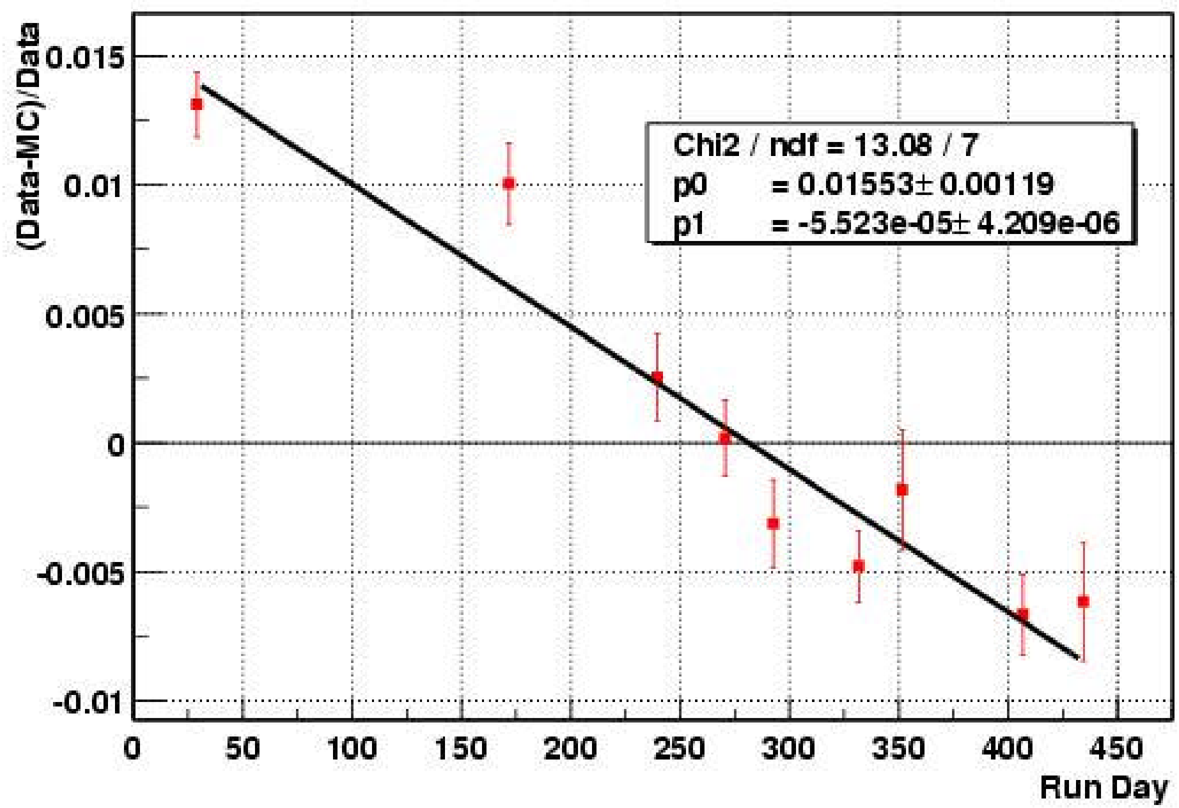


Temporal Dependence of Energy Scale

- use center ^{16}N high voltage runs and compare data and Monte-Carlo
- actual detector configurations are simulated: noise rate, working tubes

→ energy drift: 2.2 ± 0.2% year

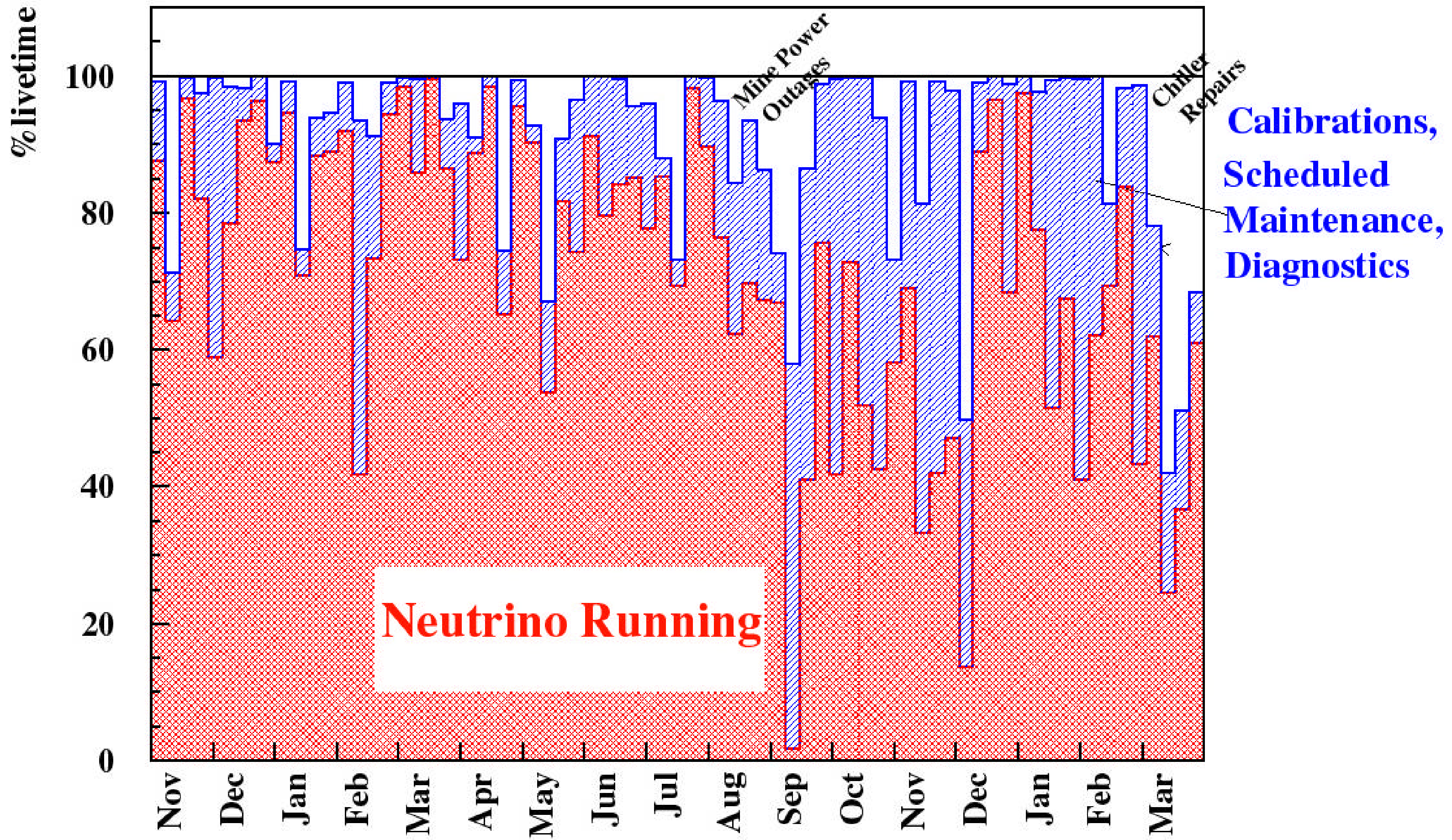
→ cause of drift is under investigation



Data Taking and Live Time

Nov 2, 1999 → Jan 15, 2001

240.9 live days
neutrino runtime



Detector Performance

Trigger Rates and Thresholds in 2001

Trigger Type	Hardware Threshold	Rate (Hz)
Pulsed Trigger	Zero Bias	5
100 ns Coincidence	16 PMTs	8
20ns Coincidence	16 PMTS	0.02
Energy sum	~150 p.e.	4
Prescaled (1:1000)	11 PMTs	0.1

Channel threshold:	~0.25 photo-electrons
Multiplicity trigger:	18 Nhit within 93 ns
Trigger efficiency:	100% efficiency by 25 Nhit (~3 MeV)

Instantaneous Trigger Rate	~15-18 Hz
Data Trigger Rate	~6-8 Hz
Hardware Threshold	~2 MeV

Solar Neutrino Data Analysis

Run Selection
Data Division
Calibration
Monte-Carlo Simulations

↓

Instrumental Background Removal Reconstruction I	Instrumental Background Removal Reconstruction II

↓

High Level Cuts

↓

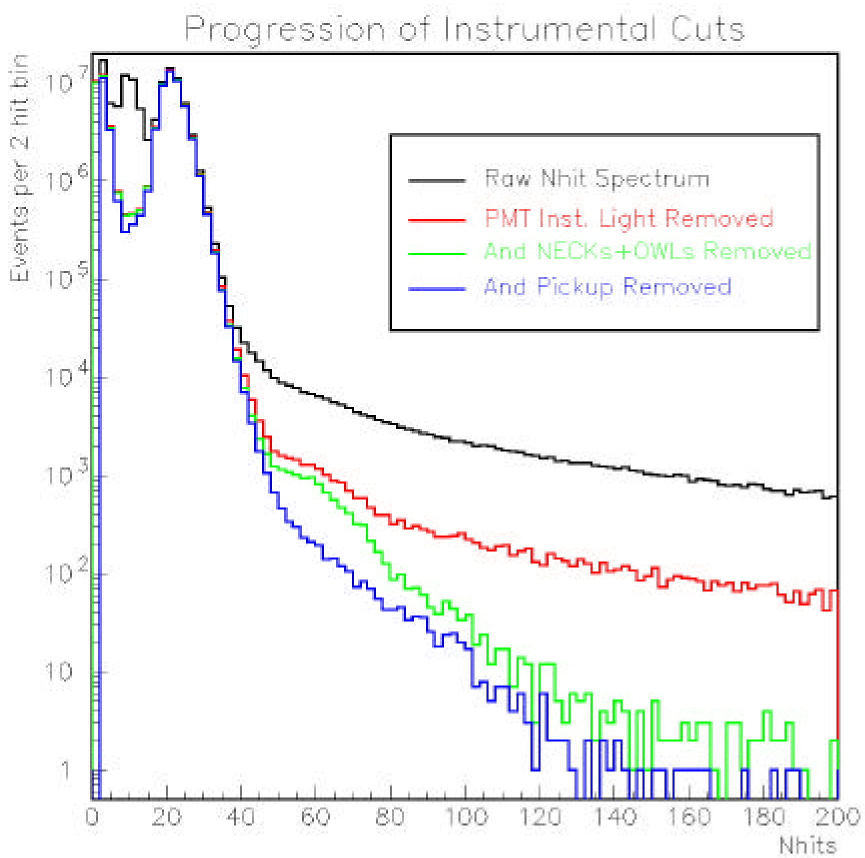
Energy Estimator (prompt light) Small Fiducial Volume High Threshold Background Estimates Signal Extraction Technique	Energy Estimator (total light) Variable Fiducial Volume Lower Threshold Fit to the Backgrounds Signal Extraction Technique

Data Flow & Instrumental Background Cuts

Data Flow

Analysis Step	Events
Total Event Triggers	355,320,964
Neutrino Data Triggers	143,756,178
Nhit≥30	6,372,899
Instrumental Background	1,842,491
Muon Followers	1,809,979
High Level Cuts	956,535
Fiducial Volume Cut	18,783
Threshold Cut, $T_{eff} \geq 6.75$ MeV	1169

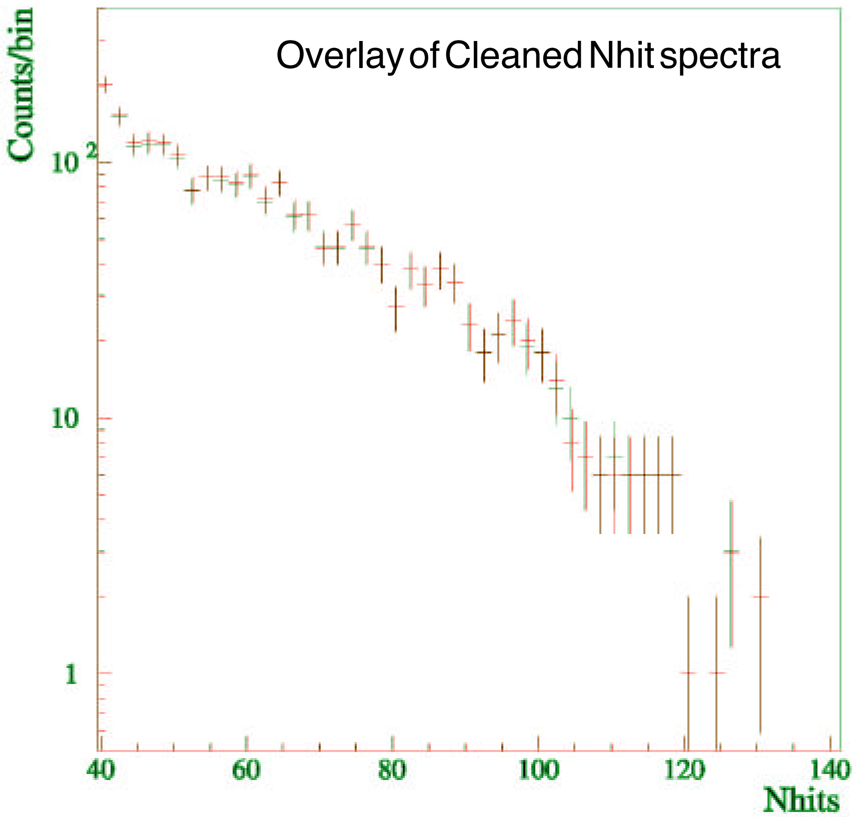
Total Events
In Final Data Set 1169

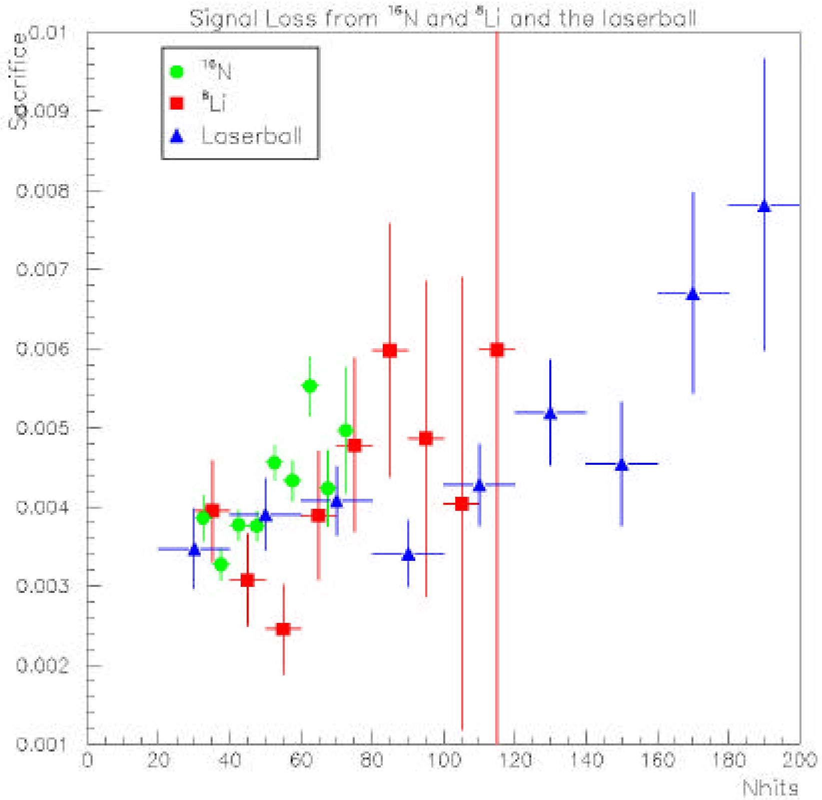


High Level Cuts: Reconstruction figures of merit
In-time light
Event isotropy (θ_{ij})

Removal of Instrumental Background

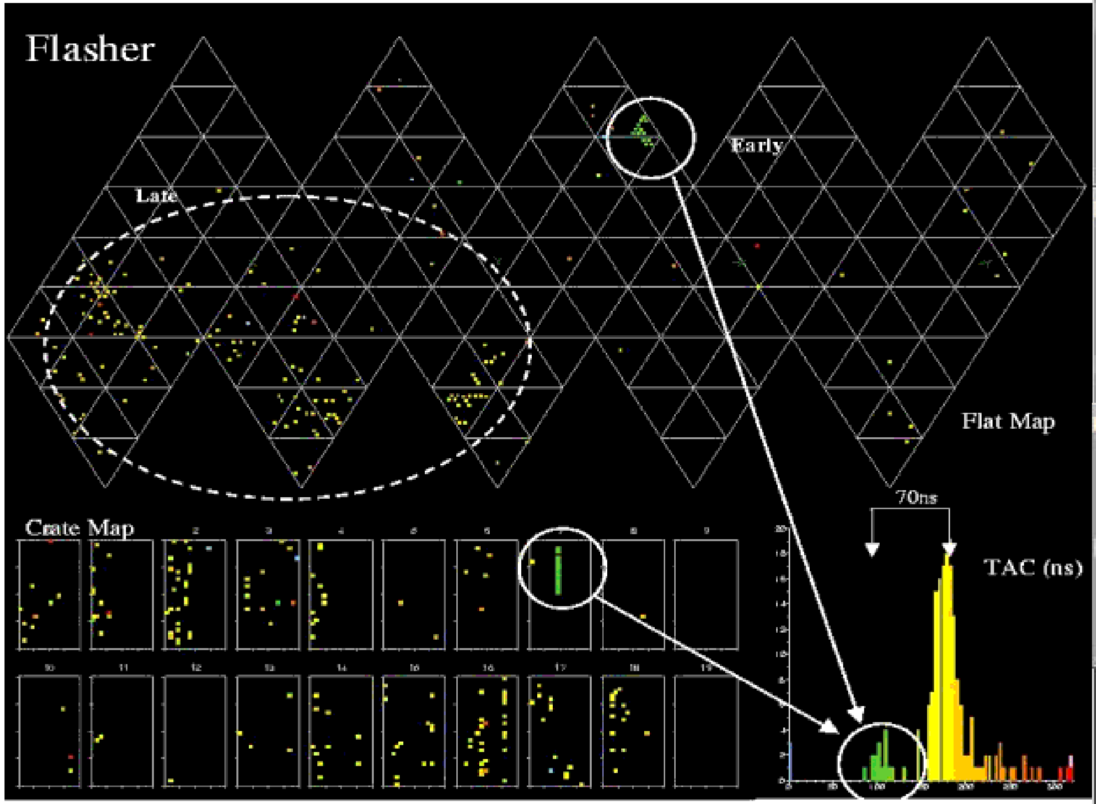
Instrumental removal: Two independent methods
Signal loss: **0.4±0.3%** within R_{fit} 550 cm from ^{16}N, ^{8}Li, and the laser ball
Contamination: limits from bifurcated analyses and hand-scanning

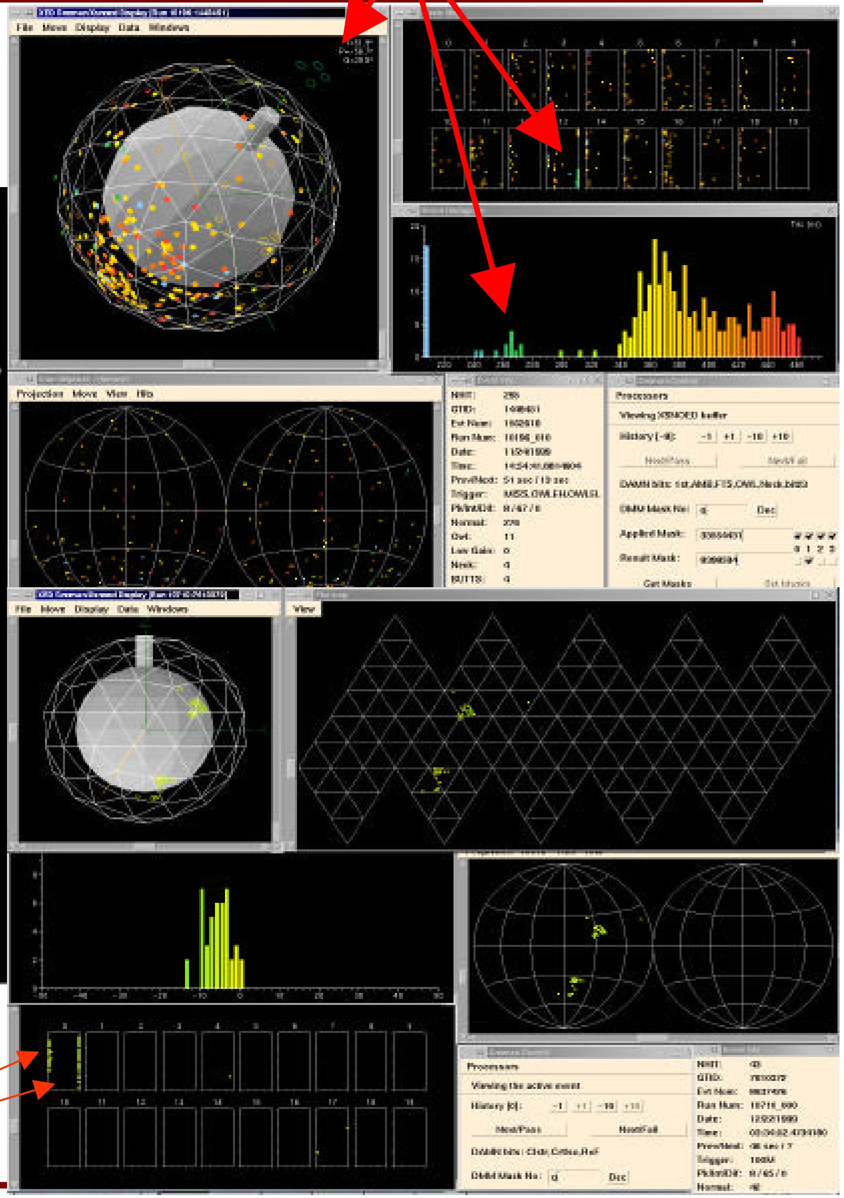




Instrumental Backgrounds

Neck Tubes Fired





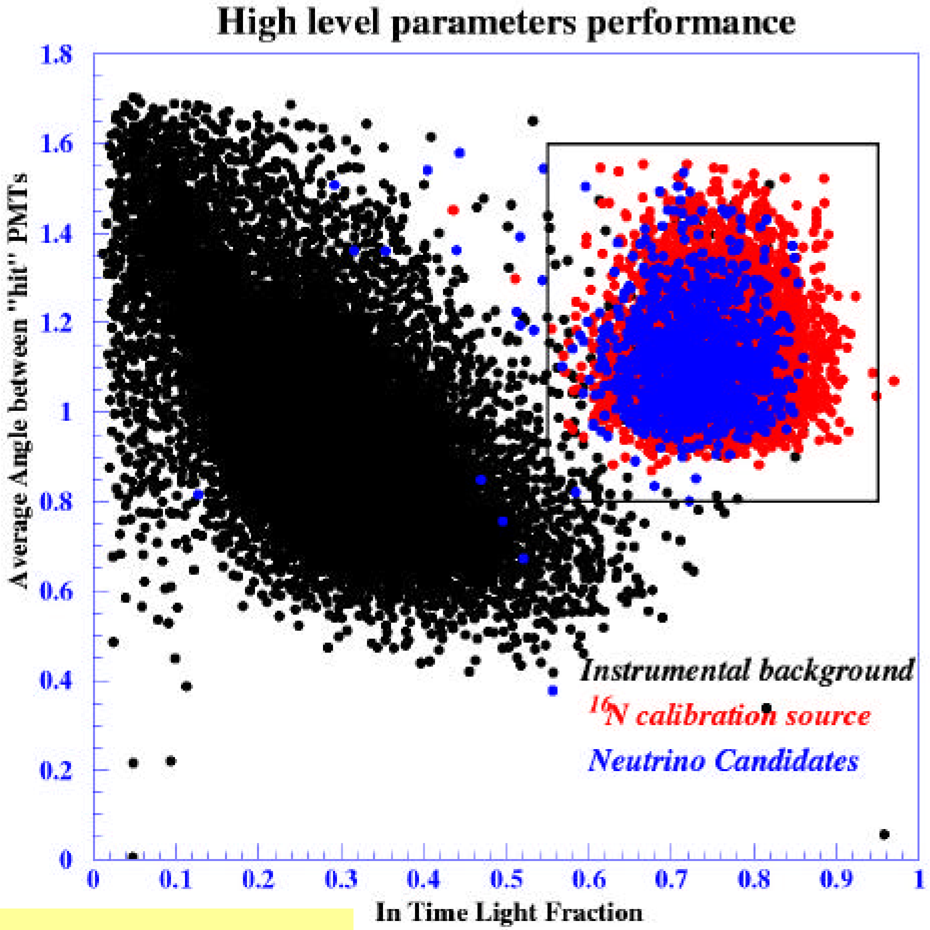
Electronic Pickup

High Level Data Cuts

- **Reconstruction Figures of Merit**

- **In**-Time Light Fraction
→ uses detailed PMT time distributions

- **Event Isotropy**
→ Average angle between hit PMTs



Event Isotropy
- Tests hypothesis of single-particle origin for each event
- Discriminates between simple Cerenkov electron and multiple vertices

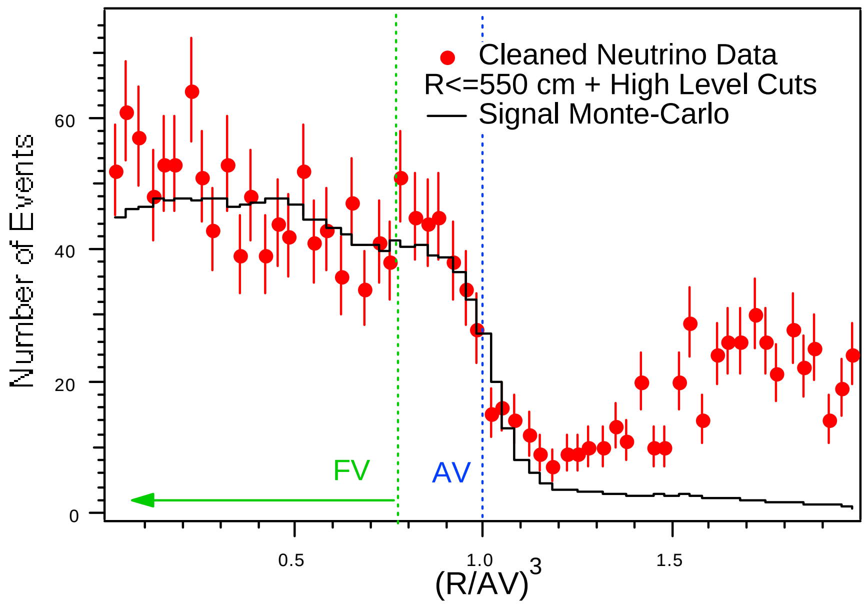
From triggered ^{16}N, ^{8}Li, and bifurcated analyses

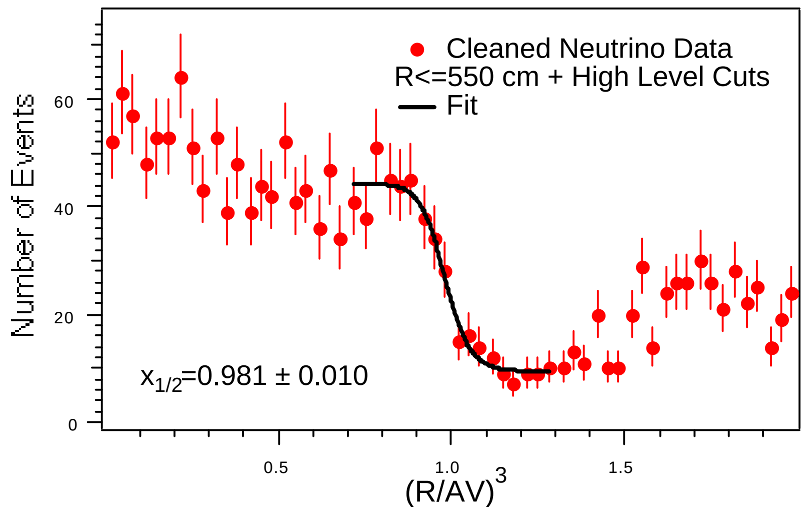
Volume-weighted signal loss: 1.4 +0.7/-0.6%

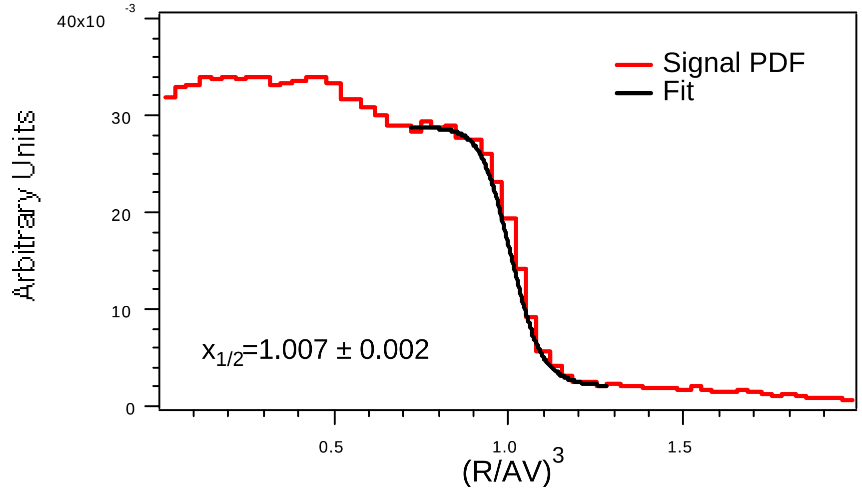
Residual instrumental contamination: < 0.2%

Reconstructed Neutrino Candidate Events

Characteristic R^3 Distribution







Fiducial Volume R 550 cm chosen to minimize backgrounds

Variable FV analysis fits backgrounds outside the AV

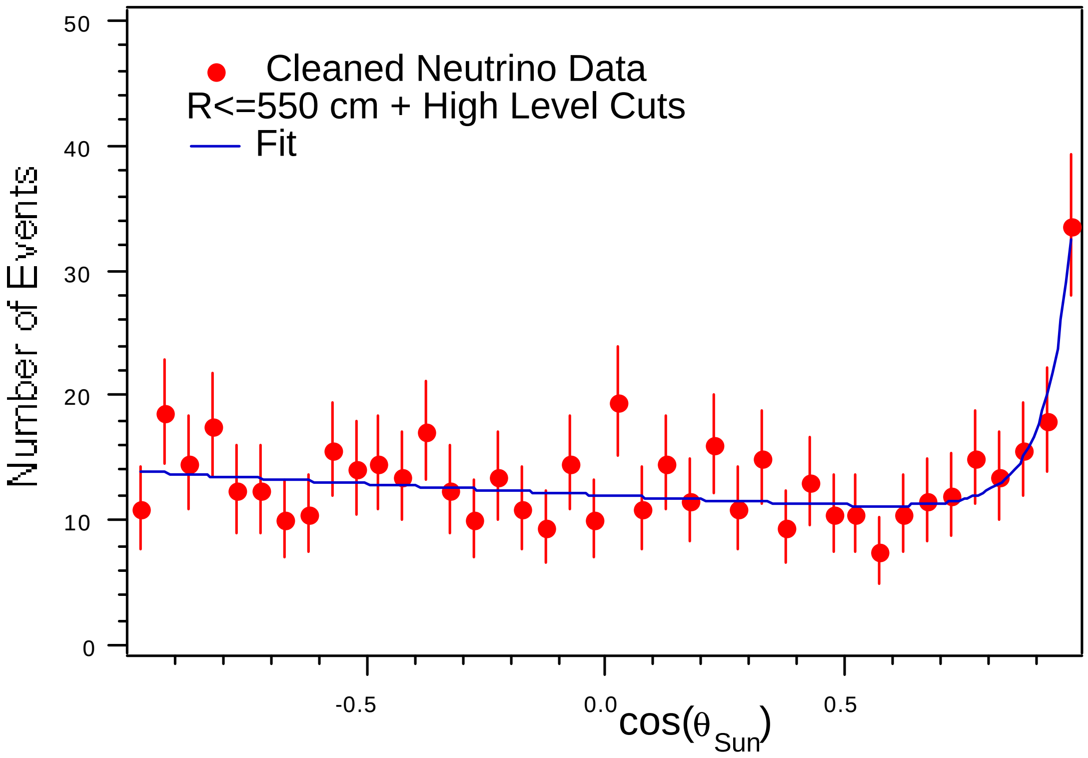
Fit to the AV Position →

Reconstructed Neutrino Candidate Events

Characteristic Solar Angle Distribution

Neutrino Candidate Events
$R_{fit} \leq 550$cm
Nhit 65
High Level Cuts

Fit based on Monte-Carlo distributions



Note: Can already extract with larger uncertainty CC and ES rate from fits to $\cos(\theta_{Sun})$ distribution alone

Reconstructed Neutrino Candidate Events

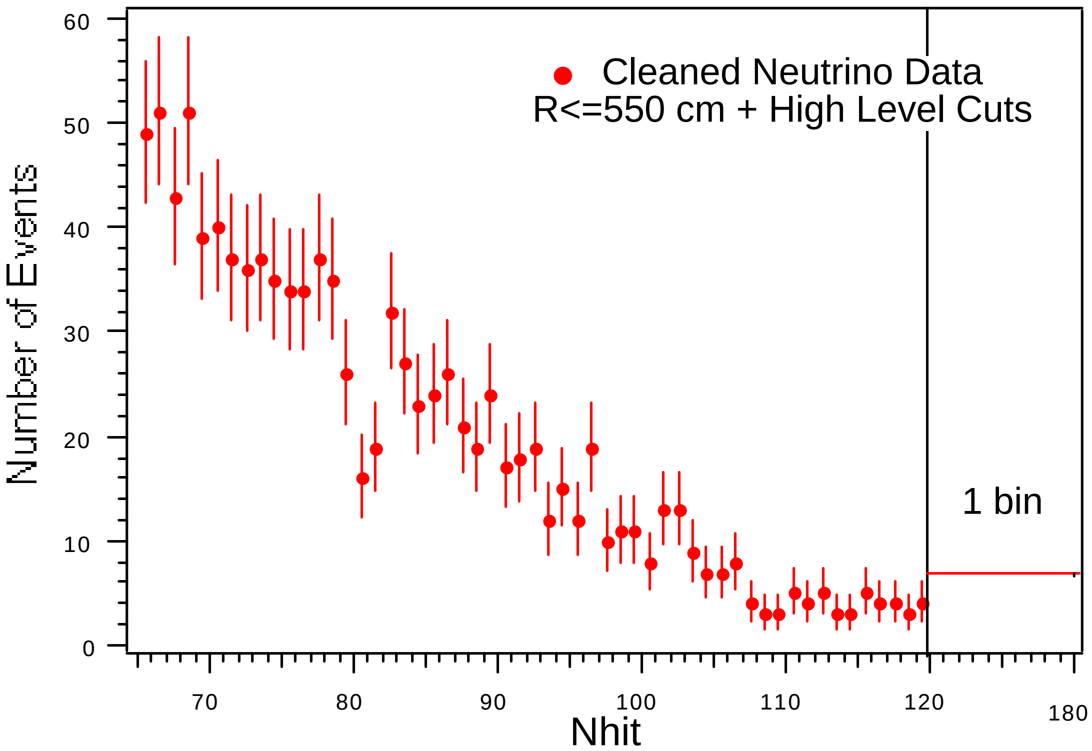
Characteristic Energy Spectrum

Event Energy Estimators

T_{eff} or Nhit

→ both are calibrated with ^{16}N

→ volume weighted mean response: ~ 9 Nhit/MeV

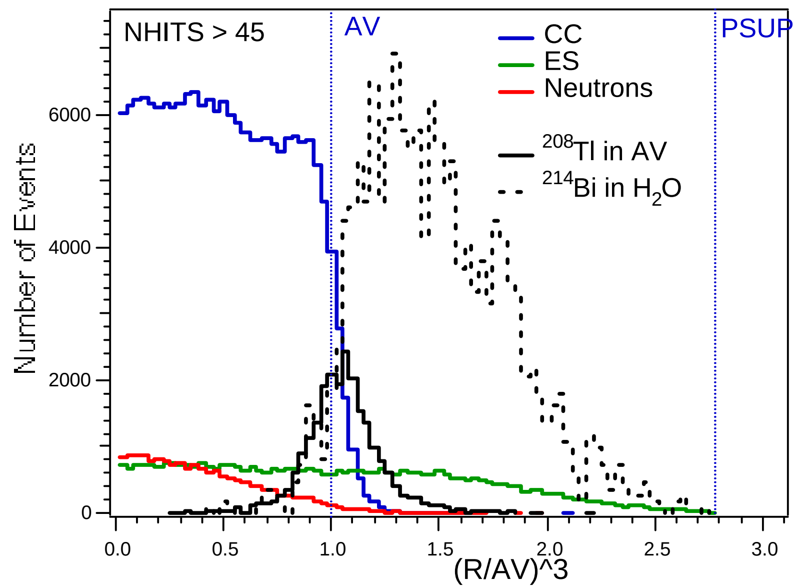


Effective Kinetic Energy T_{eff}

- effective kinetic energy, Teff, determined for each event in D_2O
- T_{eff} corrected for time variable phenomena + position + direction

Principal Physics Backgrounds

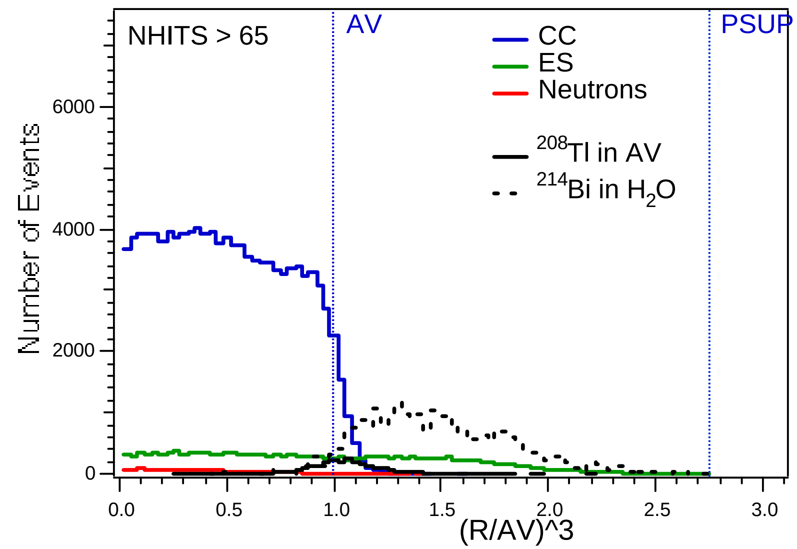
Internal D_2O Background	^{238}U, ^{232}Th
Acrylic Vessel	^{238}U, ^{232}Th
H_2O	^{238}U, ^{232}Th
PMT	β-γ
High Energy	γ



Analysis of Backgrounds

I. Estimate limits in background free region R_{fit} 550 cm

II. Fit to backgrounds in variable fiducial volumes

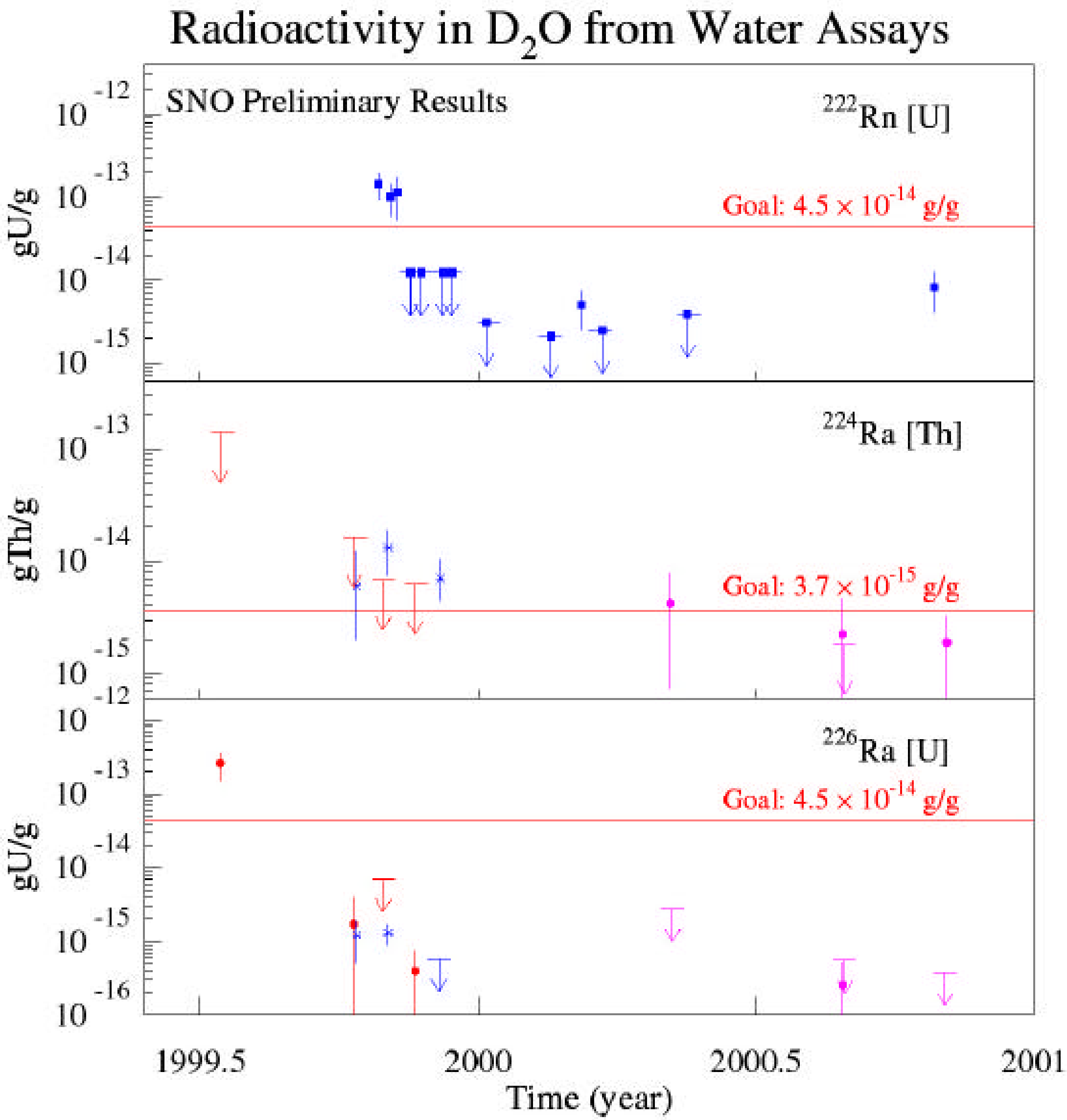


D_2O Backgrounds

Target Level
• Equivalent of 7% SSM neutrons

Measurement Techniques
• Radiochemical assays
• In-situ Cerenkov measures

Status
⇒ at or below target level

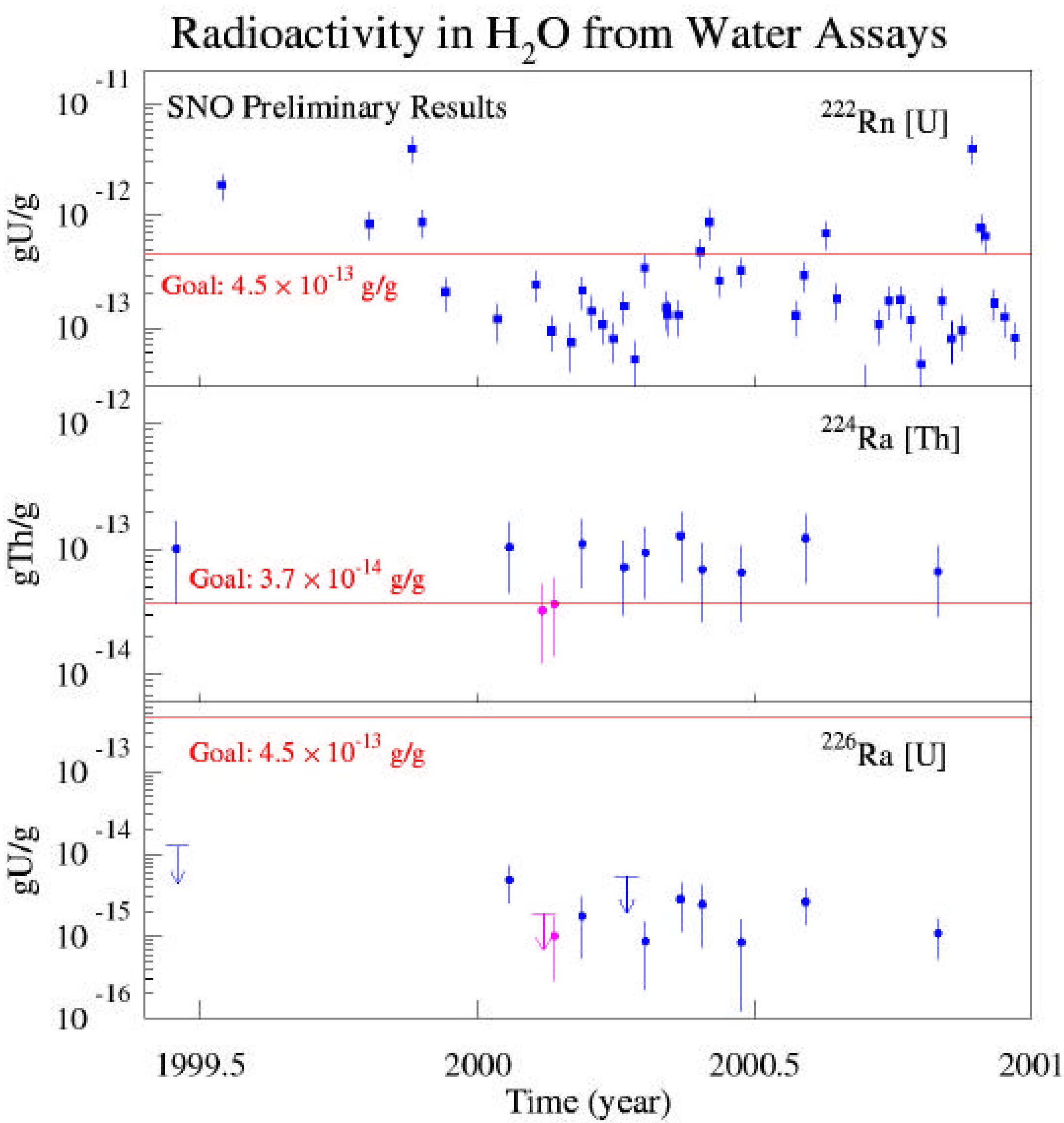


H_2O Backgrounds

Target
- Equivalent of 7% SSM neutrons

Measurement Technique
- Radiochemical assay
- Encapsulated sources
- High radon runs

Status
⇒ near or below target levels



Acrylic Vessel Backgrounds

Calibration Techniques

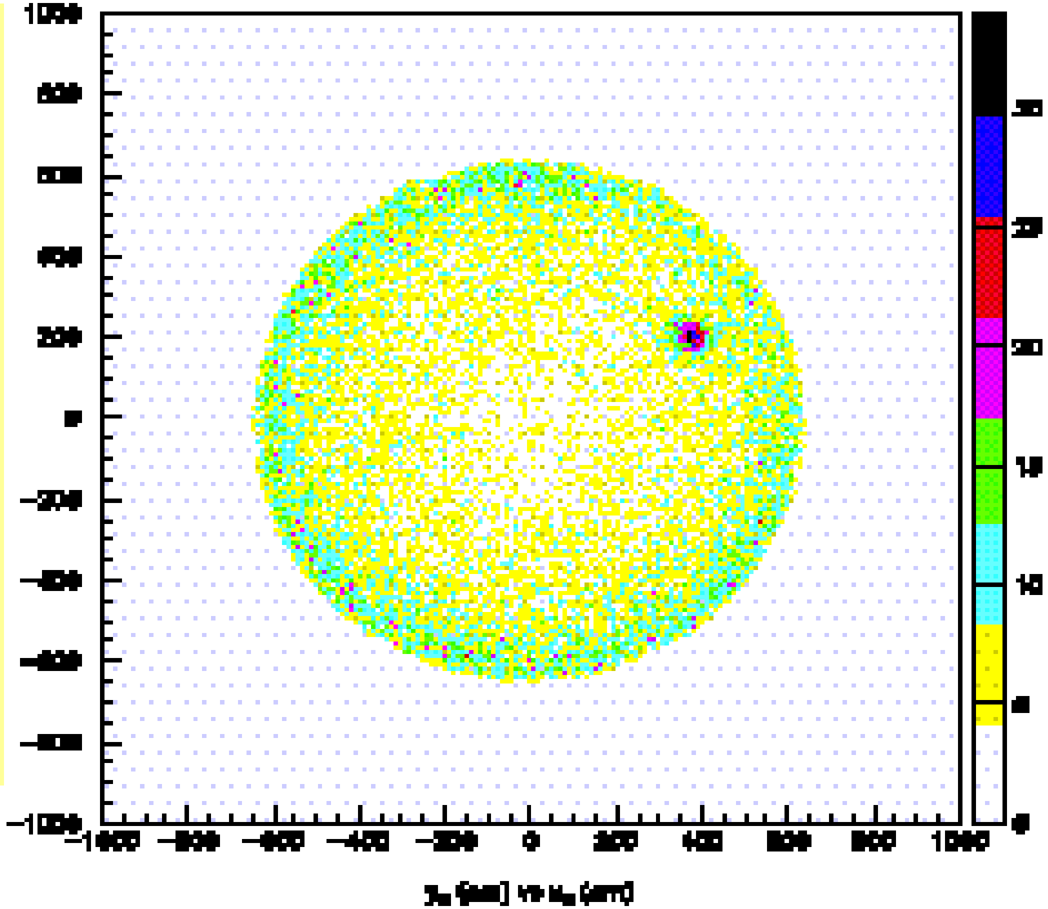
- direct counting and NAA
- encapsulated U, Th sources
- direct observation:
  Cerenkov light

AV Activity

- Activities assayed to be < 10% of target level ~ 0.2 ppt U/Th

AV Construction

- Every piece sampled and tested
- Sample bonds tested

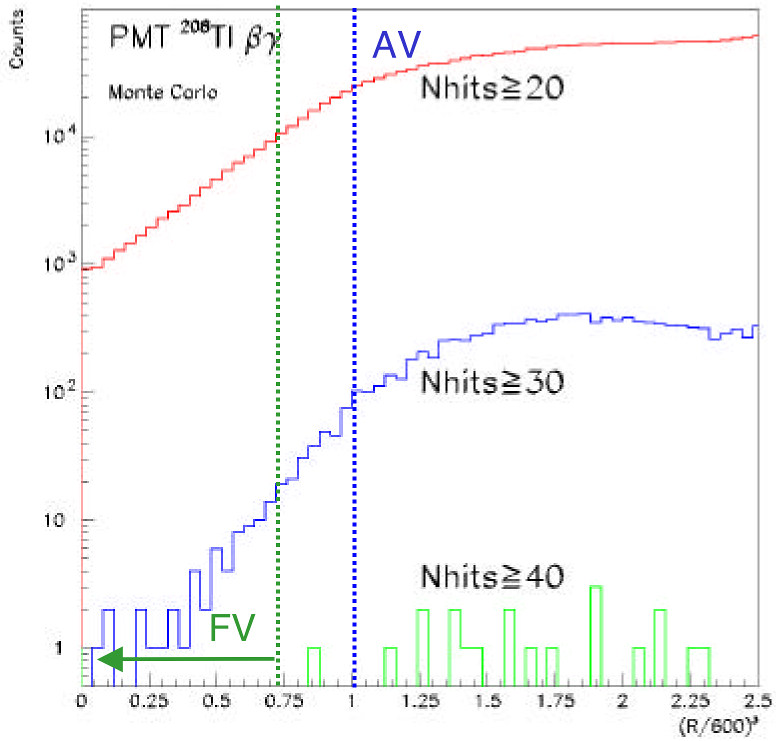


⇒ AV Blob: ~9 +20/-5 ± 3 μg ‘Th’

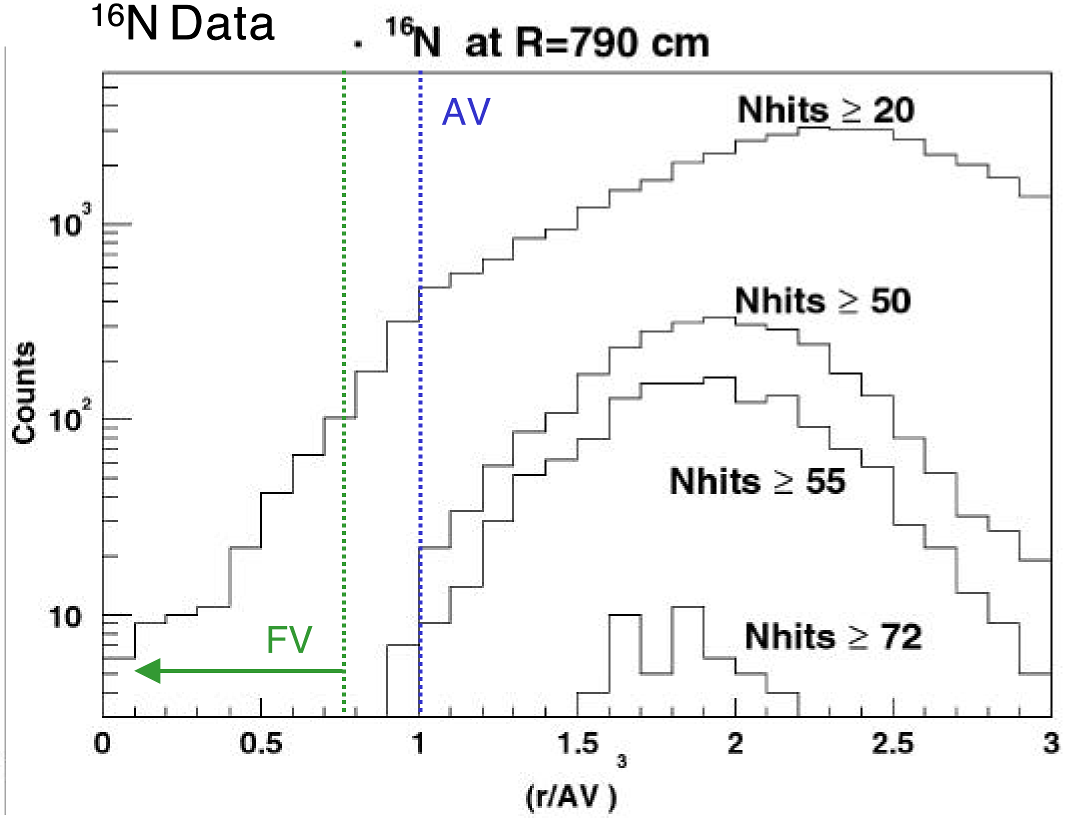
PMT β-γ

Characteristics	• Strong Nhit dependence but small tails into Cerenkov signals
Determination	→ Direct counting of materials, Monte-Carlo simulations → Hot encapsulated U and Th Sources (bkgd < 0.1% within D_2O) → ^{16}N γ's from calibration source

Monte-Carlo

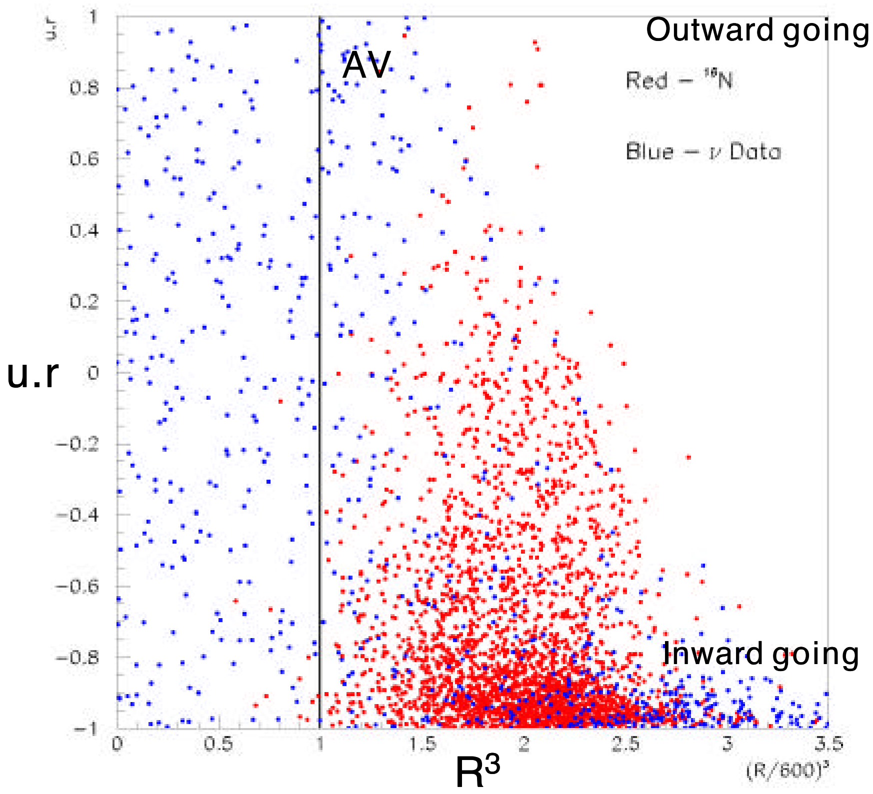


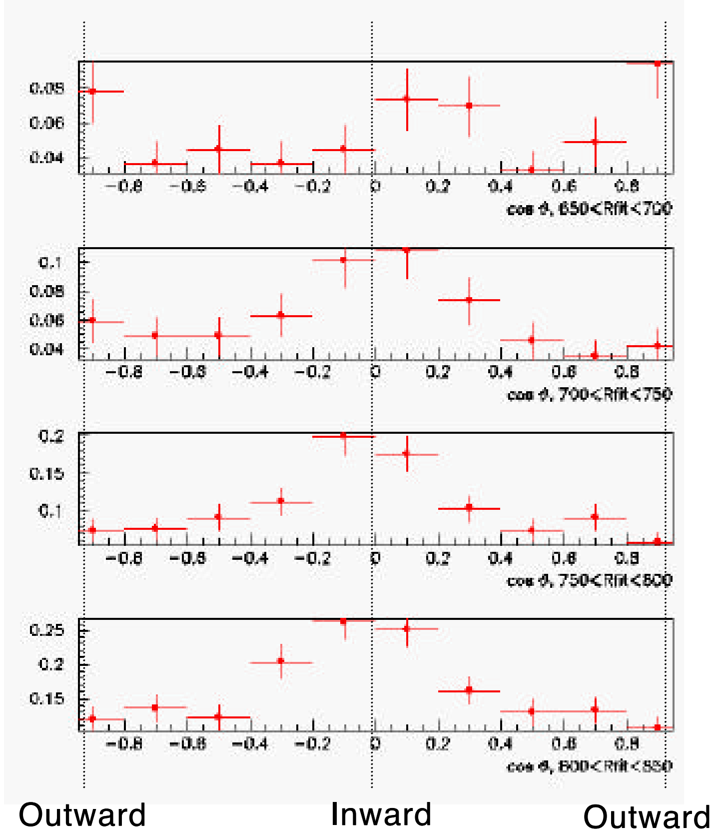
^{16}N Data



External γ-Ray Background

Origin	• from PMT's , rock wall
Determination	→ empirical estimates from cavity measures → direct observation → ^{16}N calibration γ's (bkgd < 0.8% in data set)





Experimental Systematic Errors on Fluxes

Error Source	CC Error (%)	ES Error (%)
Energy Scale	+6.1/-5.2	+5.4/-3.5
Energy Resolution	±0.5	±0.3
Energy Scale Non-Linearity	±0.5	±0.4
Vertex Shift	±3.1	±3.3
Vertex Resolution	±0.7	±0.4
Angular Resolution	±0.5	±2.2
Live Time	±0.1	±0.1
Trigger Efficiency	0.0	0.0
Cut Acceptance	+0.7/-0.6	+0.7/-0.6
Residual Backgrounds (R_{fit} *550 cm*)		
Instrumental Background	±0.1	-0.6/+0.0
High Energy γ's	-0.8/+0.0	-1.9/+0.0
Low Energy Background	-0.2/+0.0	-0.2/+0.0
Experimental Uncertainty	+7.0/-6.2	+6.8/-5.7
Cross Section	3.0	0.5

Signal Extraction

Maximum-Likelihood Fit to Characteristic Distributions

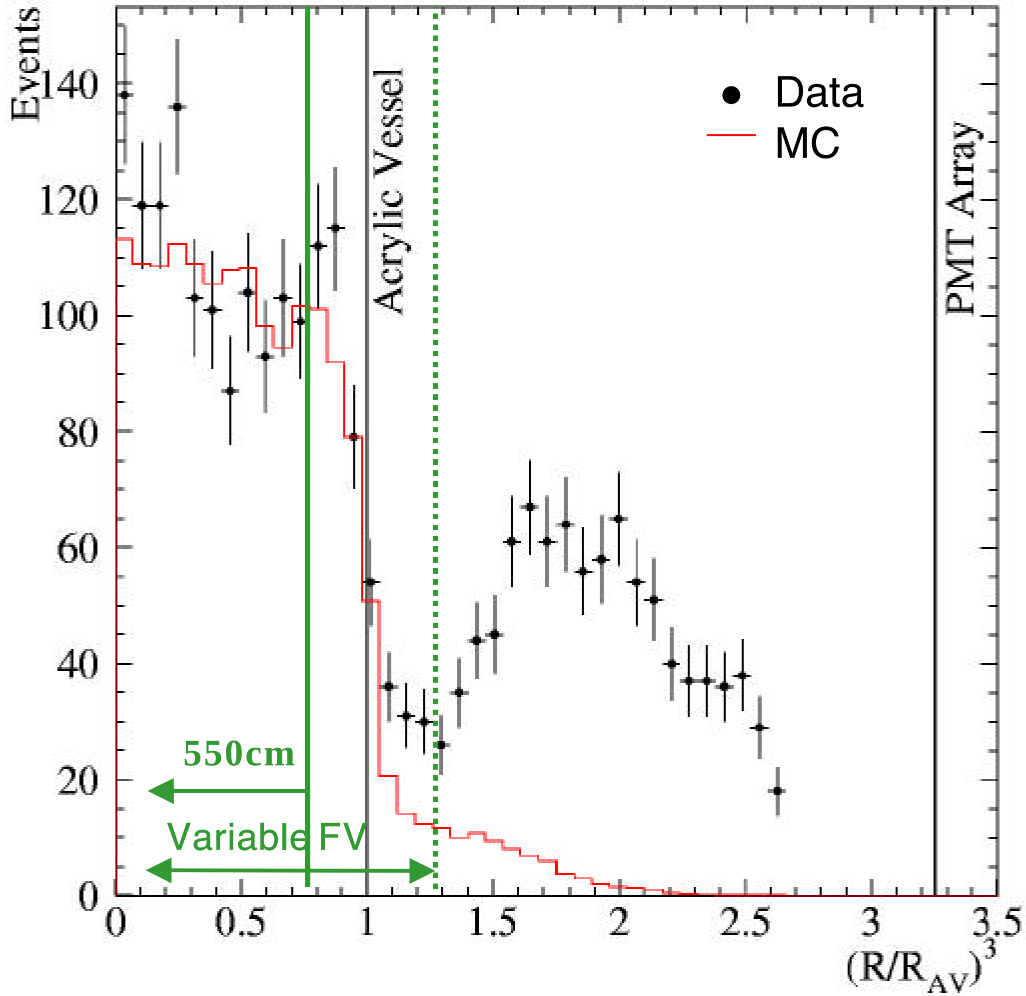
- R^3
- $\cos(\theta_{Sun})$
- Neutron Energy Response

Energy Estimators

- T_{eff}
- or Nhit

Fiducial Volume

- R_{fit} **550 cm**
- *or variable FV R 650 cm*



First Solar Neutrino Results From SNO

Solar Angle Distribution

T_{eff} 6.75 MeV and R_{fit} 550 cm

Energy Spectrum

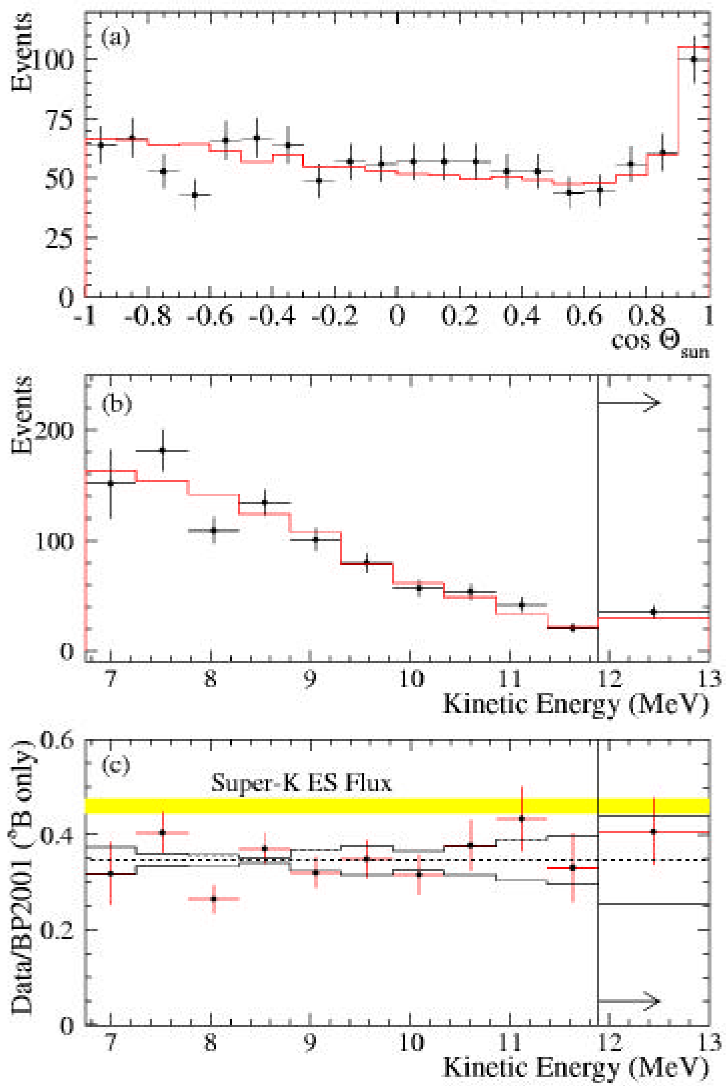
T_{eff} 6.75 MeV and R_{fit} 550 cm

derived from fit without constraint on ^{8}B shape

CC Spectrum Normalized to Predicted ^{8}B Spectrum

T_{eff} 6.75 MeV and R_{fit} 550 cm

With correlated systematic errors



Neutrino Fluxes

241-day Data from SNO

$\Phi^{CC}_{SNO}(^8B) = 1.75 \pm 0.07$ (stat.) +0.12/-0.11 (sys.) x10^6 cm^{-2} s^{-1}
$\Phi^{ES}_{SNO}(^8B) = 2.39 \pm 0.34$ (stat.) +0.16/-0.14 (sys.) x10^6 cm^{-2} s^{-1}

→ assuming ^8B spectral shape, T_{eff}<6.75 MeV
→ radiative corrections are not applied yet, will only decrease CC flux

CC Flux Relative to BP2001

$R^{CC}(^8B) = 0.347 \pm 0.029$

Total ^8B Flux from the Sun

$\phi_{SNO}(^8B) = 5.44 \pm 0.99$ x10^6 cm^{-2} s^{-1}
$\phi_{SSM}(^8B) = 5.01$ +1.01/-0.82 x10^6 cm^{-2} s^{-1} (BP2001)

⇒ Total flux in good agreement, CC is only component of total ^8B flux

CC/ES Ratio

$$\frac{CC}{ES} = \frac{\nu_e}{\nu_e + 0.15(\nu_\mu + \nu_\tau)}$$

ES_{SNO} and ES_{SK}

$\Phi^{ES}{}_{SNO}(^8B) = 2.39 \pm 0.34\,(stat.)\,{+0.16/-0.14}\,(sys.)$ $\times 10^6\ cm^{-2} s^{-1}$
$\Phi^{ES}{}_{SK}(^8B) = 2.32 \pm 0.03\,(stat.)\,{+0.08/-0.07}\,(sys.)$ $\times 10^6\ cm^{-2} s^{-1}$

→ good agreement

CC_{SNO}/ES_{SK}

$\Phi^{CC}{}_{SNO}(^8B) = 1.75 \pm 0.07\,(stat.)\,{+0.12/-0.11}\,(sys.) \pm 0.05\,(theor.)$ $\times 10^6\ cm^{-2} s^{-1}$
$\Phi^{ES}{}_{SK}(^8B) = 2.32 \pm 0.03\,(stat.)\,{+0.08/-0.07}\,(sys.)$ $\times 10^6\ cm^{-2} s^{-1}$

→ $\Phi^{ES}{}_{SK}(^8B) - \Phi^{CC}{}_{SNO}(^8B) = 0.57 \pm 0.17 \Rightarrow 3.3\ \sigma$
→ Probability of not being a downward fluctuation: 99.96%

*S. Fukuda, et al., hep-ex/0103032

Neutrino Flavor Composition of ^{8}B Flux

Flavor content analysis of ^{8}B solar neutrino flux from: $\phi^{SK}{}_{ES}$, $\phi^{SNO}{}_{CC}$

$\phi_{CC} = \phi_e$

$\phi_{ES} = \phi_e + \varepsilon\, \phi_{\mu,\tau}$

$\phi^{SNO}{}_{CC} = 1.75 \pm 0.13$

$\phi^{SK}{}_{ES} = 2.32 \pm 0.09$

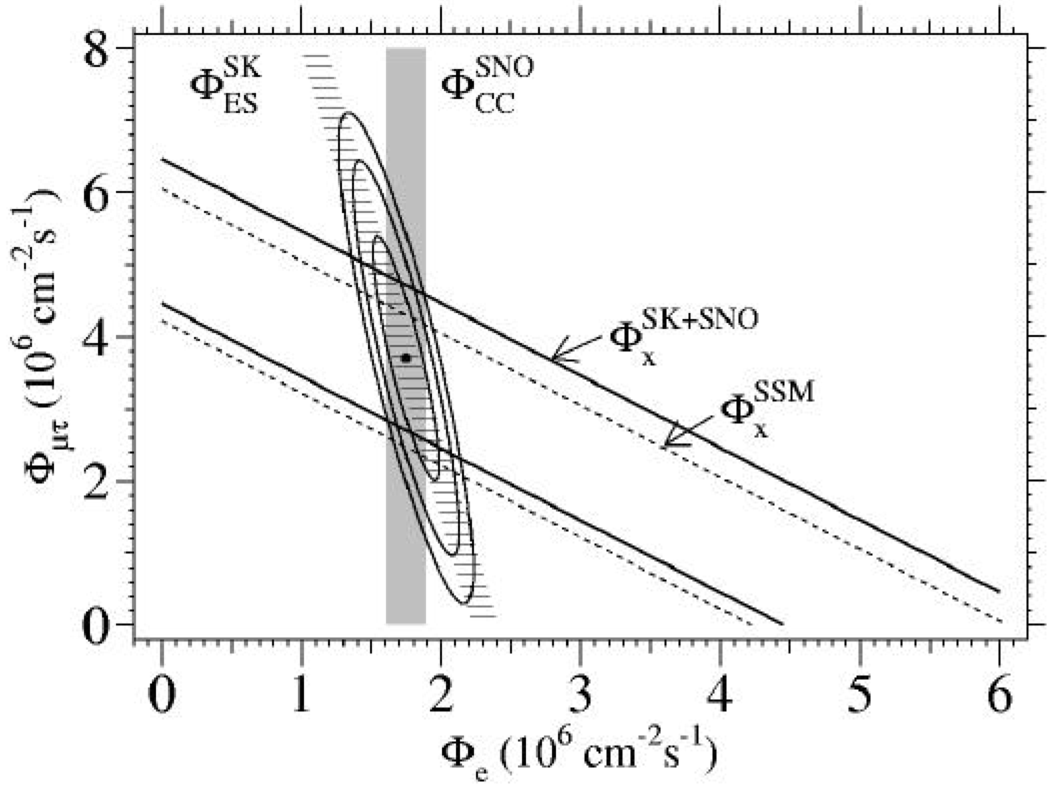
Total active neutrino flux:

$\phi_x = \phi_e + \phi_{\mu,\tau}$

$= \phi_{CC} + (\phi_{ES} - \phi_{CC})/\varepsilon$

$\phi_e = 1.75 \pm 0.13$

$\phi_{\mu,\tau} = 3.69 \pm 1.13$



$\Rightarrow$ Evidence for oscillations: $\nu_e \rightarrow \nu_{\mu\tau}$

What About Sterile Neutrinos?

Comparing the Response of SNO and SK

Ref: Fogli, Lisi, et al, hep-ph/0102288, Villante et al., hep-ph/9807360

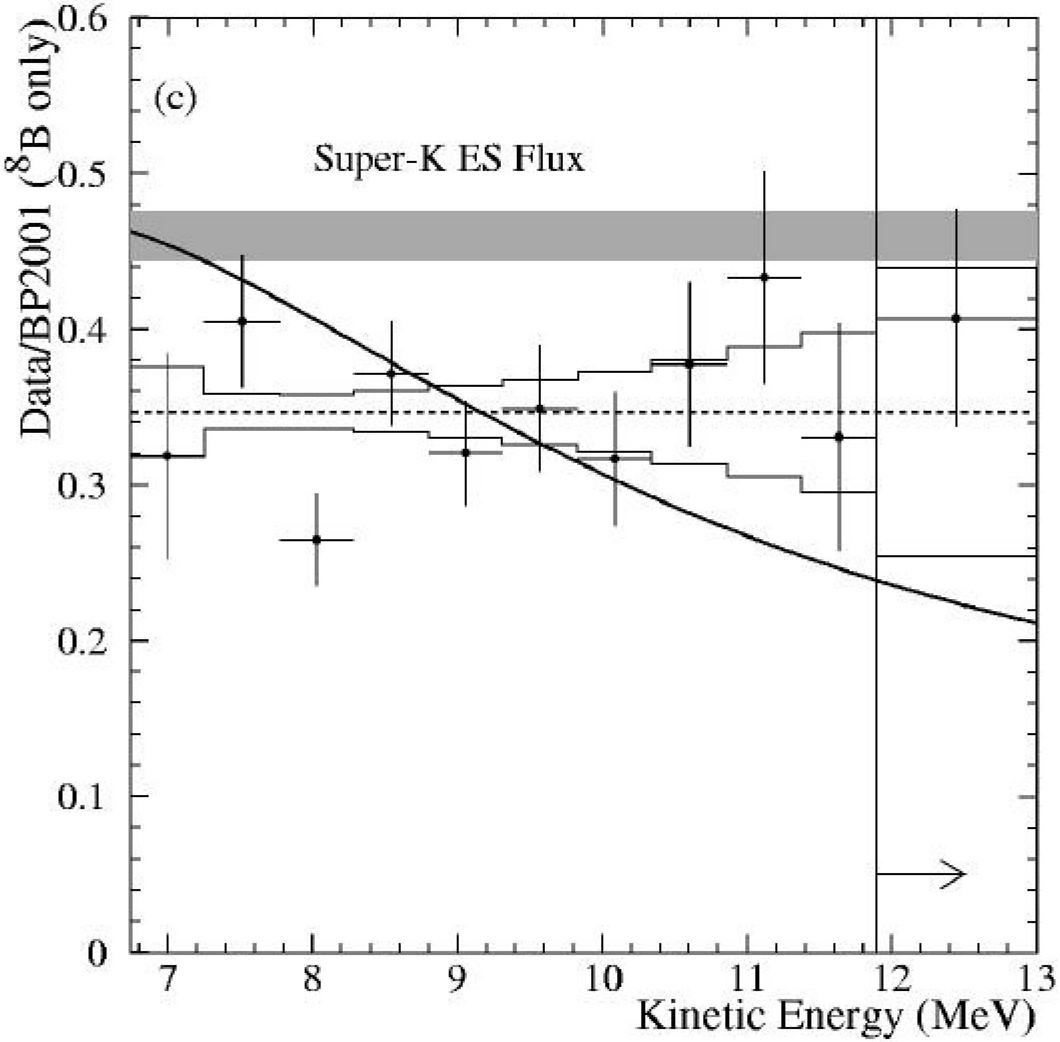
→ normalized rates over paired spectral regions are linearly related

SK Flux >8.5 MeV

SNO Flux >6.75 MeV

SK^{8B}(ES, >8.5) - SNO^{8B} (CC, >6.75) = **0.54 ± 0.17**

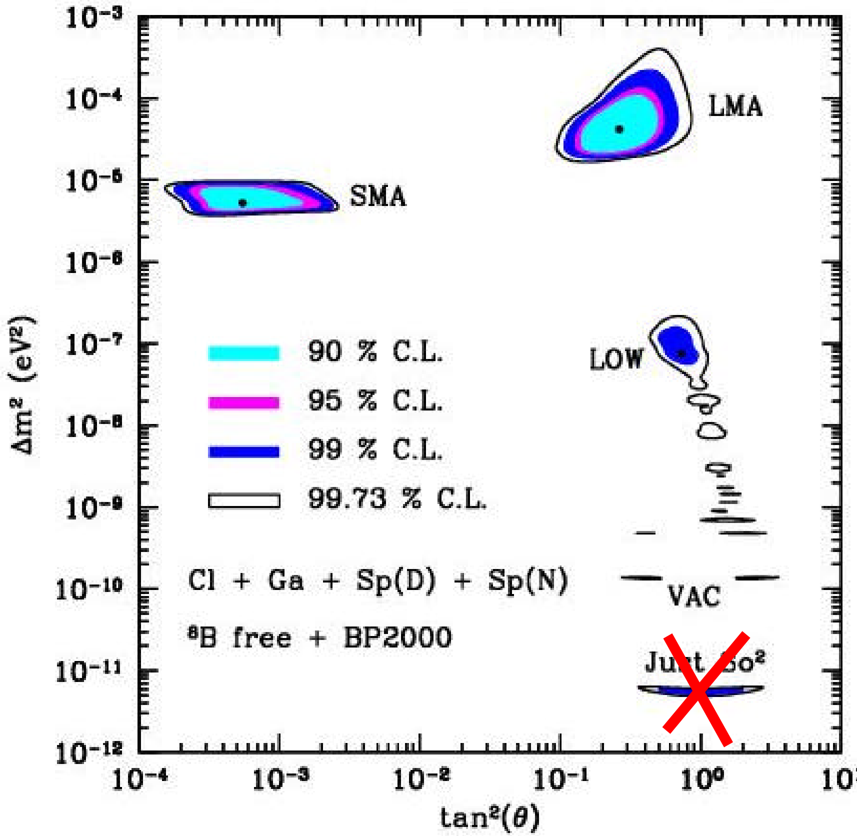
⇒ oscillations to sterile ν excluded at 3.1 σ



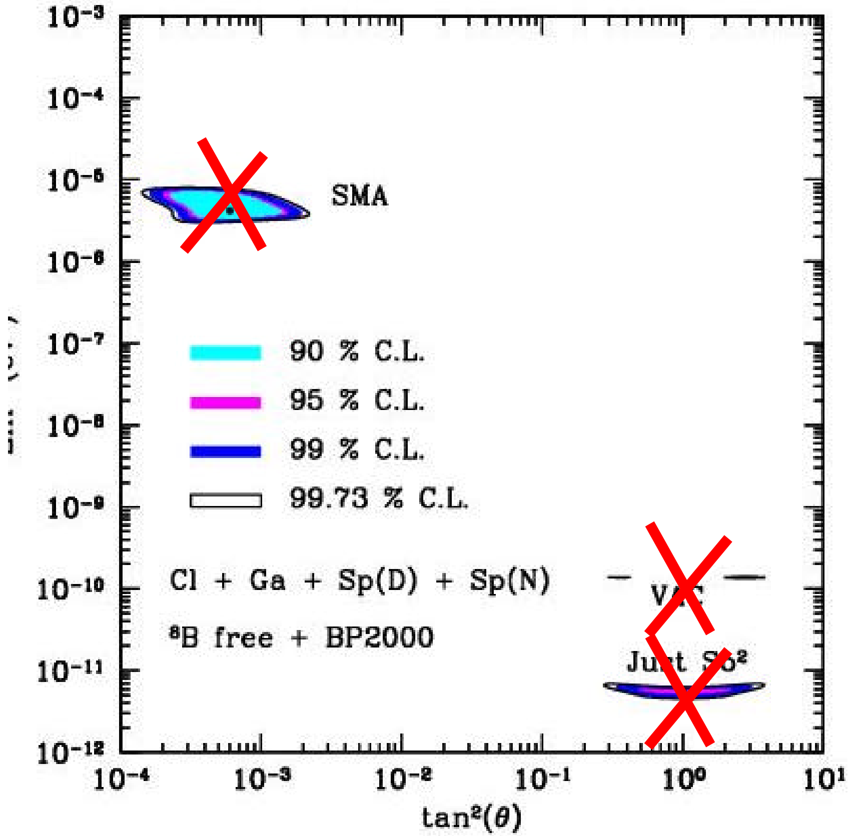
Neutrino Oscillation Scenarios

- data exclude sterile neutrinos and "Just So^2" parameter space
- oscillations to active species

To Active Neutrinos



To Sterile Neutrinos



Cosmological Implications

- These results plus previous analyses suggest:

$$(\Delta m_{e\mu})^2 < 10^{-3}\,eV^2 \text{ or } (\Delta m_{e\tau})^2 < 10^{-3}\,eV^2$$

- Limits on ν_e mass give:

$$m\nu_e < 2.8\,eV$$

- Assuming the hypothesis of $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in atmospheric neutrinos:

$$(\Delta m_{\mu\tau})^2 \approx 3 \times 10^{-3}\,eV^2$$

$\Rightarrow$ Σ neutrino masses: $0.05 < \Sigma m_{e\mu\tau} < 8.4\,eV$

$\Rightarrow$ mass fraction of neutrinos in the universe: $0.001 < \Omega_\nu < 0.18$

Conclusions

- CC rate is low compared to the SSM prediction, and to the ES rates as measured by SNO and SK

- First direct indication of solar neutrinos of type other than ν_e

- First measurement of the total flux of ^{8}B neutrinos. It agrees well with SSM predictions: $\phi_{total}(^8B) = 5.44 \pm 0.99 \times 10^6\ cm^{-2} s^{-1}$

- Data exclude the "Just-So^2" and sterile neutrino parameter spaces

- $m^2(\nu_e \rightarrow \nu_{\mu,\tau}) < 10^{-3}\ eV^2 \Rightarrow 0.05 < \Sigma m_{e\mu\tau} < 8.4\ eV$

- Cosmological limit on neutrino mass: $0.001 < \Omega_\nu < 0.18$

- Phase I of SNO experiment complete

First Results

Measurement of charged current interactions produced by ^{8}B solar neutrinos at the Sudbury Neutrino Observatory

Q.R. Ahmad[15], R.C. Allen[11], T.C. Andersen[12], J.D. Anglin[7], G. Bühler[11], J.C. Barton[13‡], E.W. Beier[14], M. Bercovitch[7], J. Bigu[4], S. Biller[13], R.A. Black[13], I. Blevis[2], R.J. Boardman[13], J. Boger[1], E. Bonvin[9], M.G. Boulay[9], M.G. Bowler[13], T.J. Bowles[6], S.J. Brice[6,13], M.C. Browne[15], T.V. Bullard[15], T.H. Burritt[15,6], K. Cameron[12], J. Cameron[13], Y.D. Chan[5], M. Chen[9], H.H. Chen[11*], X. Chen[5,13], M.C. Chon[12], B.T. Cleveland[13], E.T.H. Clifford[9,3], J.H.M. Cowan[4], D.F. Cowen[14], G.A. Cox[15], Y. Dai[9], X. Dai[13], F. Dalnoki-Veress[2], W.F. Davidson[7], P.J. Doe[15,11,6], G. Doucas[13], M.R. Dragowsky[6,5], C.A. Duba[15], F.A. Duncan[9], J. Dunmore[13], E.D. Earle[9,3], S.R. Elliott[15,6], H.C. Evans[9], G.T. Ewan[9], J. Farine[2], H. Fergani[13], A.P. Ferraris[13], R.J. Ford[9], M.M. Fowler[6], K. Frame[13], E.D. Frank[14], W. Frati[14], J.V. Germani[15,6], S. Gil[10], A. Goldschmidt[6], D.R. Grant[2], R.L. Hahn[1], A.L. Hallin[9], E.D. Hallman[4], A. Hamer[6,9], A.A. Hamian[15], R.U. Haq[4], C.K. Hargrove[2], P.J. Harvey[9], R. Hazama[15], R. Heaton[9], K.M. Heeger[15], W.J. Heintzelman[14], J. Heise[10], R.L. Helmer[10†], J.D. Hepburn[9,3] H. Heron[13], J. Hewett[4], A. Hime[6], M. Howe[15], J.G. Hykawy[4], M.C.P. Isaac[5], P. Jagam[12], N.A. Jelley[13], C. Jillings[9], G. Jonkmans[4], J. Karn[12], P.T. Keener[14], K. Kirch[6], J.R. Klein[14], A.B. Knox[13], R.J. Komar[10,9], R. Kouzes[8], T. Kutter[10], C.C.M. Kyba[14], J. Law[12], I.T. Lawson[12], M. Lay[13], H.W. Lee,[9] K.T. Lesko[5], J.R. Leslie[9], I. Levine[2], W. Locke[13], M.M. Lowry[8], S. Luoma[4], J. Lyon[13], A.B. MacDonald[9,8], S. Majerus[13], H.B. Mak[9], A.D. Marino[5], N. McCauley[13]. D.S. McDonald[14]. K. McFarlane[2]. G. McGregor[13]. W. McLatchie[9]. R. Meijer Drees[15], H. Mes[2],
C. Miff ... auer[14],
F.M. N ... Okada[5],
R.W. O ... oberge[4],
B.C. Robertson[9], R.G.H. Robertson[15,6], J.K. Rowley[1], V.L. Rusu[14], E. Saettler[4], K.K. Schaffer[15], A. Schuelke[5], M.H. Schwendener[4], H. Seifert[4,6,15], M. Shatkay[2], J.J. Simpson[12], D. Sinclair[2], P. Skensved[9], A.R. Smith[5], M.W.E. Smith[15], N. Starinsky[2], T.D. Steiger[15], R.G. Stokstad[5], R.S. Storey[7*], B. Sur[3,9], R. Tafirout[4], N. Tagg[12], N.W. Tanner[13], R.K. Taplin[13], M. Thorman[13], P. Thornewell[6,13,15] P.T. Trent[13‡], Y.I. Tserkovnyak[10], R. Van Berg[14], R.G. Van de Water[14,6], C.J. Virtue[4], C.E. Waltham[10], J.-X. Wang[12], D.L. Wark[13,6§], N. West[13], J.B. Wilhelmy[6], J.F. Wilkerson[15,6] J. Wilson[13], P. Wittich[14], J.M. Wouters[6], M. Yeh[1]

(The SNO Collaboration)

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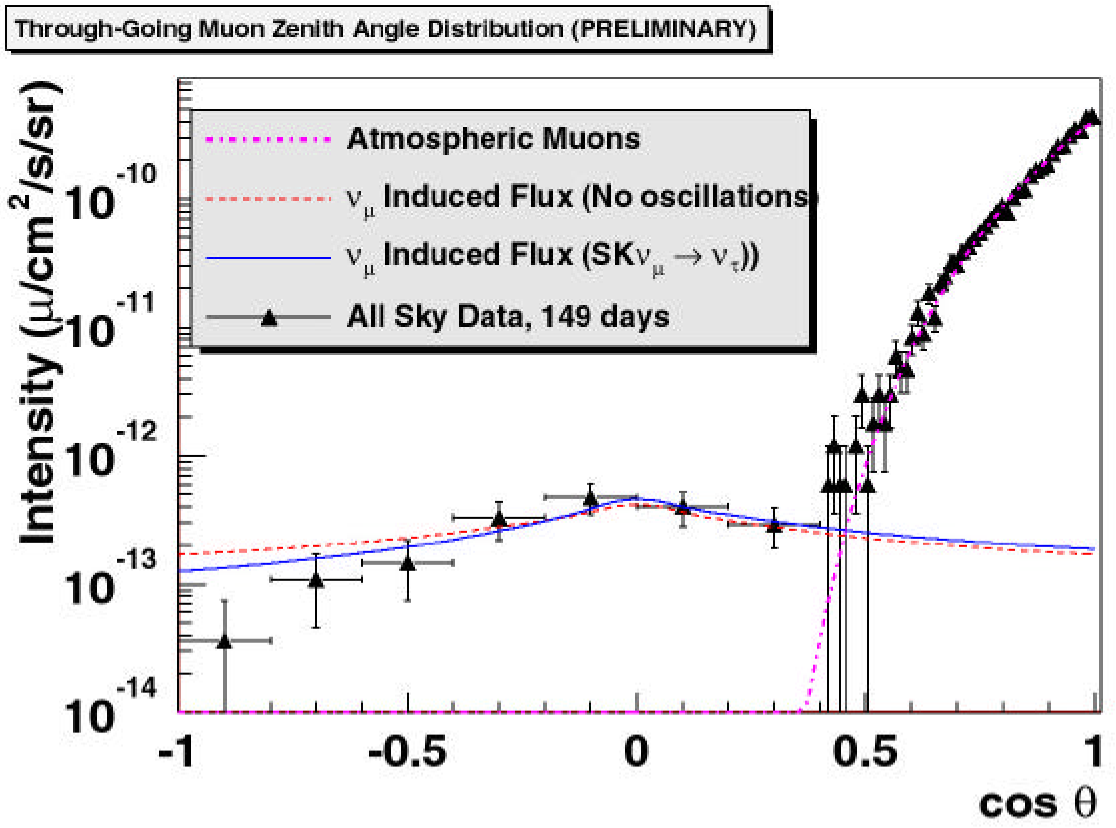
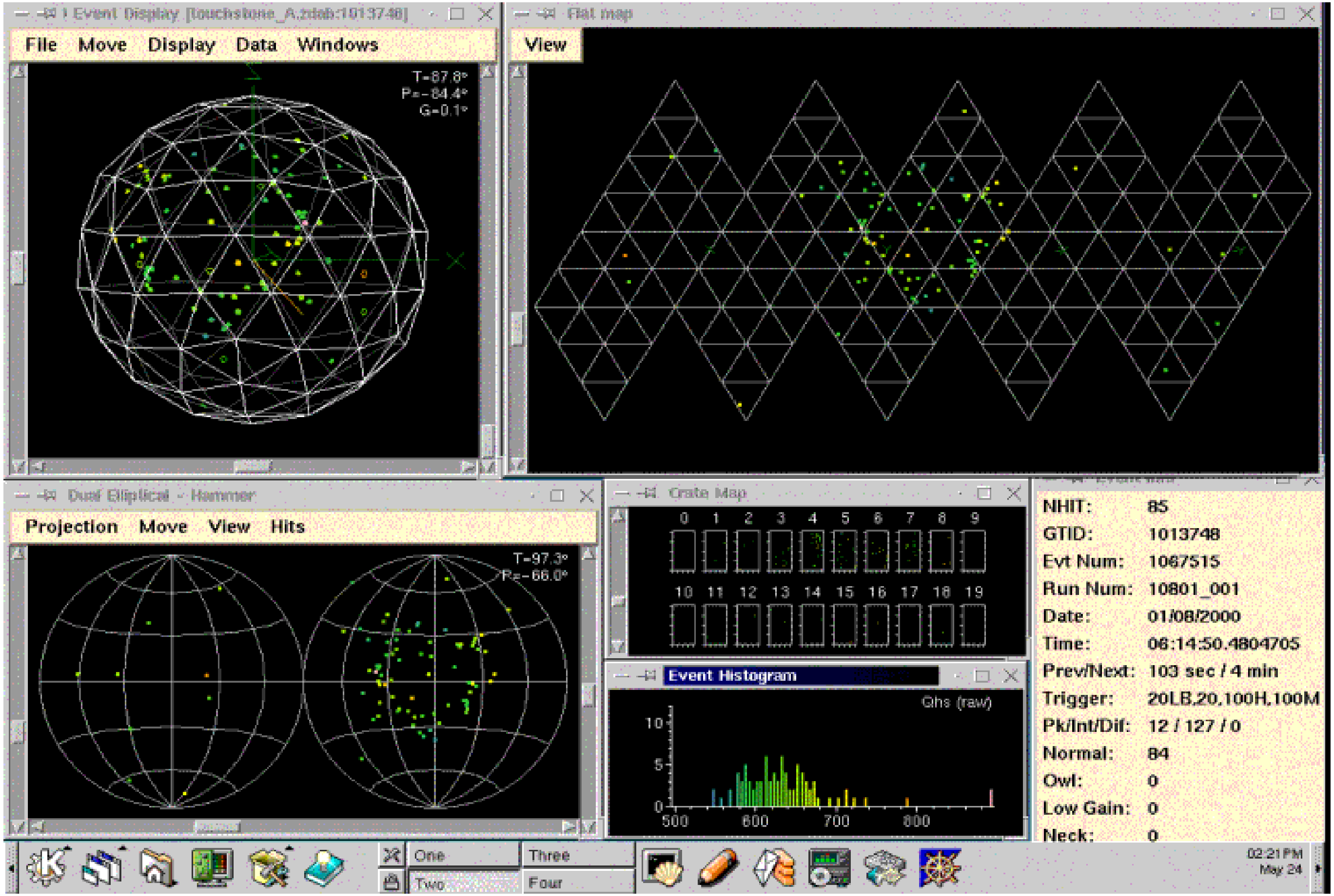
http://www.sno.phy.queensu.ca

Additional Slides

Muon Analysis



Neutrino Event



Oscillation Scenarios and SNO

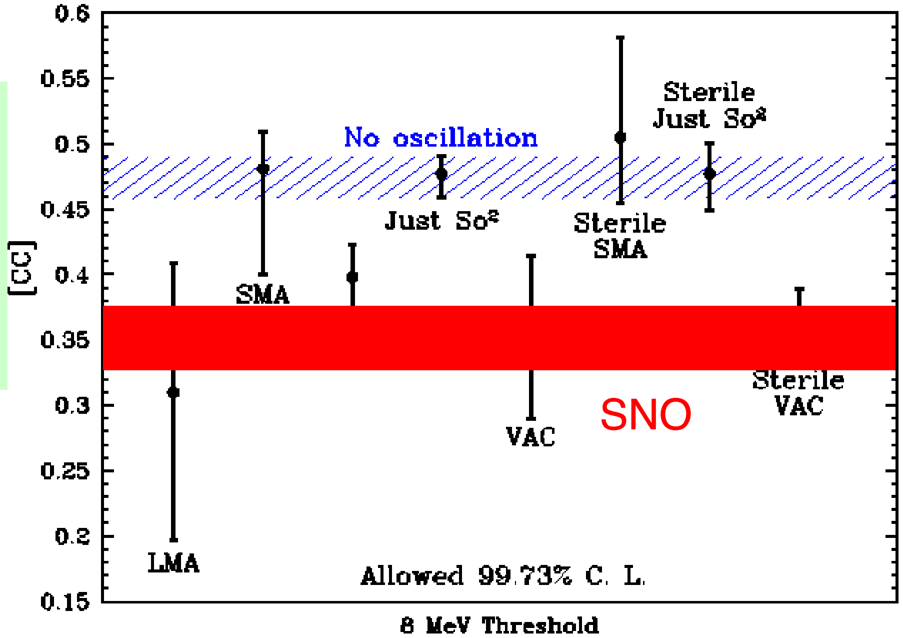
Ratio of measured ^{8}B flux relative to BP2000:

R^{CC}_{SNO}=0.346 ±0.014 (stat.) ±0.020 (sys.) ±0.010 (theor.)

R^{ES}_{SNO}=0.529 ±0.073 (stat.) ±0.035 (sys.) ±0.014 (theor.)

→ Neutrino oscillation models with maximal mixing are not compatible

→ Data exclude "Just So^2" parameters at m^2=6x10^{-12} eV^2



From Bahcall, Krastev, and Smirnov
hep-ph/0103179