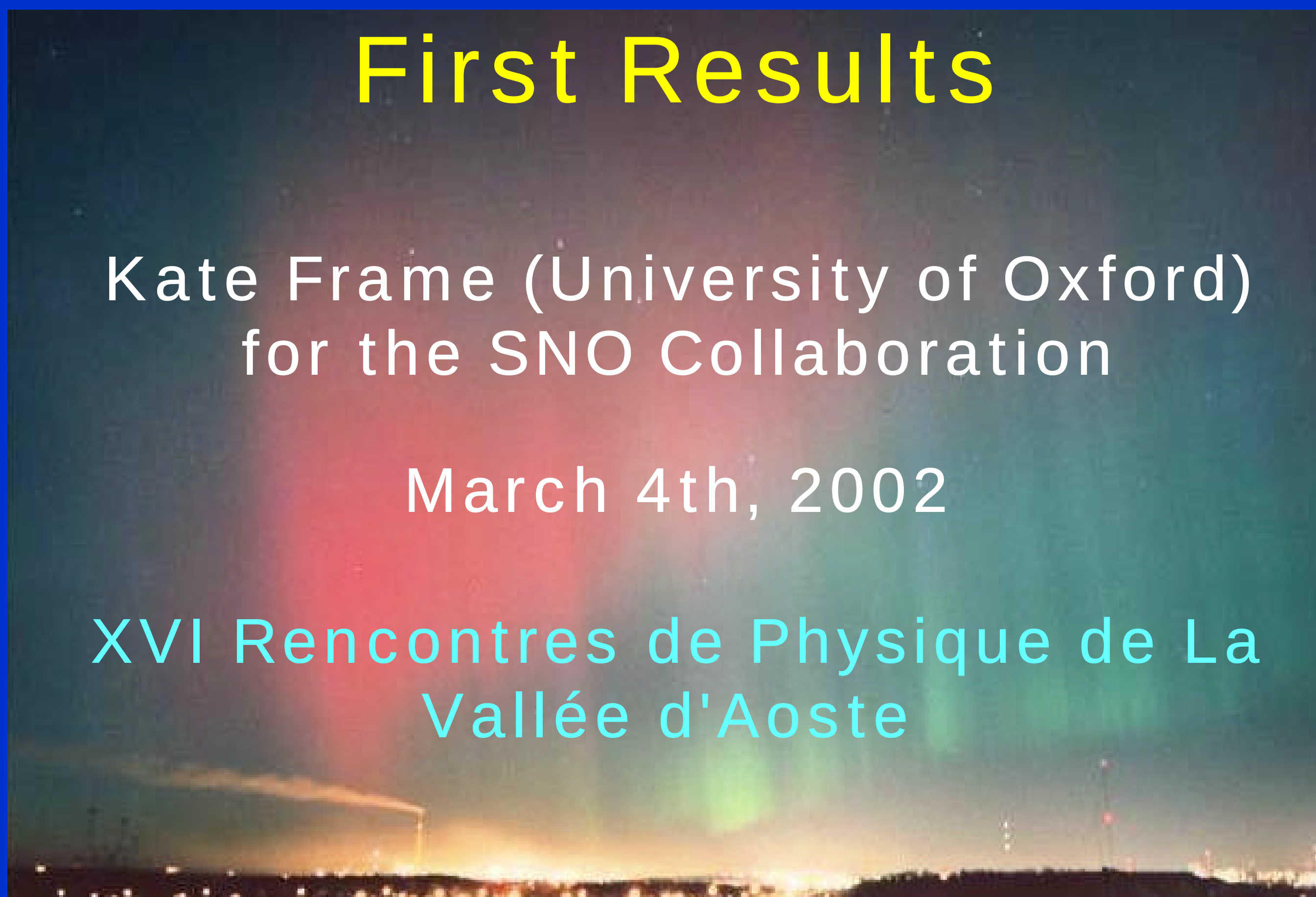
The Sudbury Neutrino Observatory



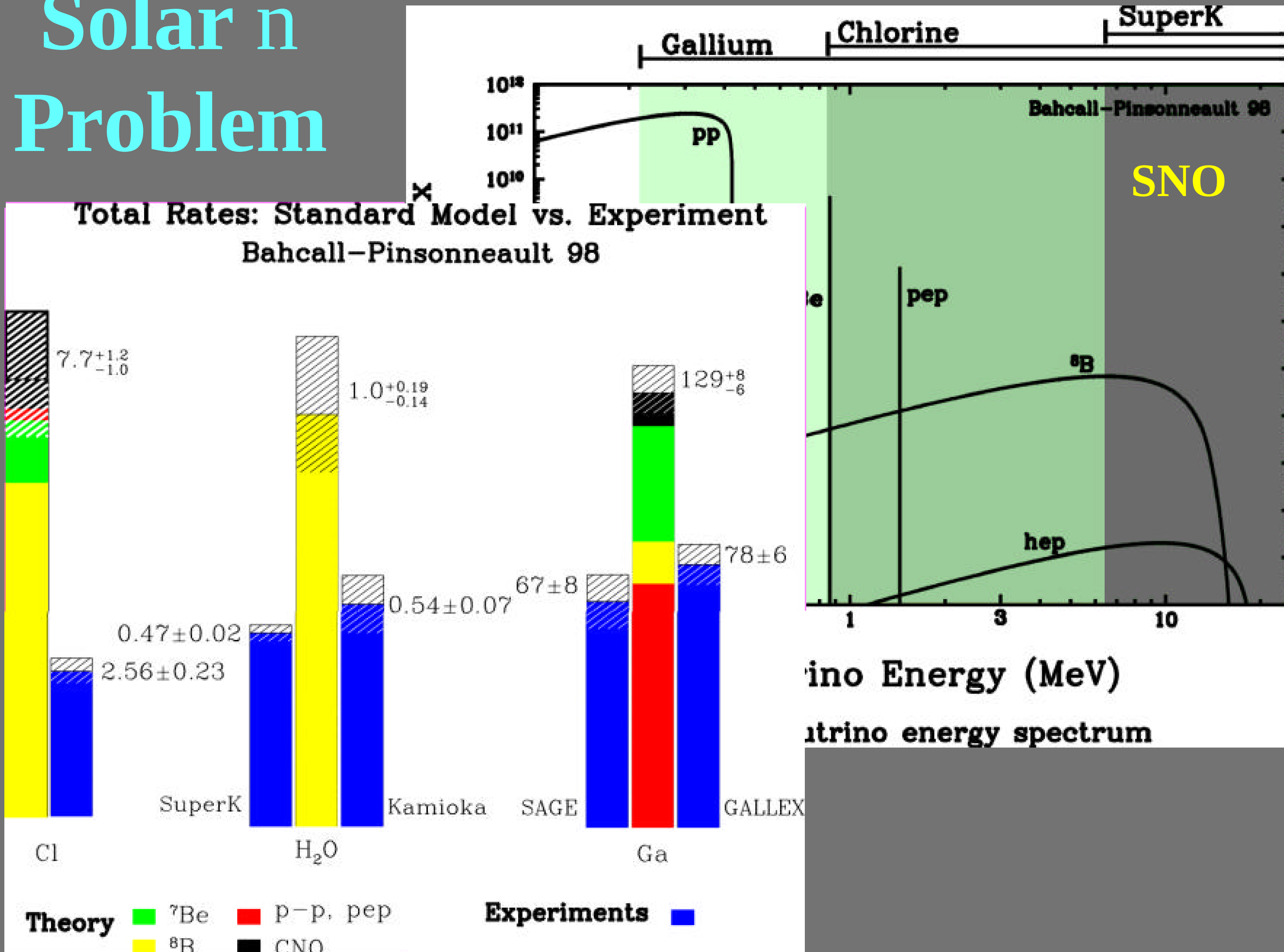
First Results

Kate Frame (University of Oxford)
for the SNO Collaboration

March 4th, 2002

XVI Rencontres de Physique de La Vallée d'Aoste

Solar n Problem



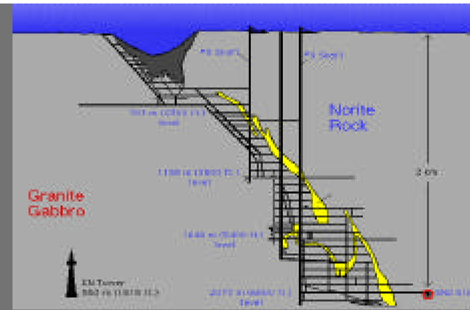
SNO Collaboration

Carleton University
Queen's University
University of Guelph
Laurentian University
University of British Columbia
TRIUMF

University of Pennsylvania
Los Alamos National Laboratory
Lawrence Berkeley National Laboratory
University of Washington
Brookhaven National Laboratory
University of California, Irvine

Birkbeck College, London
University of Oxford
University of Sussex/RAL

The SNO Detector

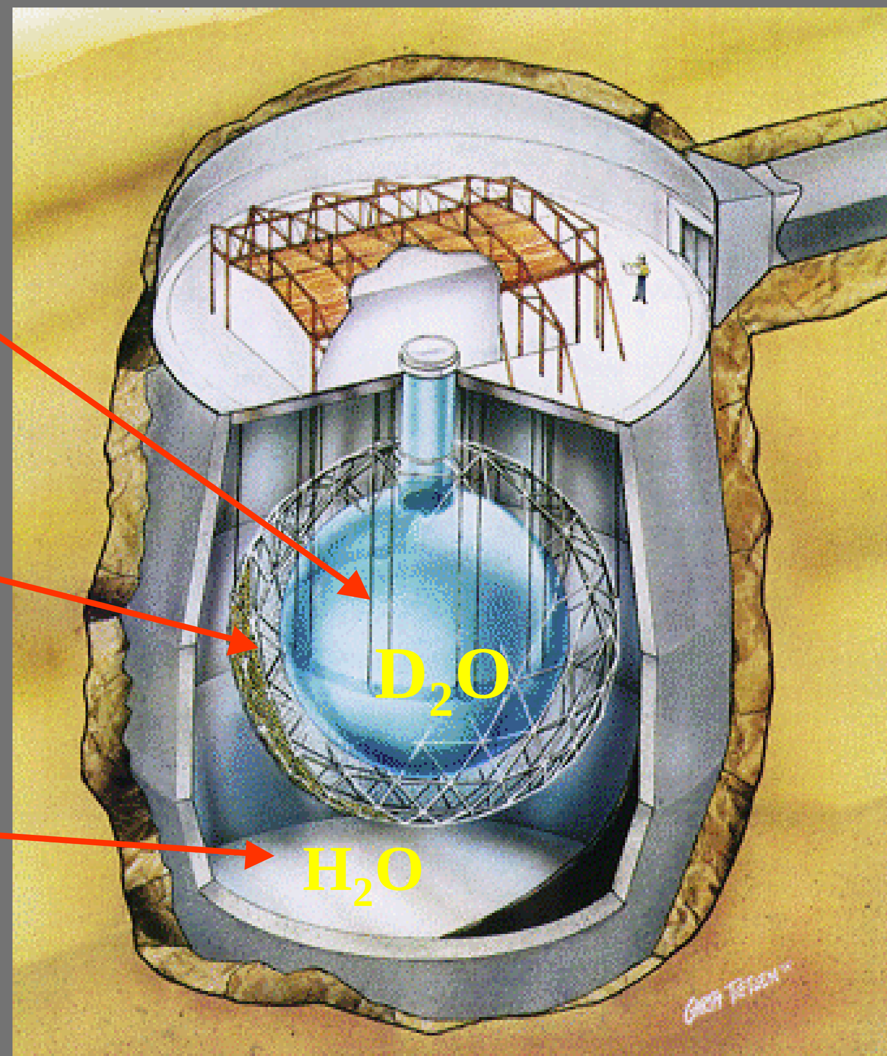


2 km to surface
10^{11} m to Sun

1000 tonnes D_2O
in a 12 m diameter
acrylic vessel

1700 tonnes H_2O
~9500 PMTs
with concentrators

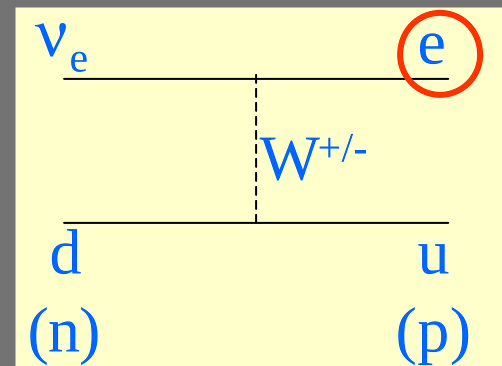
5300 tonnes H_2O



n Reactions in SNO

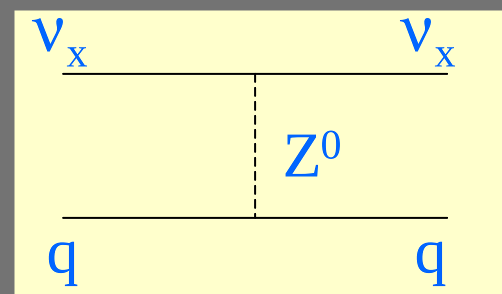
CC $n_e + d \Rightarrow p + p + e^-$

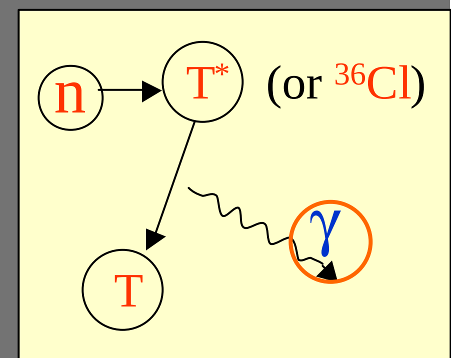
- -Good measurement of ν_e energy spectrum
- -Weak directional sensitivity ∝ 1-1/3cos(θ)
- - ν_e only.



NC $n_x + d \Rightarrow p + n + n_x$

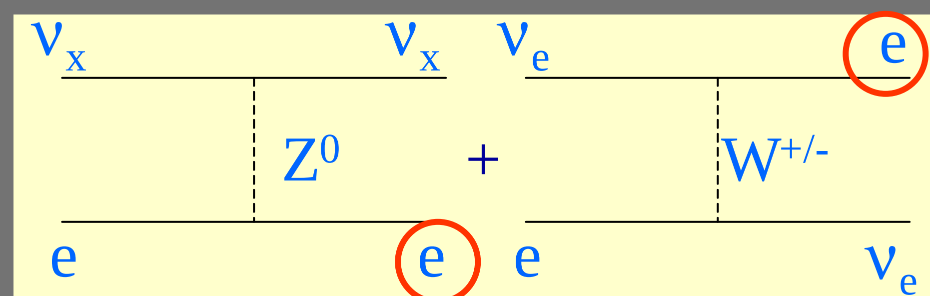
- -Measure total ^{8}B ν flux from the sun.
- - Equal cross section for all ν types
- -E_γ=6.3MeV (D_2O) $E_{\Sigma\gamma}$=8.6MeV (^{36}Cl)



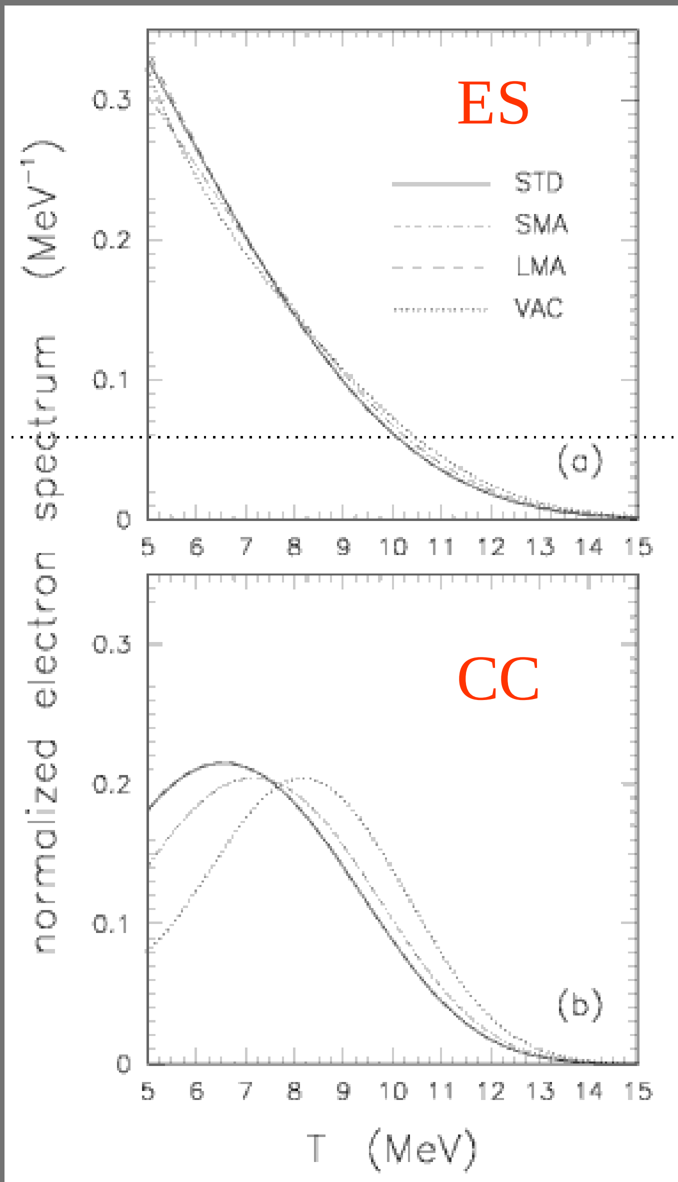


ES $?_x + e^- \Rightarrow ?_x + e^-$

- -Low Statistics
- -All n types but enhanced sensitivity to ν_e
- -Strong directional sensitivity

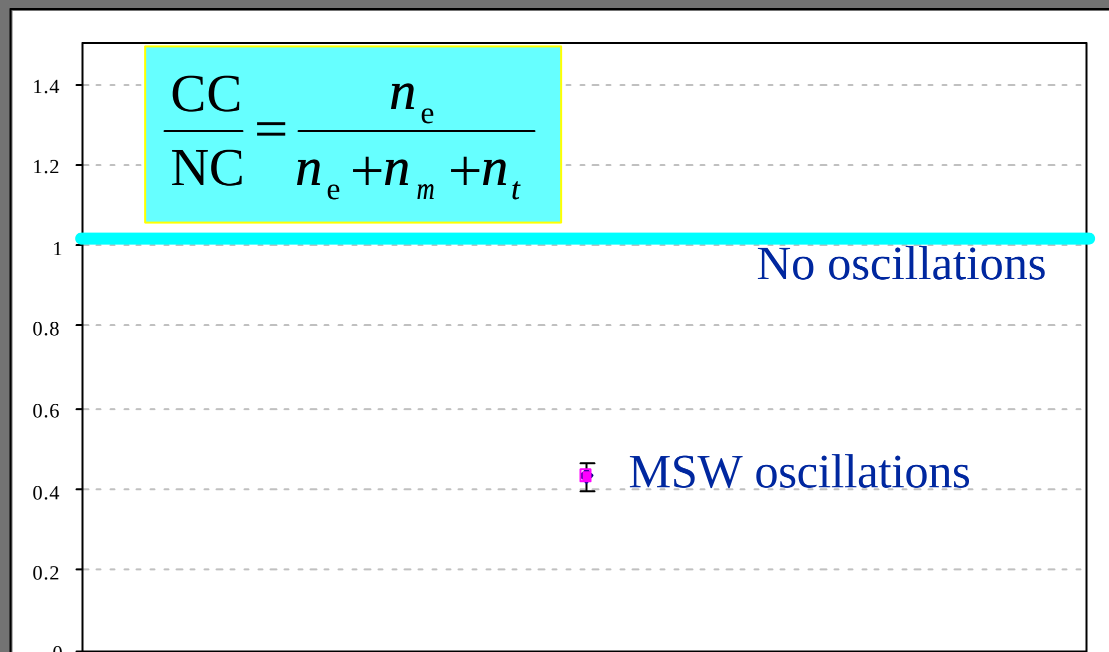


Signals in SNO



Charged-current spectrum is more sensitive to shape distortions!

Charged-Current to Neutral Current ratio is a direct signature for oscillations

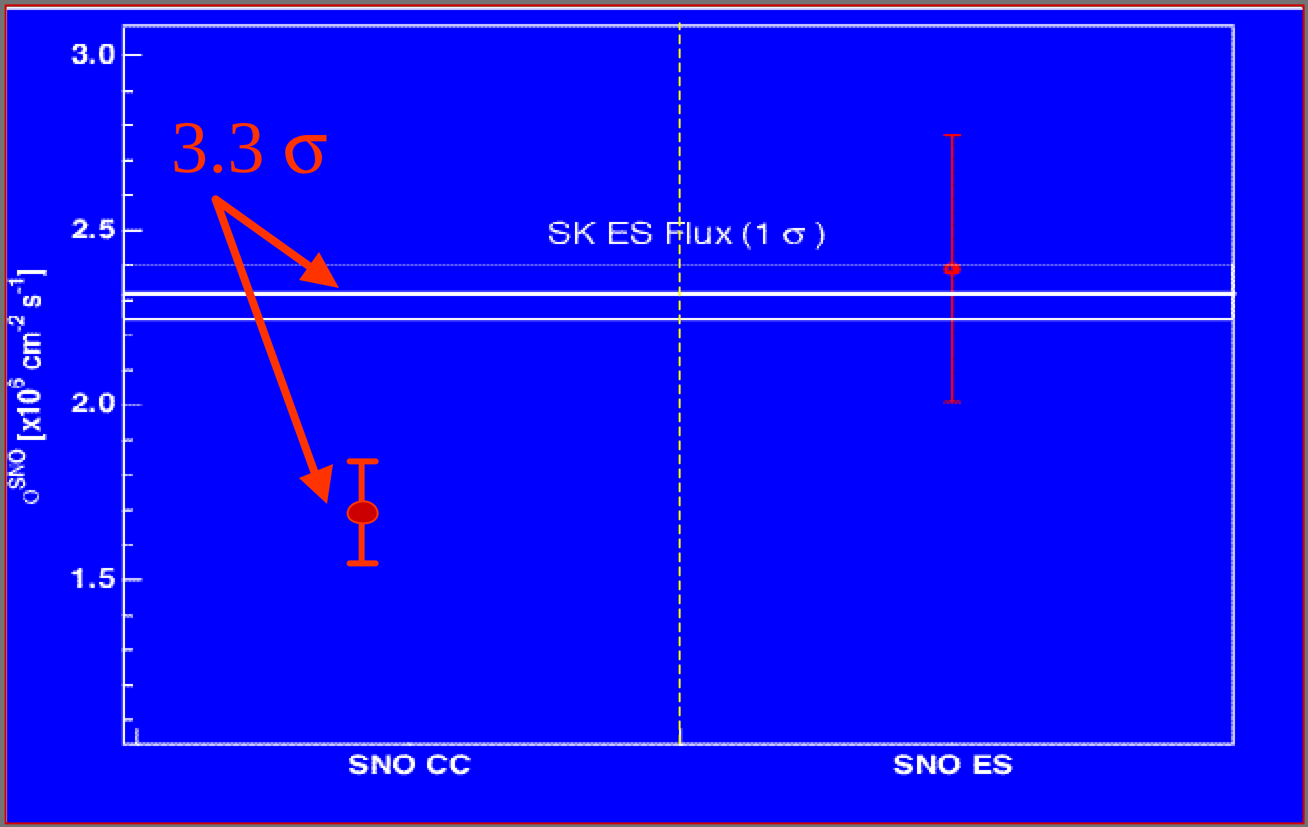


SNO's Anticipated CC/NC Sensitivity

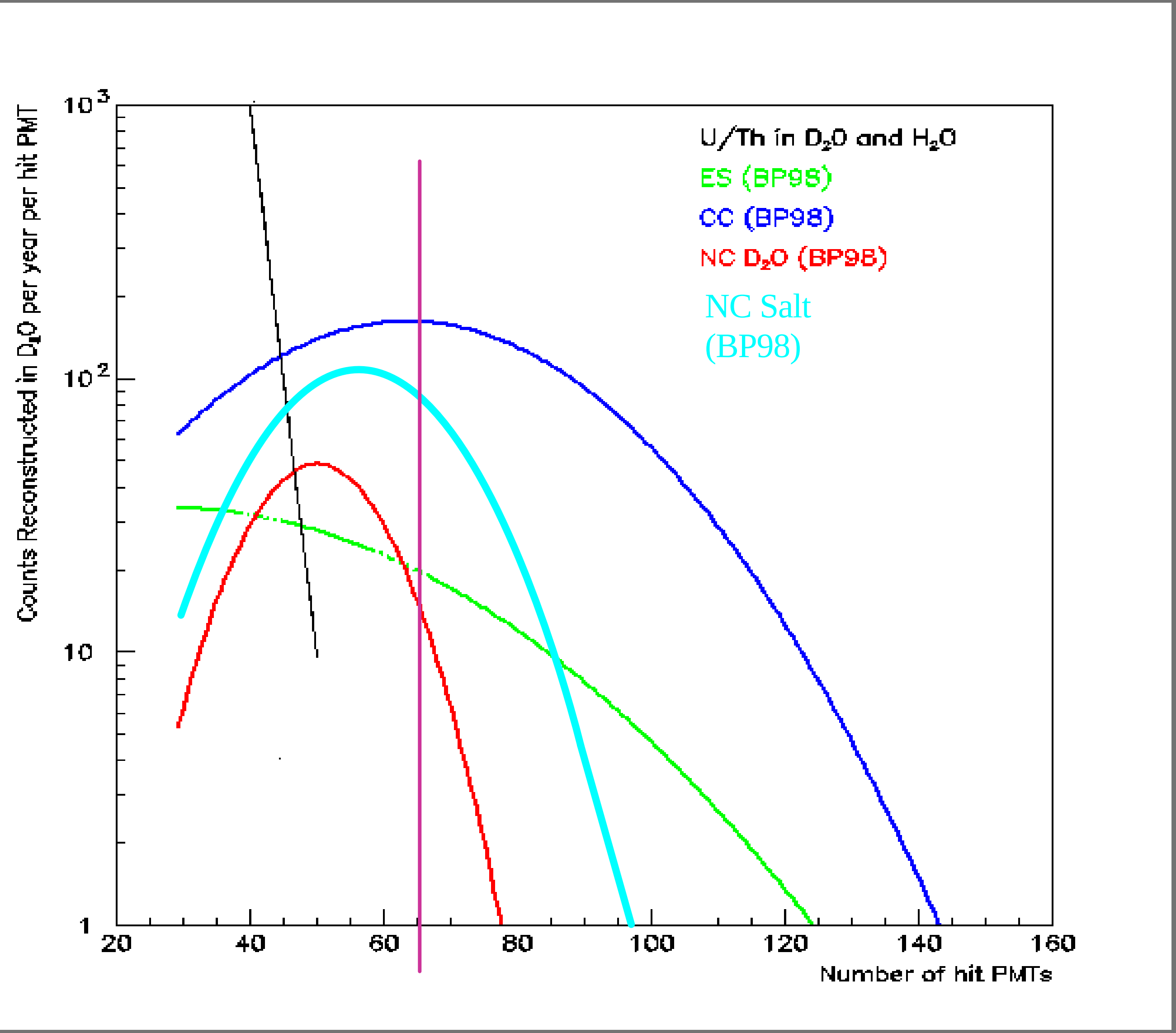
Evidence for Neutrino Oscillations

CC/ES Could also show significant effects!

$$\frac{CC}{ES} = \frac{n_e}{n_e + 0.154(n_m + n_t)}$$



Signals in SNO



SNO Calibrations

Electronics Calibration

Electronic pulsers

Optical Calibration

Pulsed laser ~2ns (337, 365, 386, 420, 500 and 620 nm)

→Attenuation, Reflection, Scattering, Relative QE

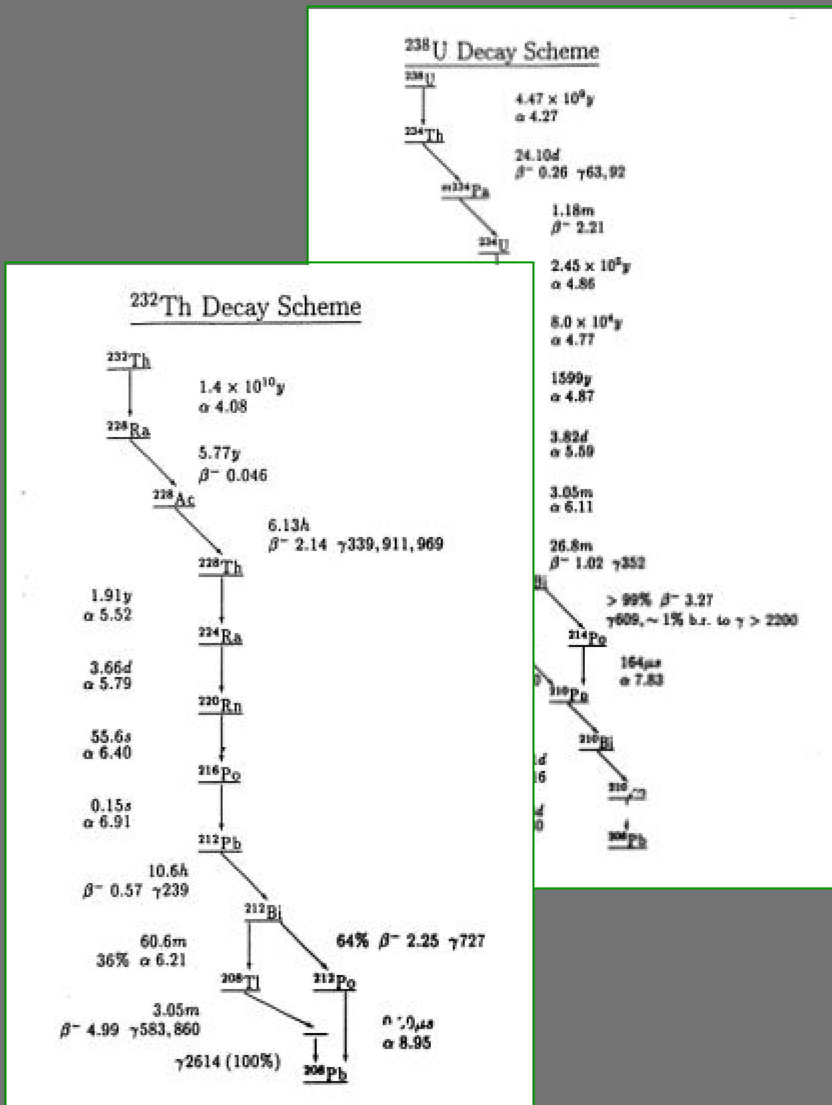
Energy Calibration

- ^{16}N → 6.13 MeV γ's
- p,T → 19.8 MeV γ's
- neutrons → 6.25 MeV γ's
- ^{8}Li → β spectrum endpoint

Low Energy Backgrounds

Encapsulated Th and U sources

The enemy.....



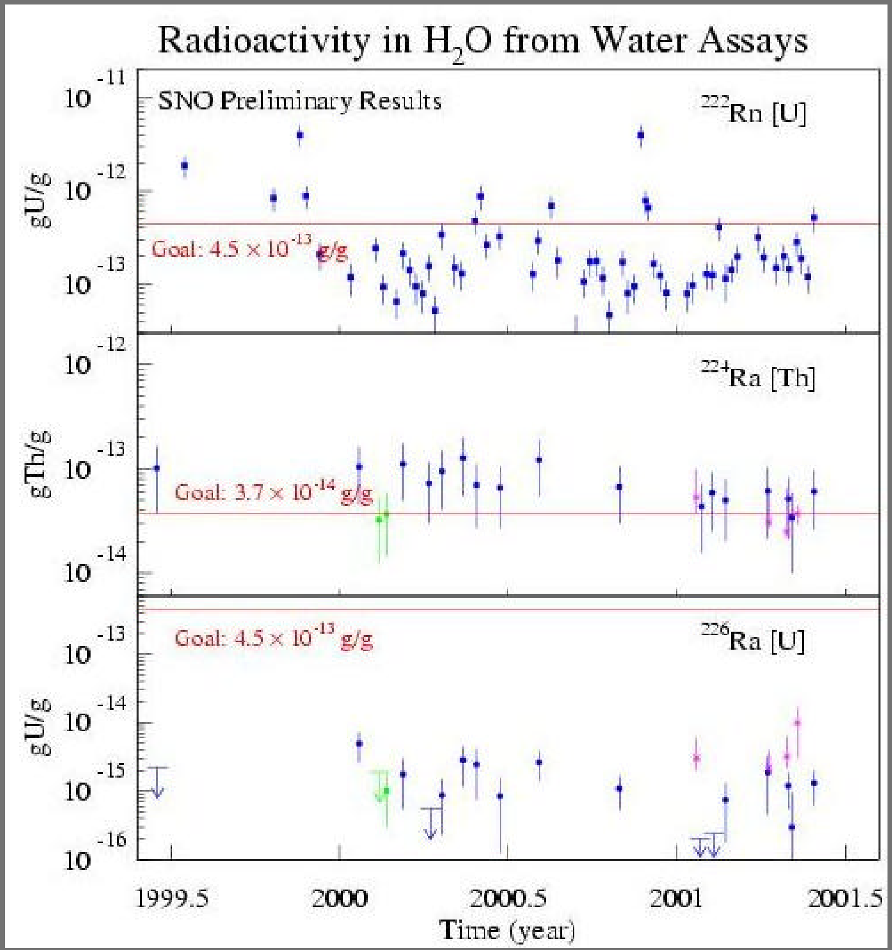
βs and γs from decays in these chains interfere with our signals at low energies

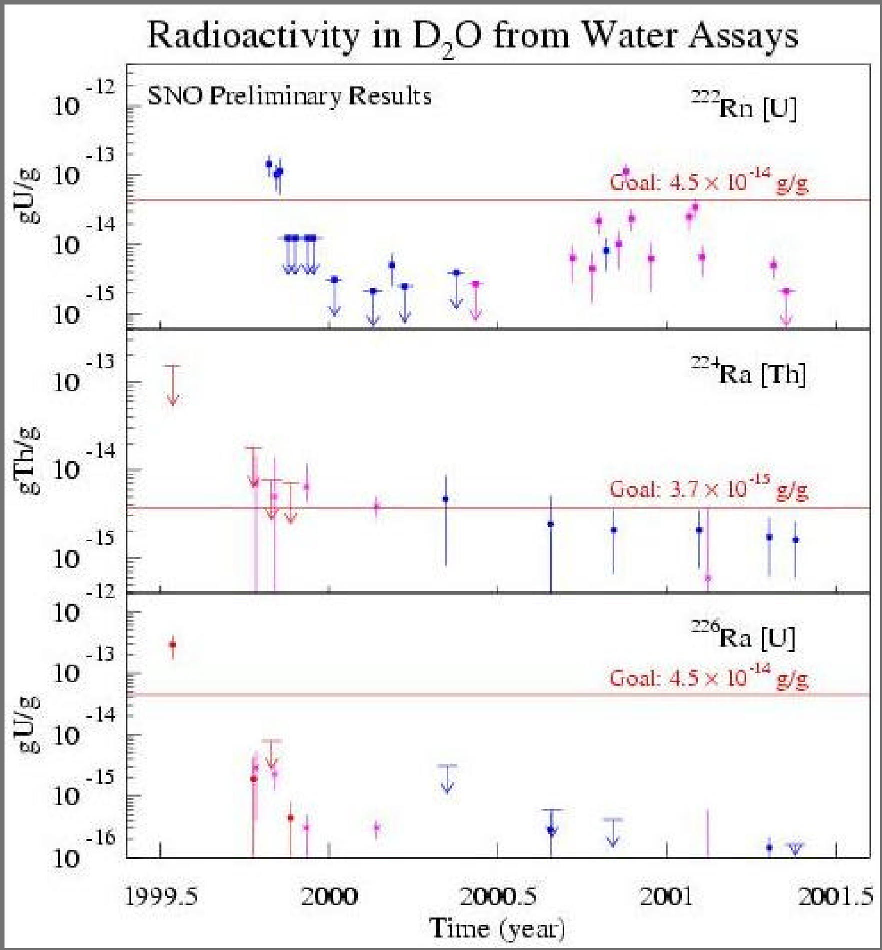
And worse, γs over 2.2 MeV cause $d + \gamma \rightarrow n + p$

Design called for:

- D_2O $< 10^{-15}$ gm/gm U/Th
- H_2O $< 10^{-14}$ gm/gm U/Th
- Acrylic $< 10^{-12}$ gm/gm U/Th

SNO Water Assays

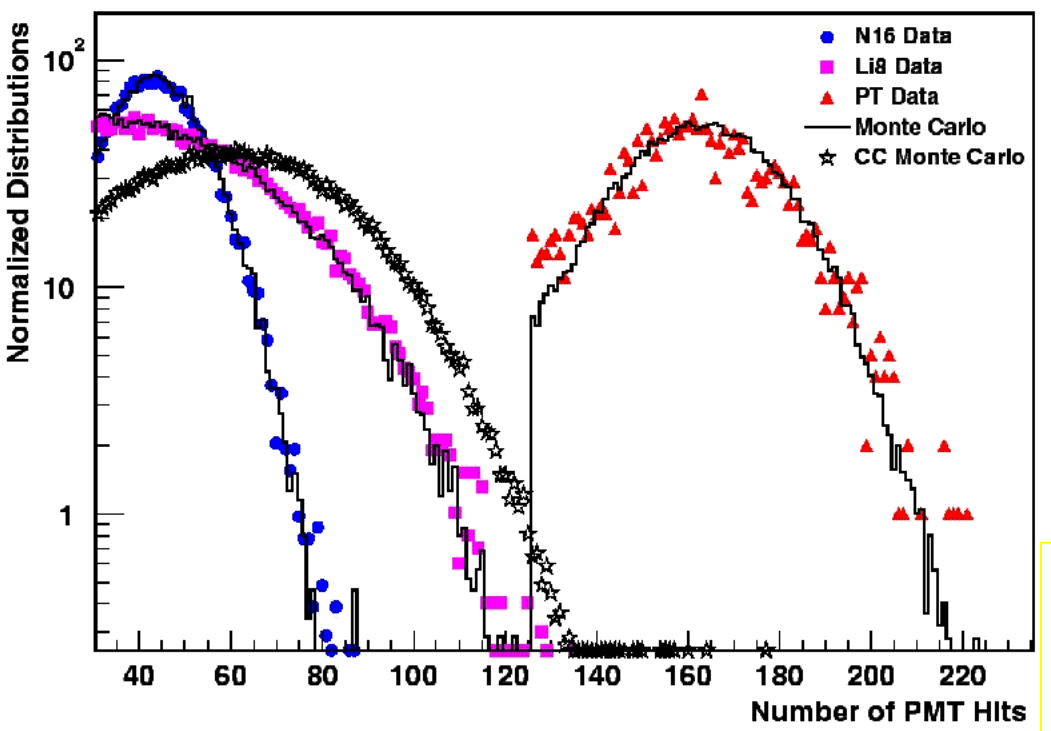




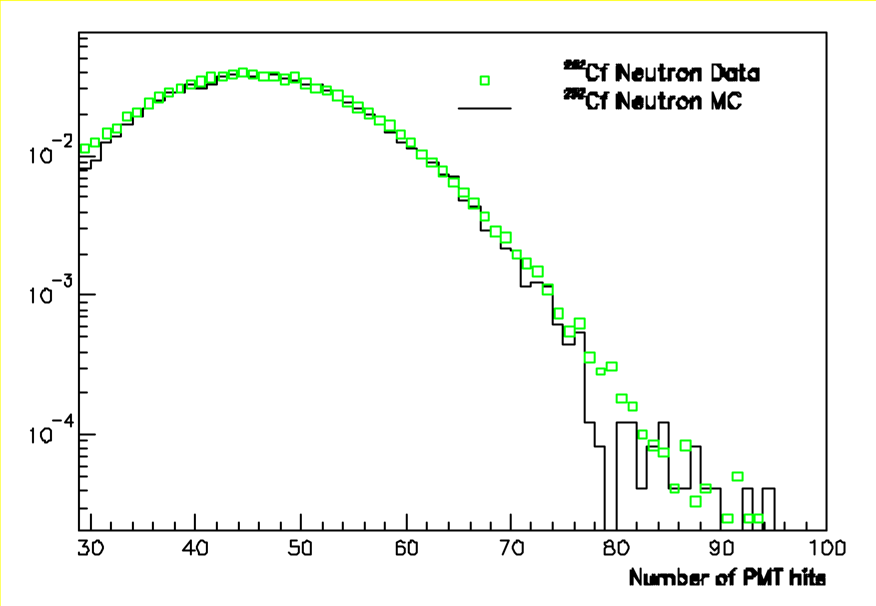
Targets are set to reduce β-γ events reconstructing inside 6m

Targets for D_2O represent a 5% background from $d+\gamma \rightarrow n+p$

SNO Energy Calibrations



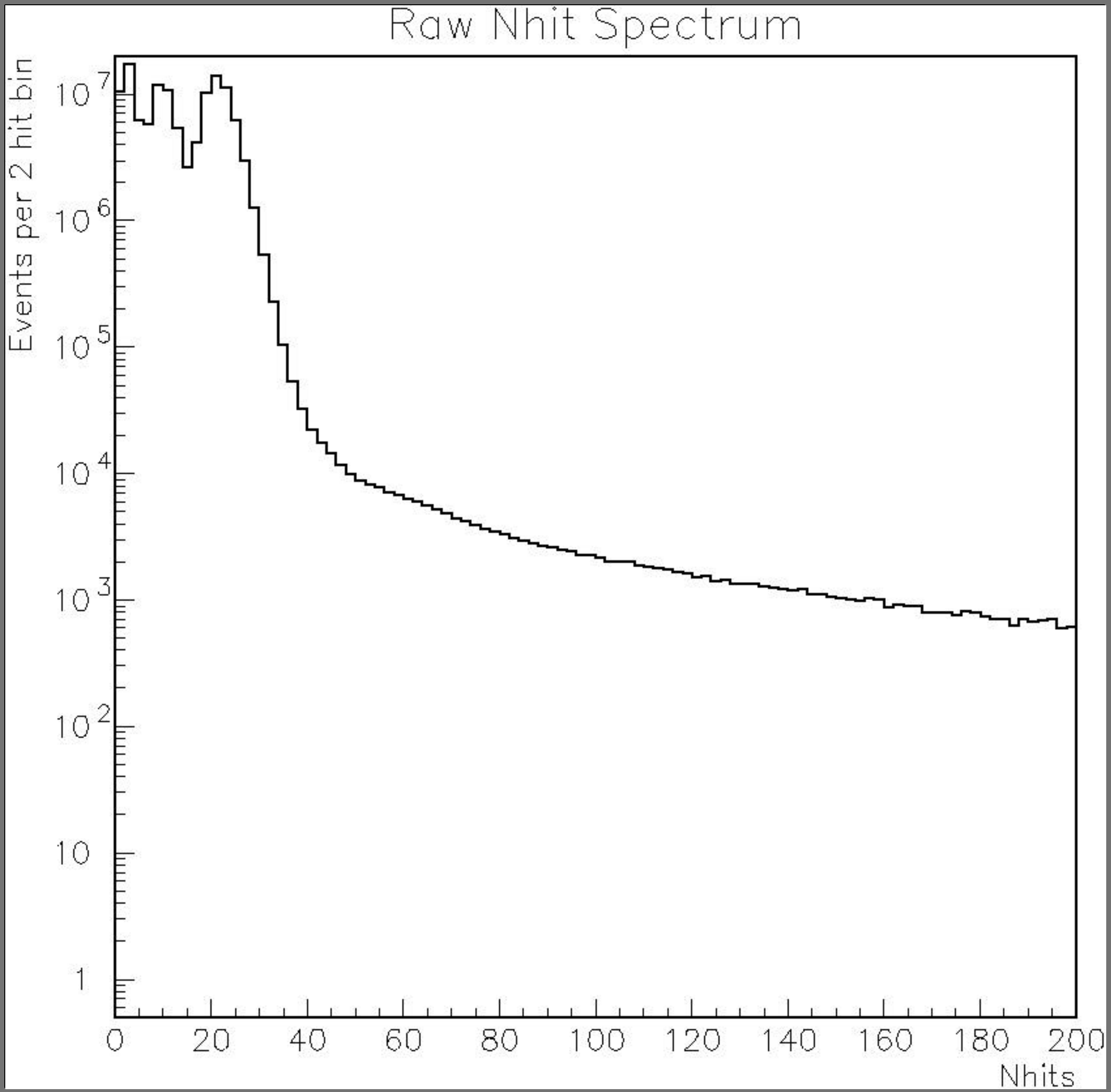
^{252}Cf neutrons



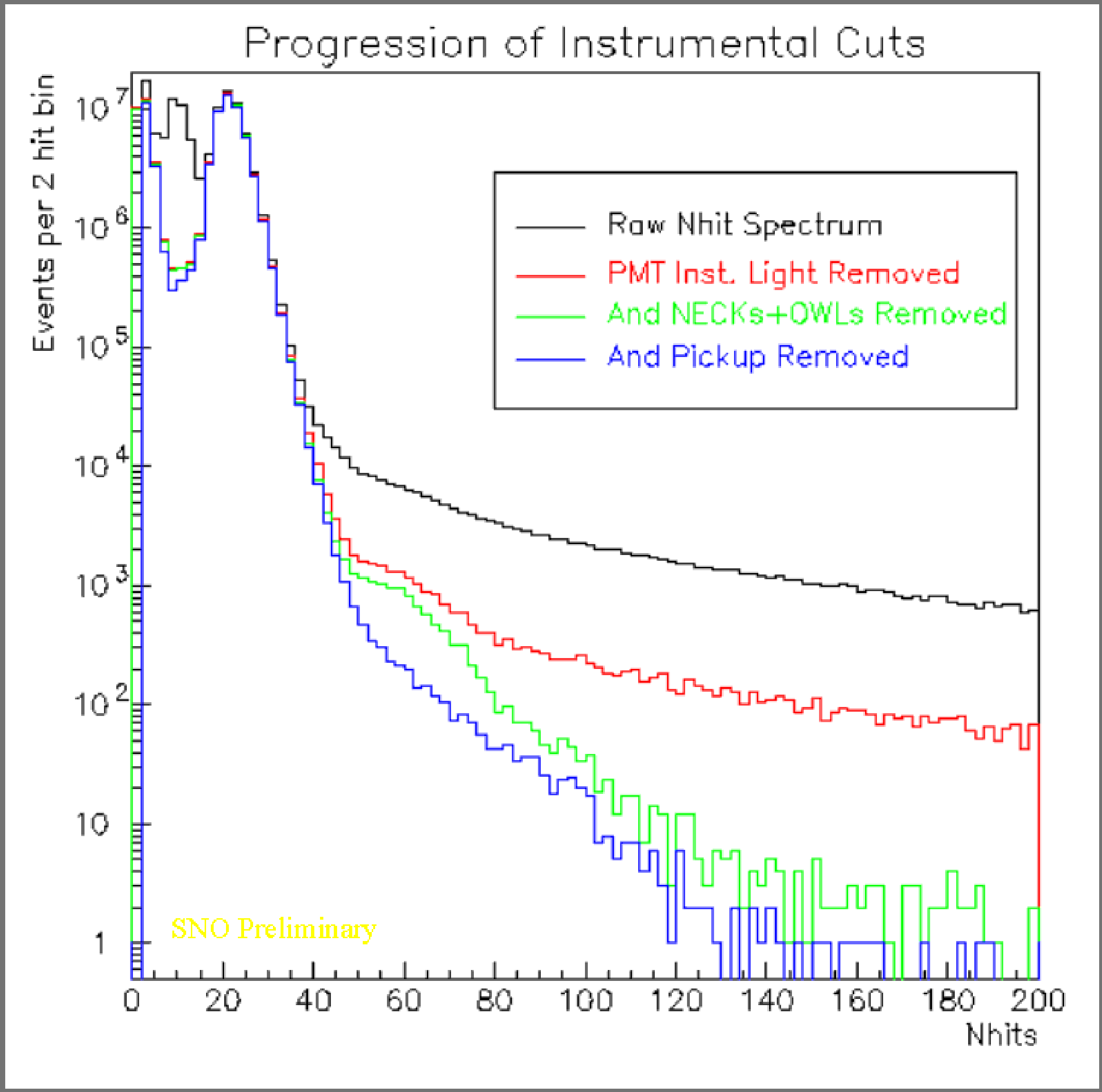
β's from ^{8}Li

γ's from ^{16}N and t(p,γ)^{4}He

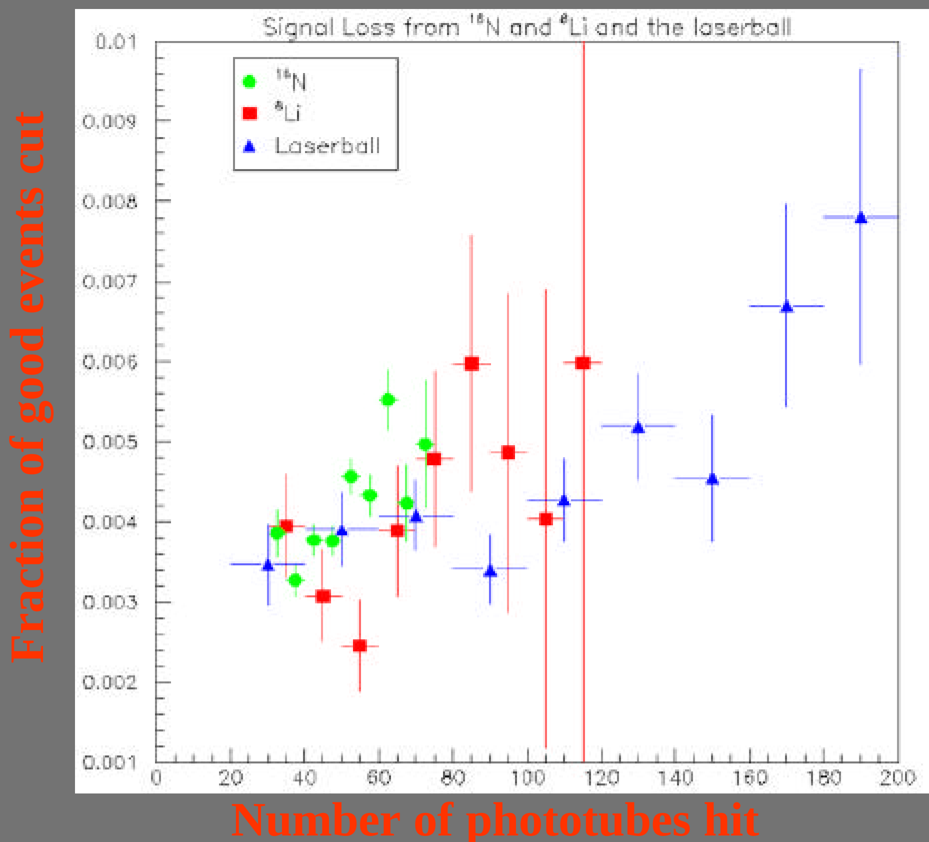
Raw Nhit Spectrum

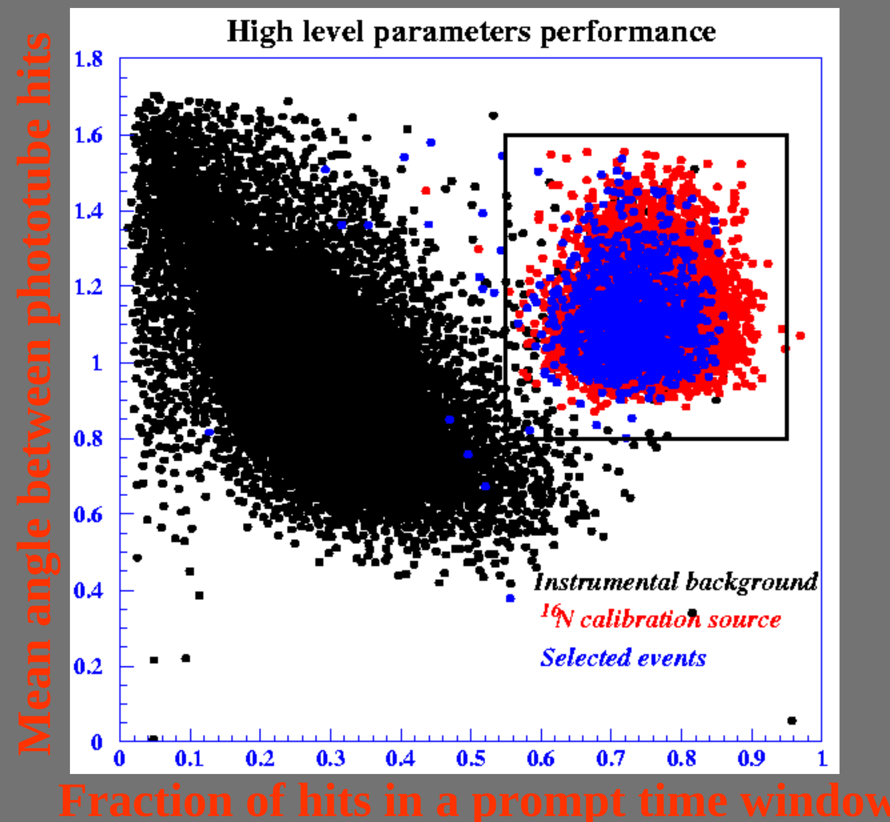


Instrumental Background Cuts



How do we know this worked?

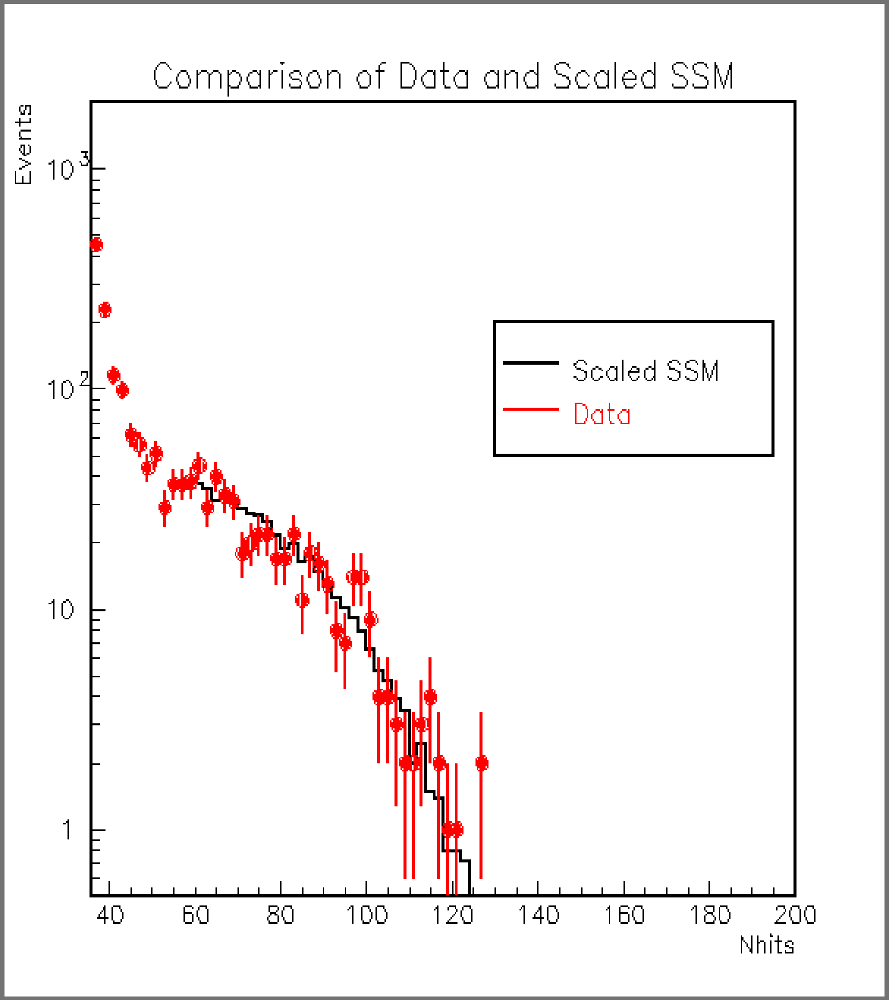


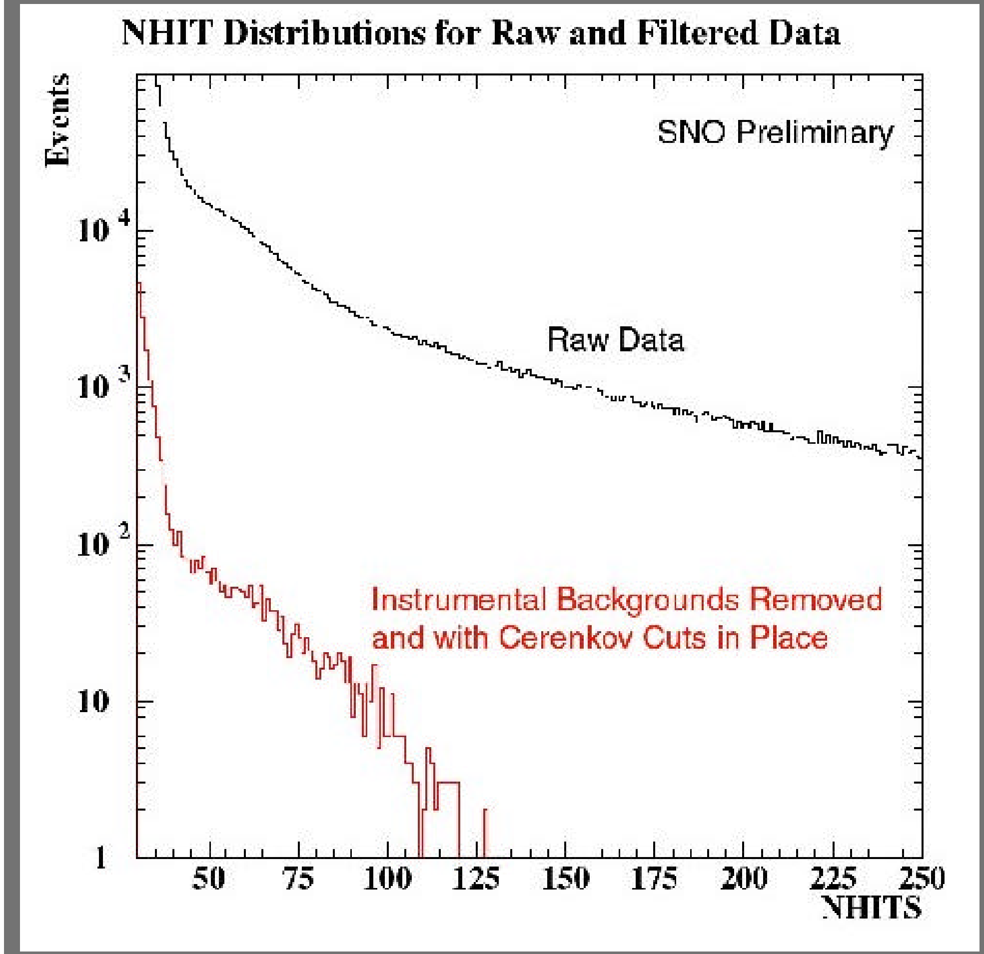


Signal loss measured with calibration sources

Contamination measured with independent cuts

Solar Neutrino Spectrum



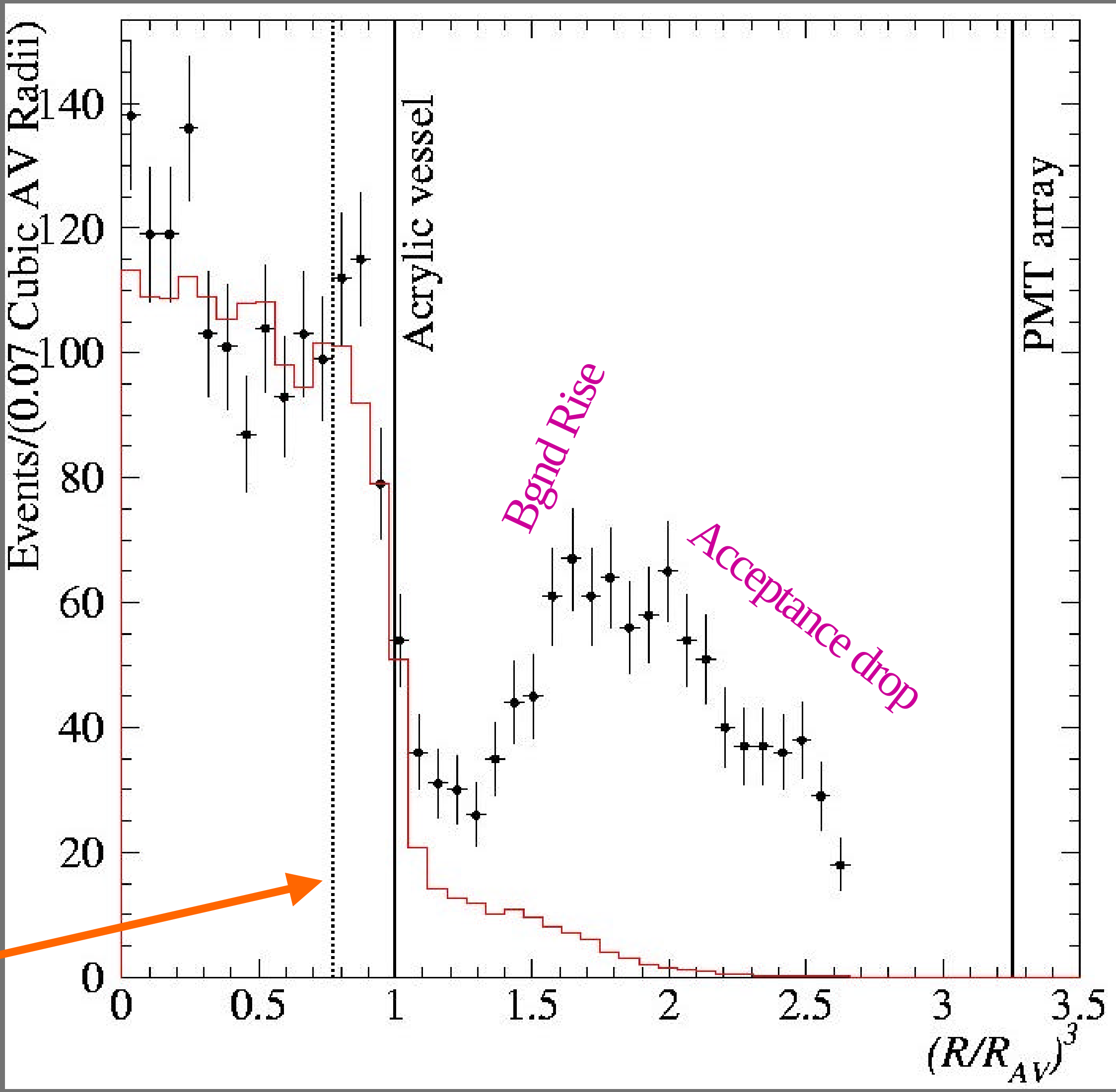


Radial Distribution

Nhit ≥ 65 (no neutrons, no low energy backgrounds)

Edge of AV is quite sharp.
➥ Events from D_2O clearly identified.

Fiducial Volume Cut at 550 cm

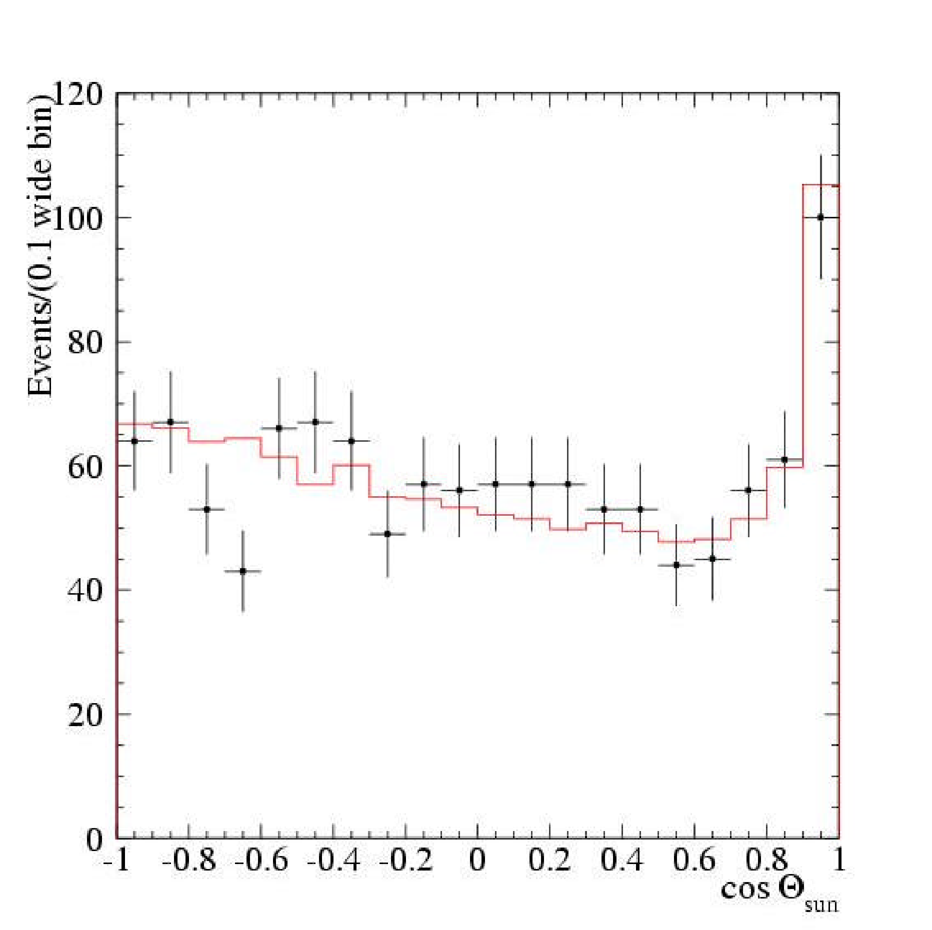


SNO cos$\theta_{\odot}$ distribution

ES: strongly peaked

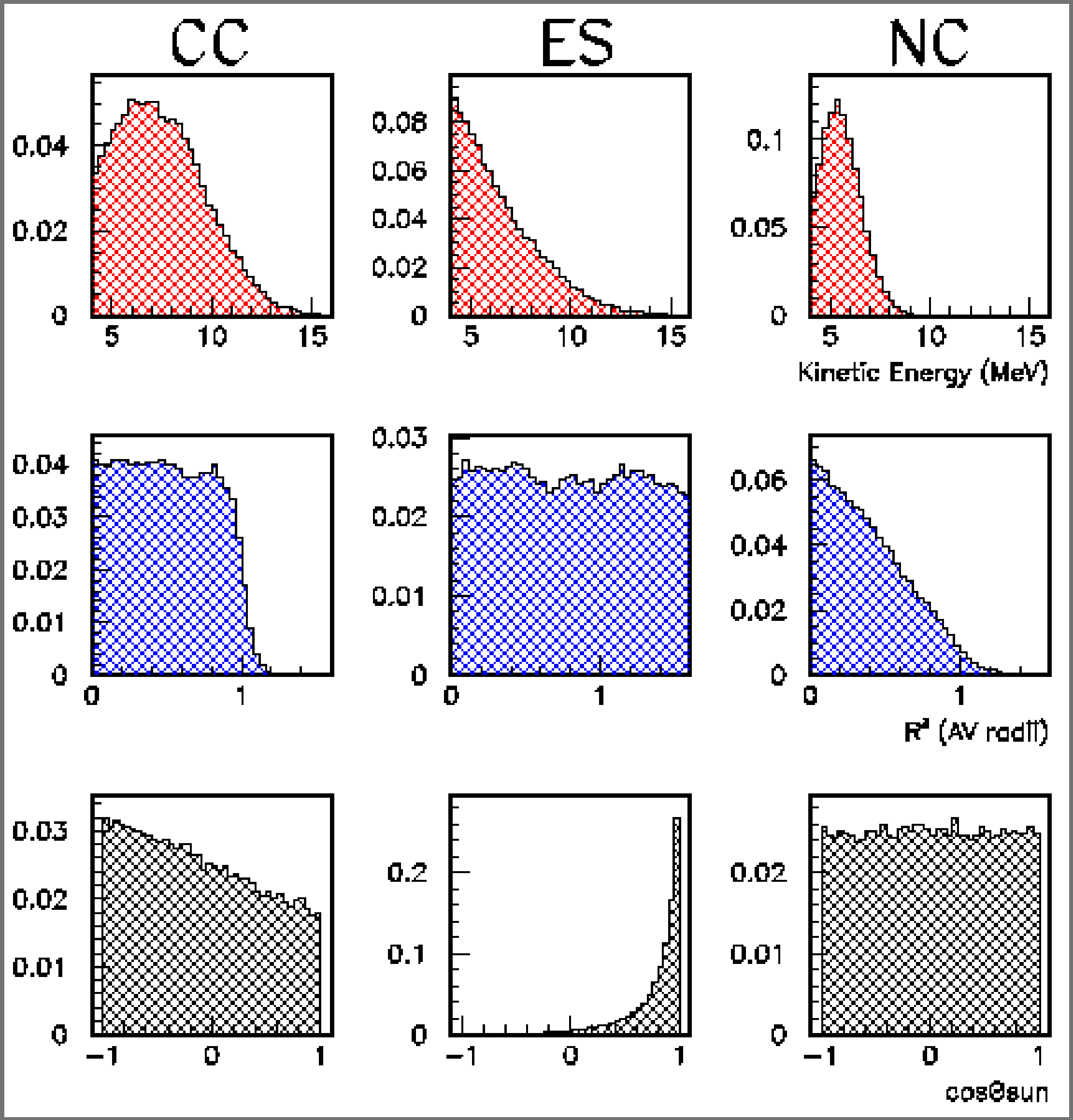
CC: 1-1/3cos$\theta_{\odot}$

Neutrons: isotropic



Electron Angle with respect to the direction from the Sun

Signal Extraction



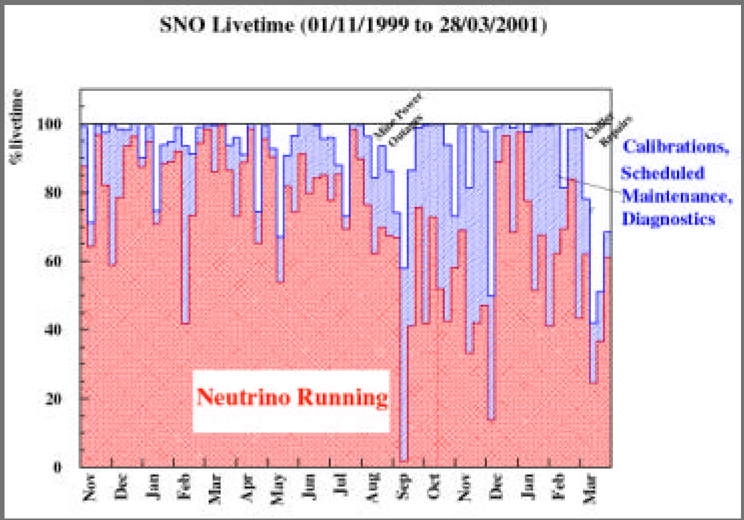
Signal Extraction Results

Data resolved into CC, ES, neutron components with Monte Carlo pdfs of T_{eff}, $\cos\theta_{sun}$, $(R/R_{AV})^3$ With the hypothesis of no neutrino oscillations

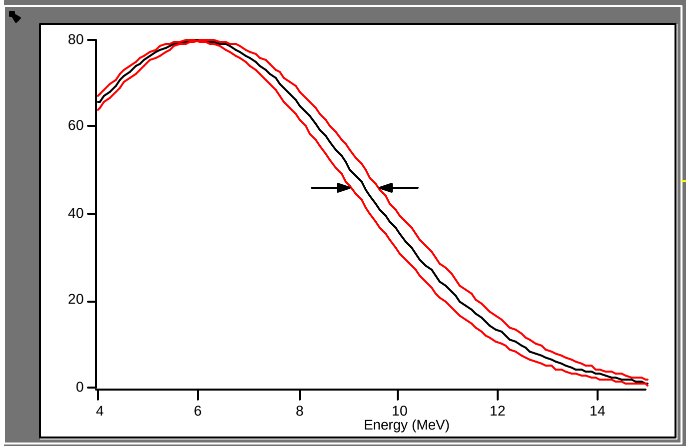
CC	975.4 ± 39.7 events
ES	106.1 ± 15.2 events
Tail of Neutrons	87.5 ± 24.7 events

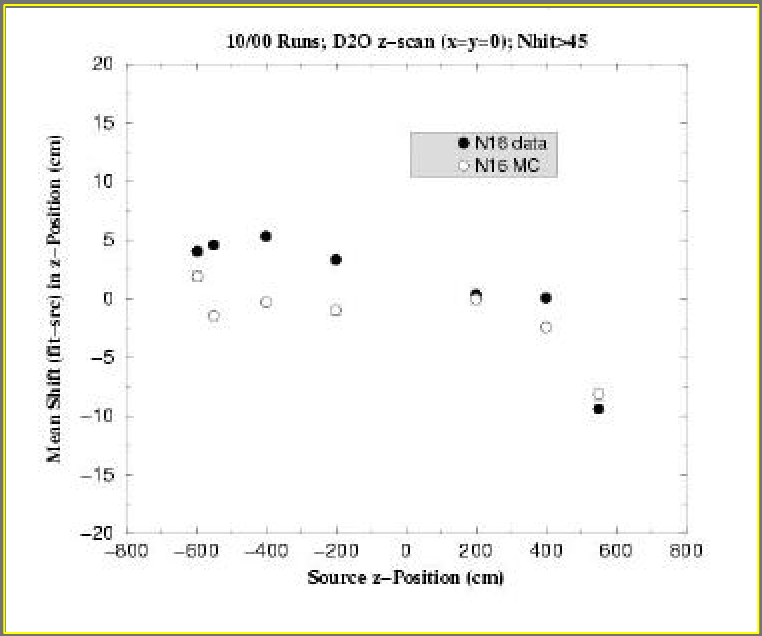
240.9 live-days
between 11/99-1/01

No statistically significant differences between Blind and Open data sets (75 days/166 days)



Systematic Uncertainties



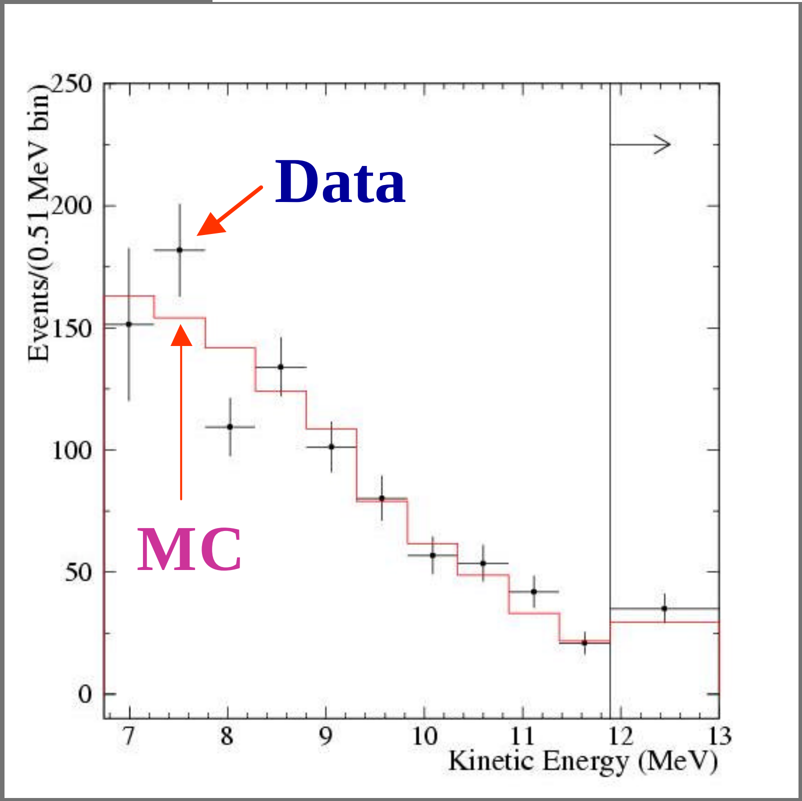


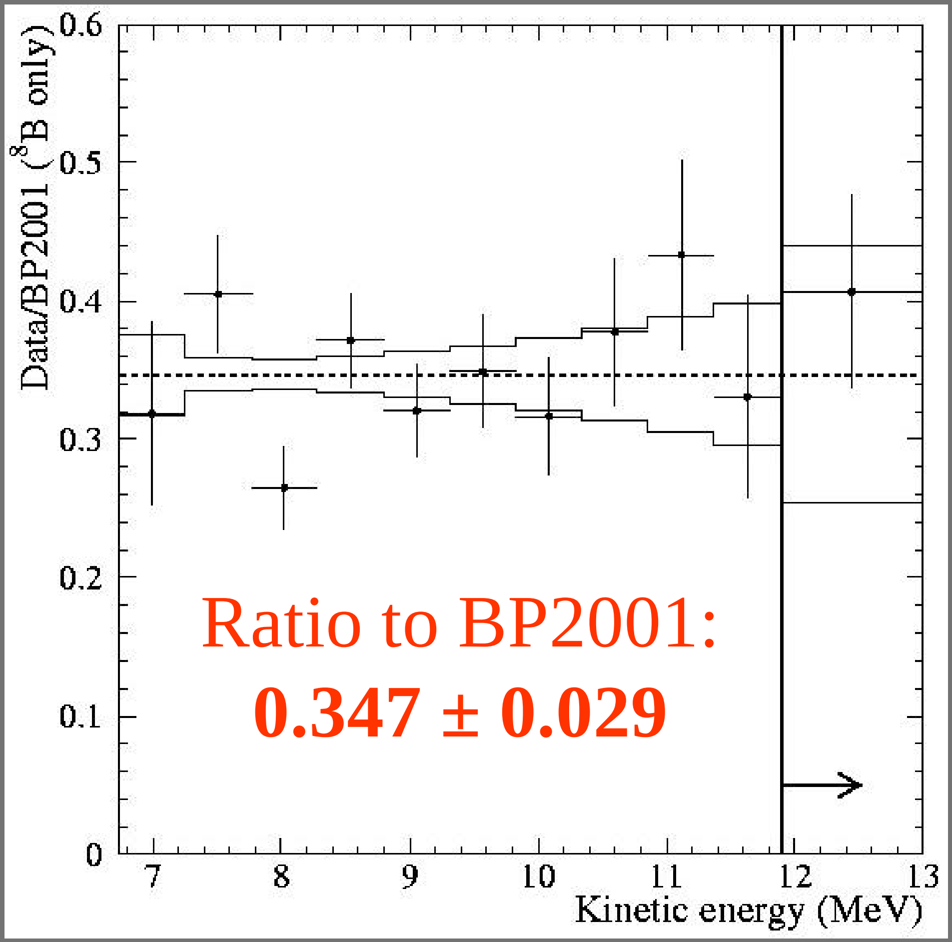
N(HE γ events): <10 events (68% CL)

Source	*CC (%)*	*ES (%)*
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 accuracy	±3.1	±3.3
Vertex resolution	±0.7	±0.4
Angular resolution	±0.5	±2.2
High energy g	+0, -0.8	+0, -1.9
Low energy background	0.0 –0.2	0.0 –0.2
Instrumental background	+0.0, -0.2	+0.0, -0.5
Trigger efficiency	0.0	0.0
Live Time	±0.1	±0.1
Cut acceptance	+0.7, -0.6	+0.7, -0.6
Earth orbit eccentricity	±0.2	±0.2
^{17}O, ^{18}O	0.0	0.0
Experimental uncertainty	**+7.0, -6.2**	**+6.8, -5.7**
Cross section	**3.0**	**3.0**
Solar model	**+20, -16**	**+20, -16**

SNO energy (CC) spectrum / ^{8}B spectrum

No evidence for shape distortion





Data points derived by fitting each energy bin independently

Monte Carlo of undistorted ^{8}B spectrum normalized to the data

(Adding syst. bin by bin in quadrature give c^2 of ~12 for 11 D.O.F.)

Solar Neutrino Fluxes

- Absolute fluxes (x 10^6 cm^{-2} s^{-1}):

SNO:

$$F^{CC}(^8B) = 1.75 \pm 0.07\ \text{(stat)}\ {}^{+0.12}_{-0.11}\ \text{(sys.)} \pm 0.05\ \text{(theory)}$$

$$F^{ES}(^8B) = 2.39 \pm 0.34\ \text{(stat)}\ {}^{+0.16}_{-0.14}\ \text{(sys.)}$$

Super-K* $$F^{ES}(^8B) = 2.32 \pm 0.03\ \text{(stat)}\ {}^{+0.08}_{-0.07}\ \text{(sys.)}$$

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

“Flux” Differences

- CC at **SNO** vs ES at **SNO**
  - $\Phi^{ES}_{SK} - \Phi^{CC}_{SNO} = 0.64 \pm 0.40 \Rightarrow 1.6\sigma$ effect

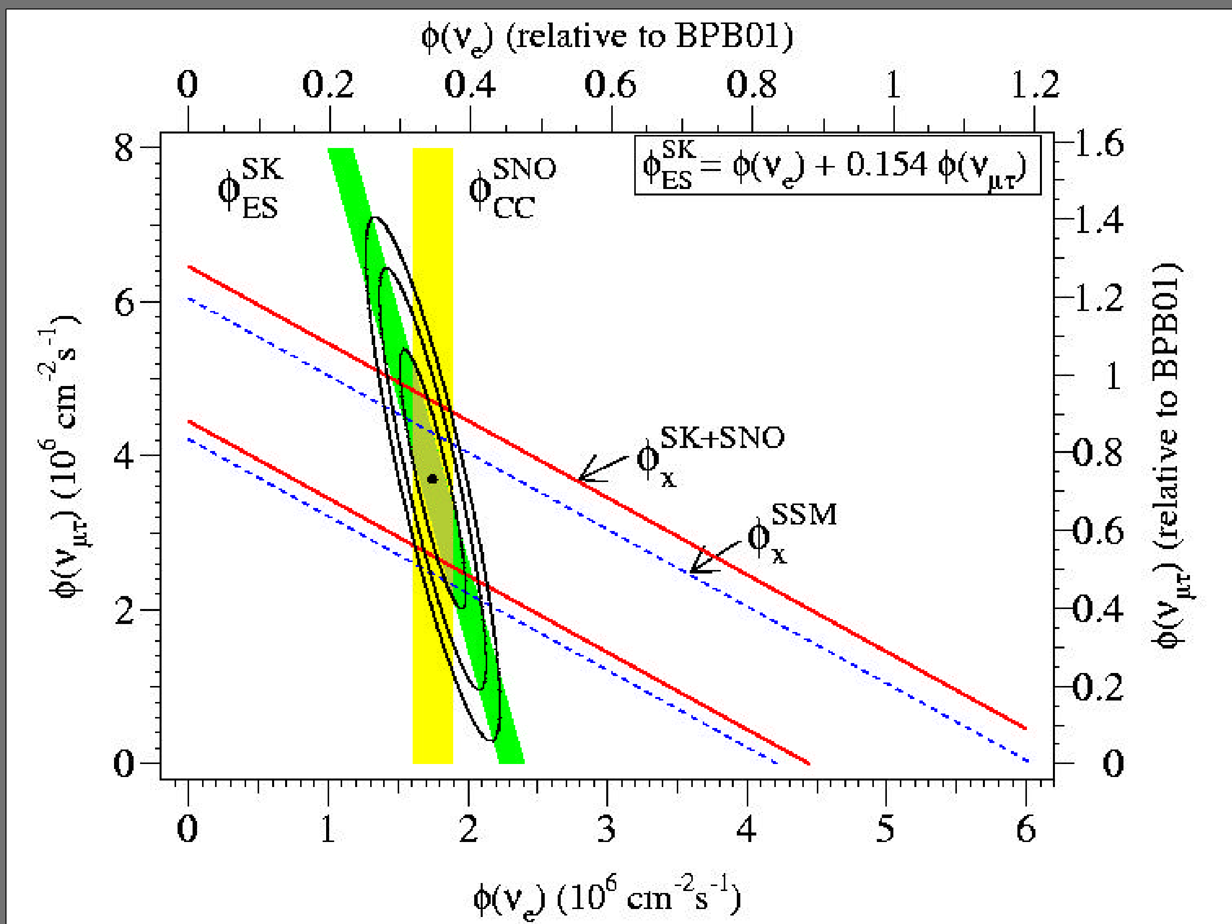
- CC at **SNO** vs ES at **SK**
  - $\Phi^{ES}_{SK} - \Phi^{CC}_{SNO} = 0.57 \pm 0.17 \Rightarrow$ <u>3.35σ effect</u>

The hypothesis that this is a downward statistical fluctuation is ruled out at 99.96%

F_{mt} vs. F_{e}

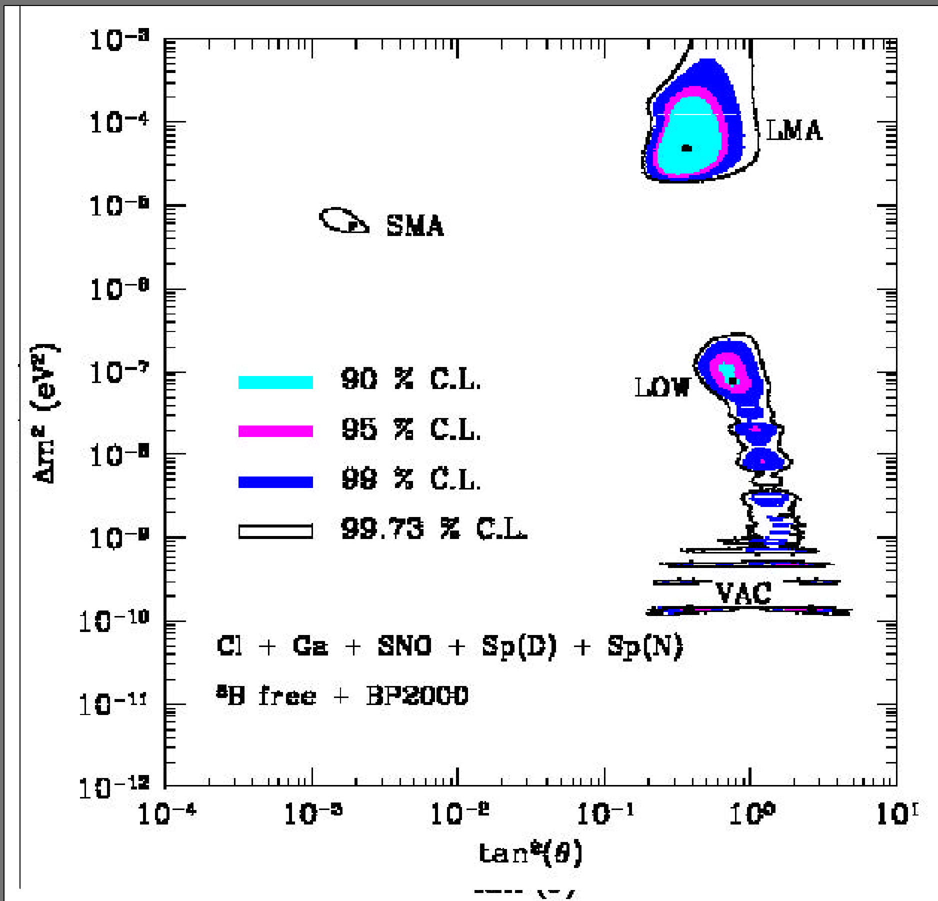
$\Phi_{SNO+SK}(^8B) = 5.44 \pm 0.99 \times 10^6\ cm^{-2}s^{-1}$

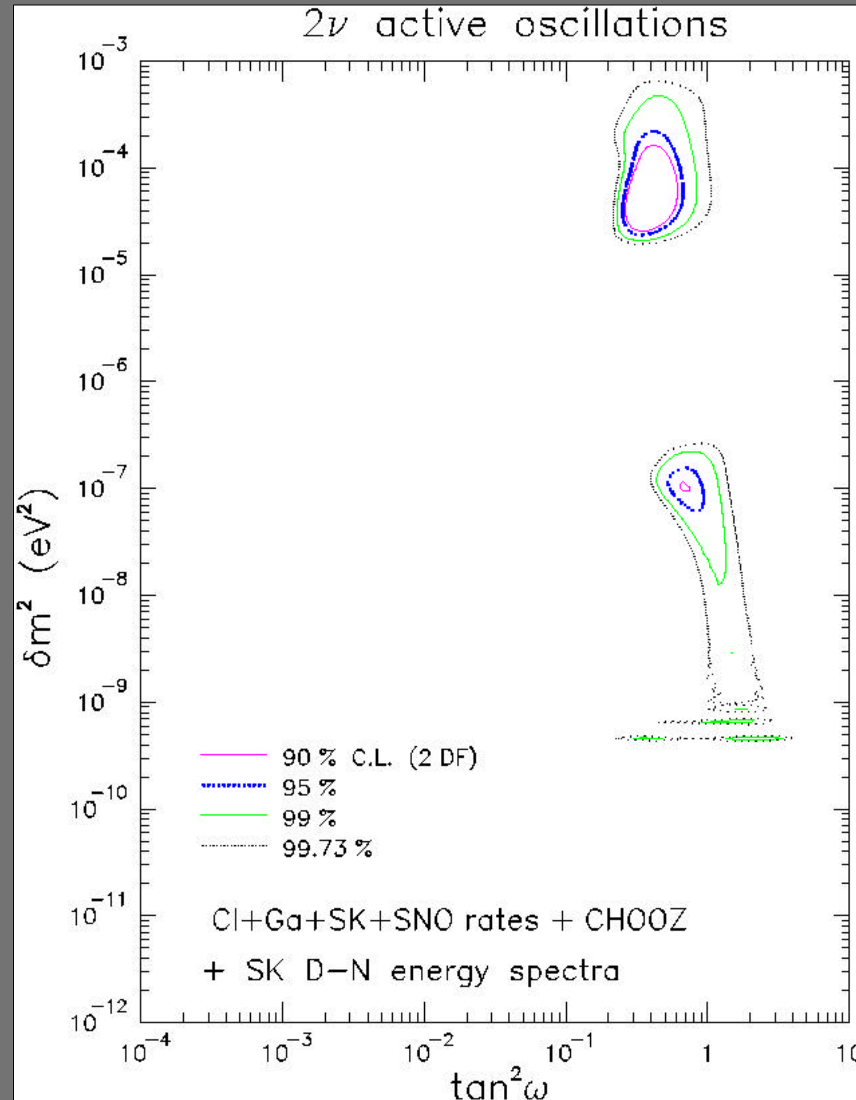
$\Phi_{SSM}(^8B) = 5.05 ^{+1.01}_{-0.81} \times 10^6\ cm^{-2}s^{-1}$



The Standard Solar Models are correct

SNO + Ga + Cl + S-K





Bahcall, Krastev and Smirnov hep-ph/0106258

Krastev and Smirnov hep-ph/0108177

Fogli,Lisi,Montanino,Palazzo hep-ph/0106247

SNO Schedule

- Now- Summer 2002
  Salt data
- Summer 2002- Autumn 2002
  Pure D_2O run
- January 2003 - 2005
  Neutral Current detectors
- Summer 2005
  SN-2005A

Conclusions

- ☺ The SNO detector is working and taking beautiful data.
- ☺ The CC rate measured in SNO is incompatible with the Super-K ES rate.
- ☺ This is strong evidence (>99.8% c.l.) for the appearance of μ or τ neutrinos from the Sun.
- ☺ Sterile and Just-So^2 oscillations are excluded by these results at >99.8% c.l.
- ☺ The ^8B ν flux from the Sun is measured to be in agreement with the predictions of Standard Solar Models.

Outlook

- ☺ These results are just the first of what SNO will produce.
- ☺ The conclusions listed on the preceeding slide are systematics dominated. They will be severely tested by new measurements:
  - ☺ NC measurements in pure D_2O
  - ☺ Day/night in pure D_2O
- ☺ The same measurements with NaCl added
- ☺ The same measurements with the NCDs
- ☺ hep ν, μ, anti-ν, seasonal variations, and much more . . .
- ☺ It will be a very exciting time!