Results from SNO

David Sinclair
For the SNO Collaboration

SeeSaw - 2004

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Neutrino Oscillations
Pre SNO/Super-K

- Theoretical bias is for small mixing
- SeeSaw model gives $m_{\nu i} \sim m_{qi}^2$
- Bias favoured SMA for solar neutrinos
- SMA + SeeSaw -> m_τ is Dark Matter
- SMA + SeeSaw -> m_τ explains super nova explosions

SNO

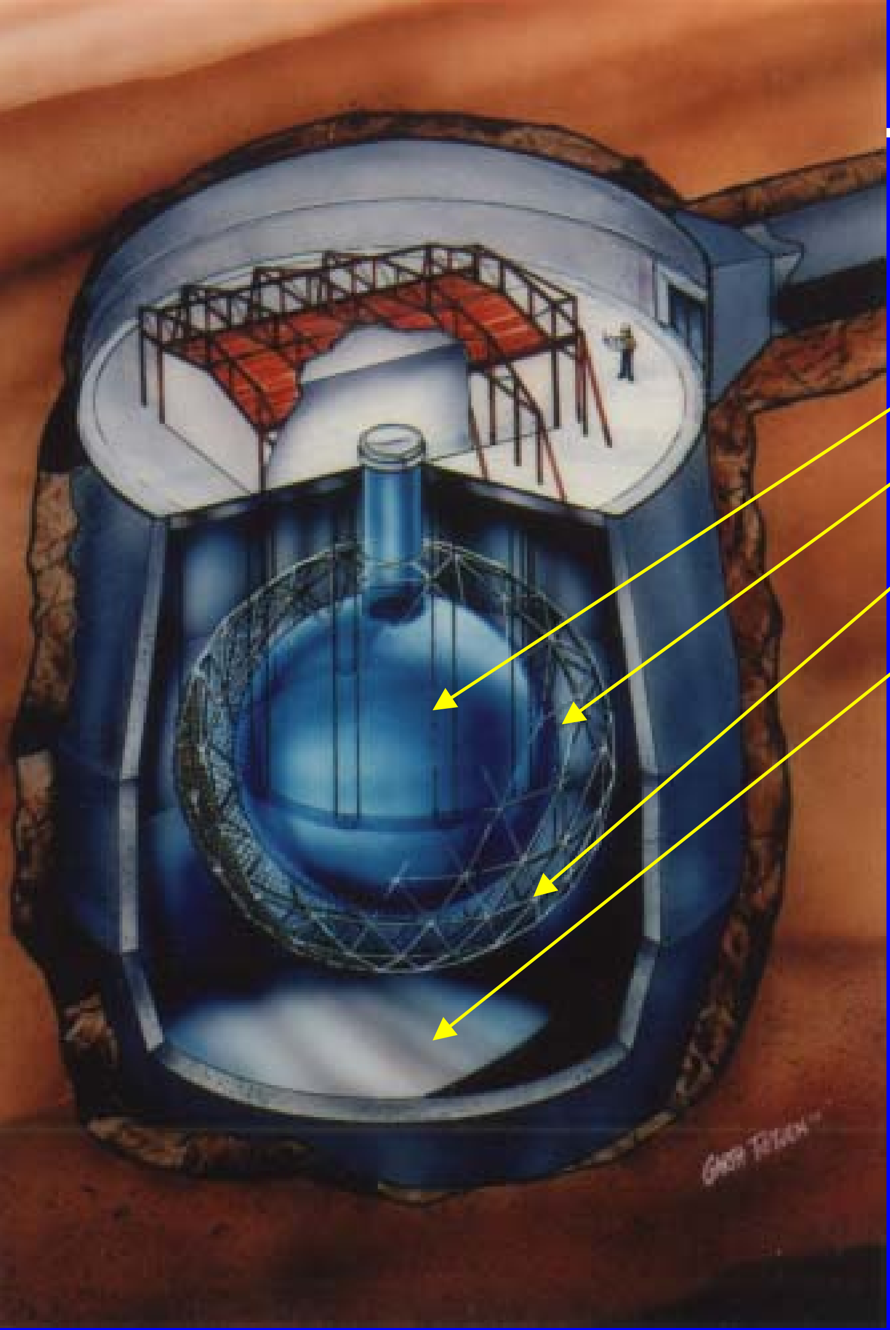
- Detector built to solve the Solar Neutrino Problem
- Measure the neutrino flux through 3 reactions:

$$\nu_e + d \rightarrow p + p + e^- \qquad \text{CC}$$

$$\nu_x + e^- \rightarrow \nu_x + e^- \qquad \text{ES}$$

$$\nu_x + d \rightarrow n + p + \nu_x \qquad \text{NC}$$

x means any neutrino type

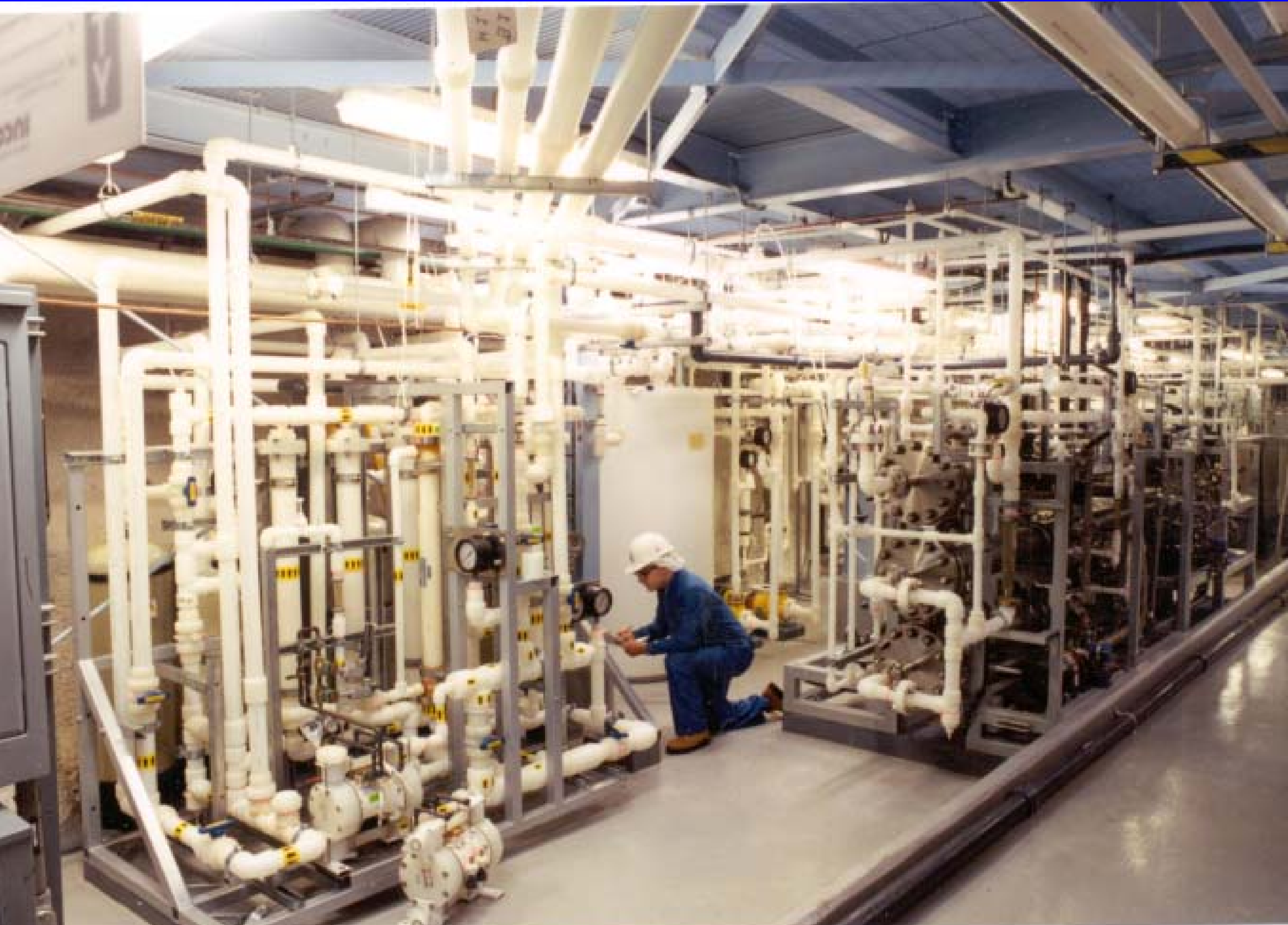


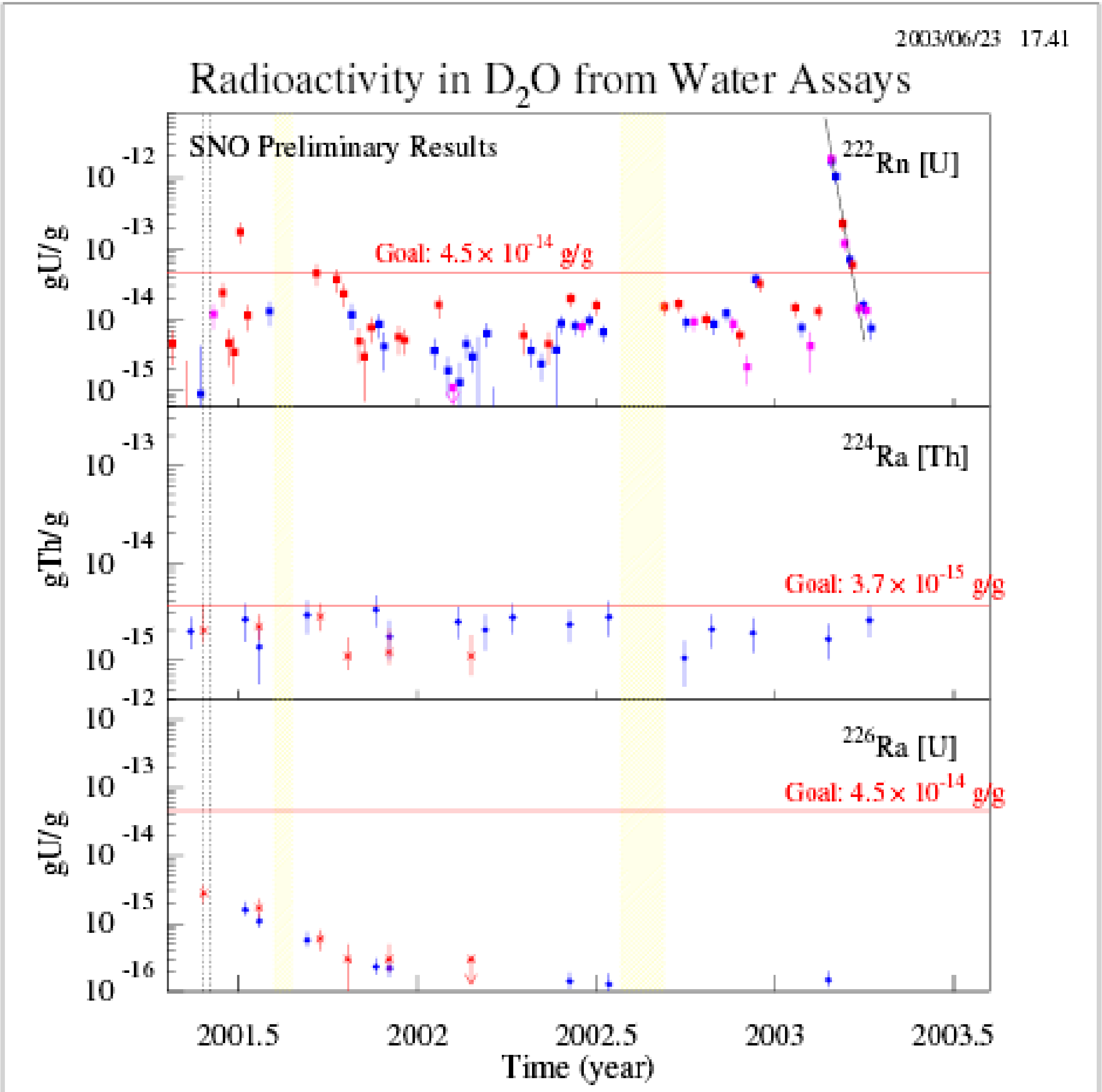
The SNO Detector

- 1000 Tonnes of D_2O
- 12 M Acrylic vessel
- 10,000 phototubes
- 8000 Tonnes of pure light water
- 2000 m deep in Mine
- World's largest deep cavern
- All materials very pure

3 Phases of SNO

- 1) Run with pure Heavy Water
- 2) Add 0.2% NaCl to enhance NC detection
- 3) Remove NaCl, add Neutral Current Detectors (NCDs)
- Each phase is approx. 2 years

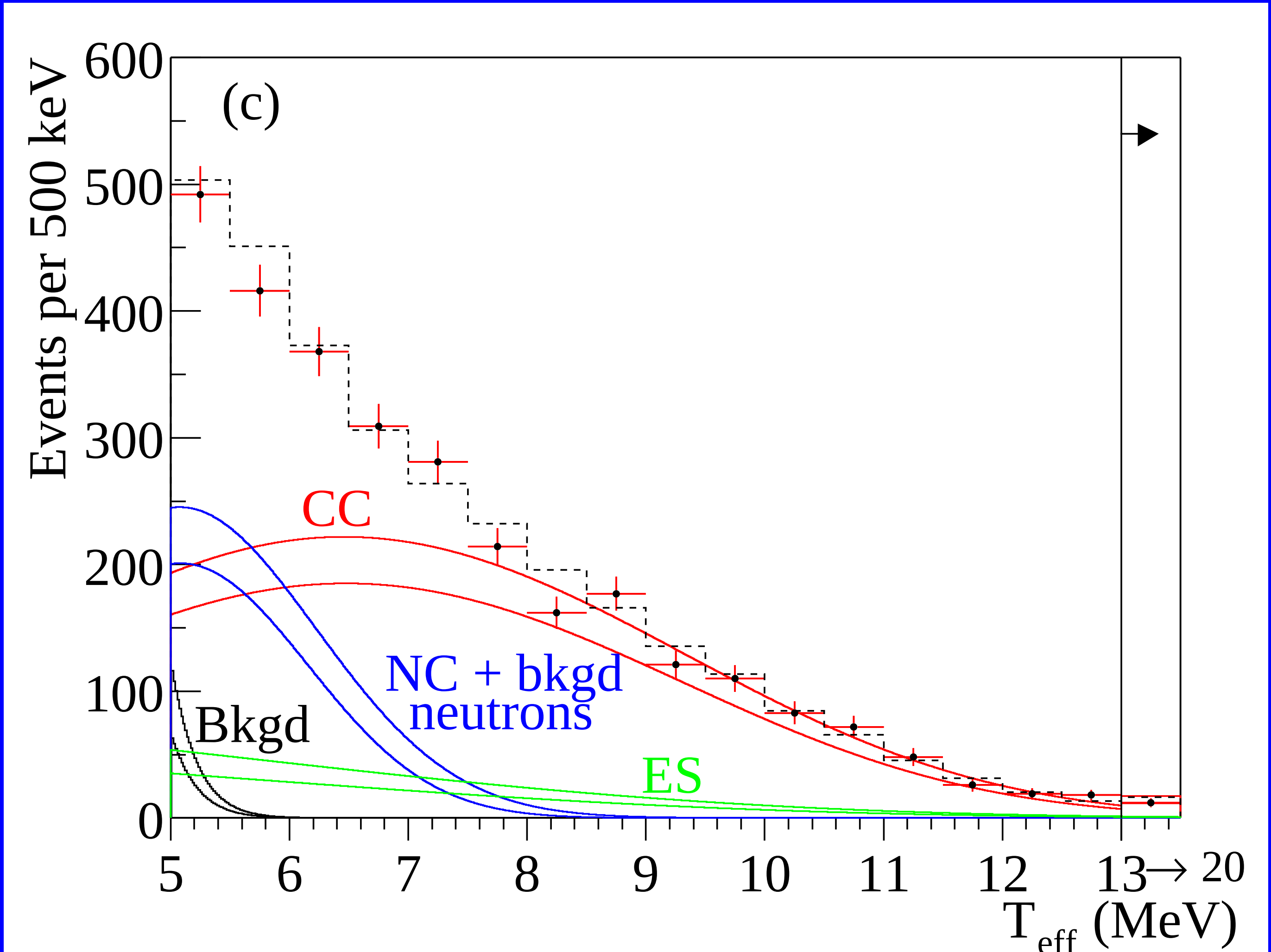




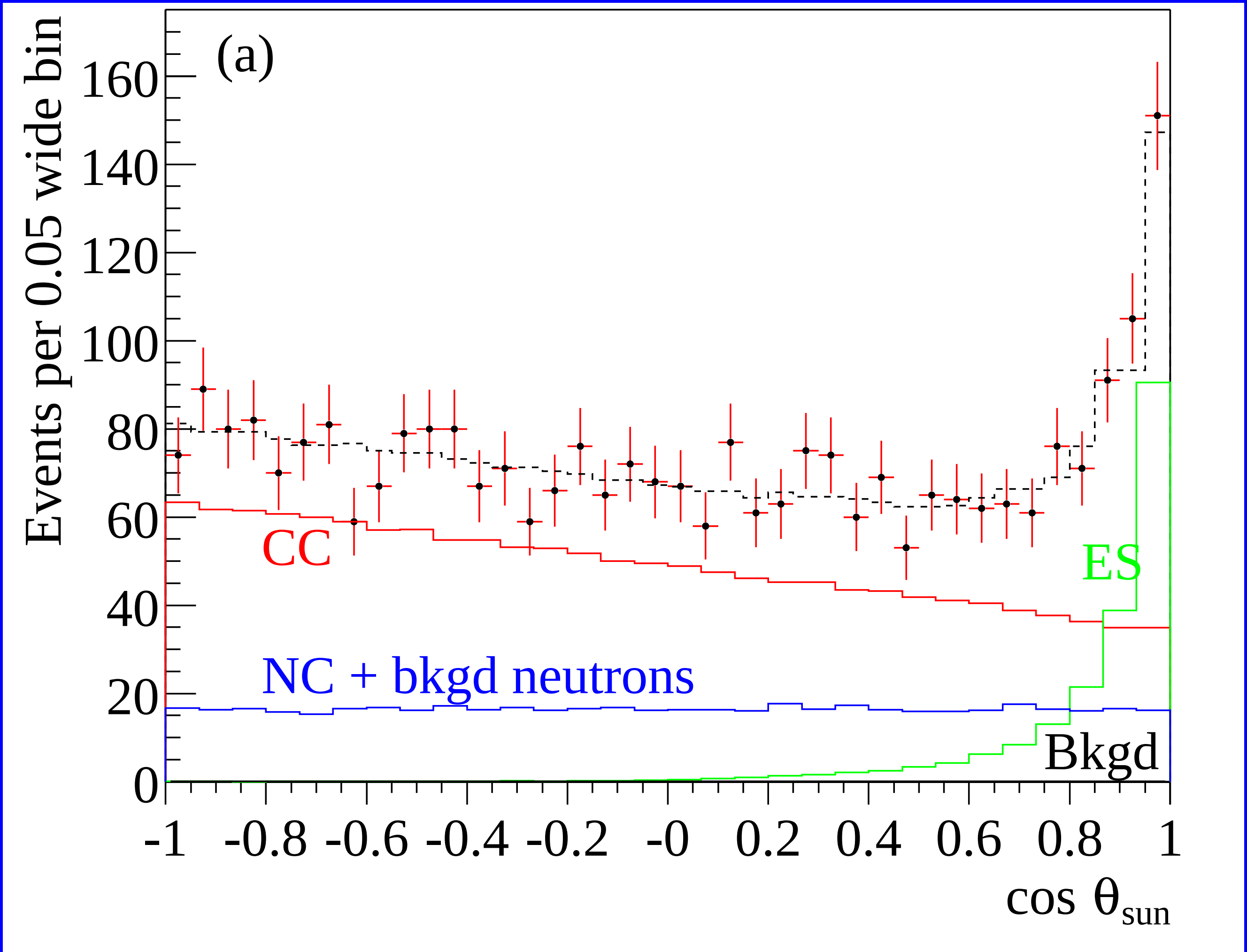
Goal: for NC

Signal/Bkgd >10

SNO Energy Spectrum
Pure Heavy Water



Data plotted as function of Direction to Sun – Pure D_2O



Results for Pure Heavy Water

Shape of ^{8}B spectrum in CC and ES not constrained:

$$\phi_{NC}^{SNO} = 6.42^{+1.57}_{-1.57}(\text{stat})^{+0.55}_{-0.58}(\text{syst})$$

Constrain CC and ES shape to Ortiz et al

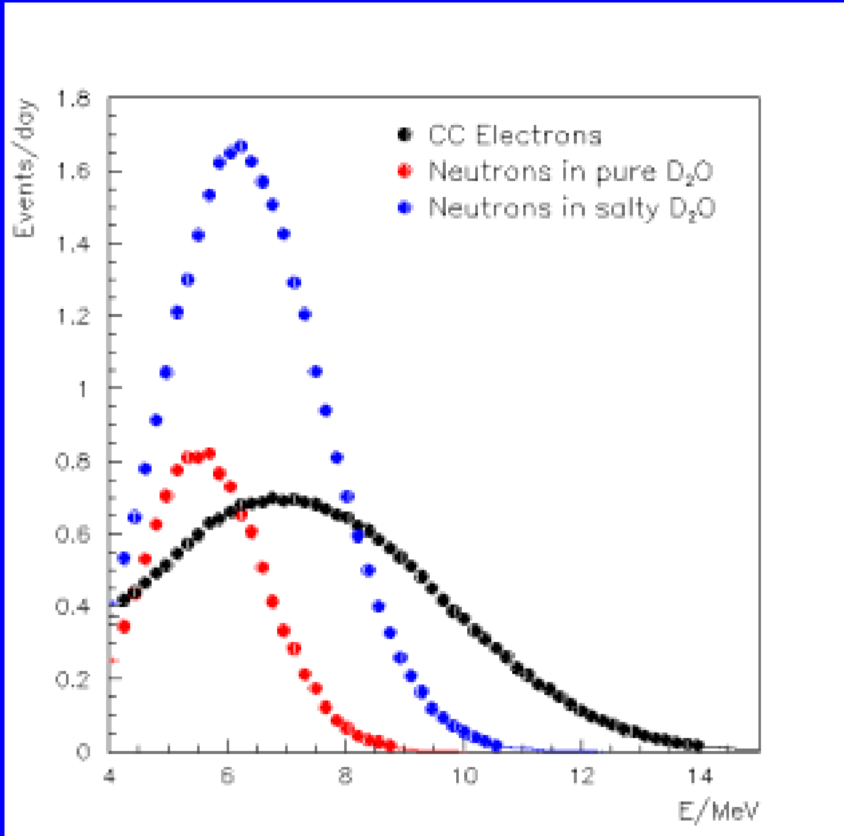
$$\phi_{CC}^{SNO} = 1.76^{+0.06}_{-0.05}(\text{stat})^{+0.09}_{-0.09}(\text{syst}),$$

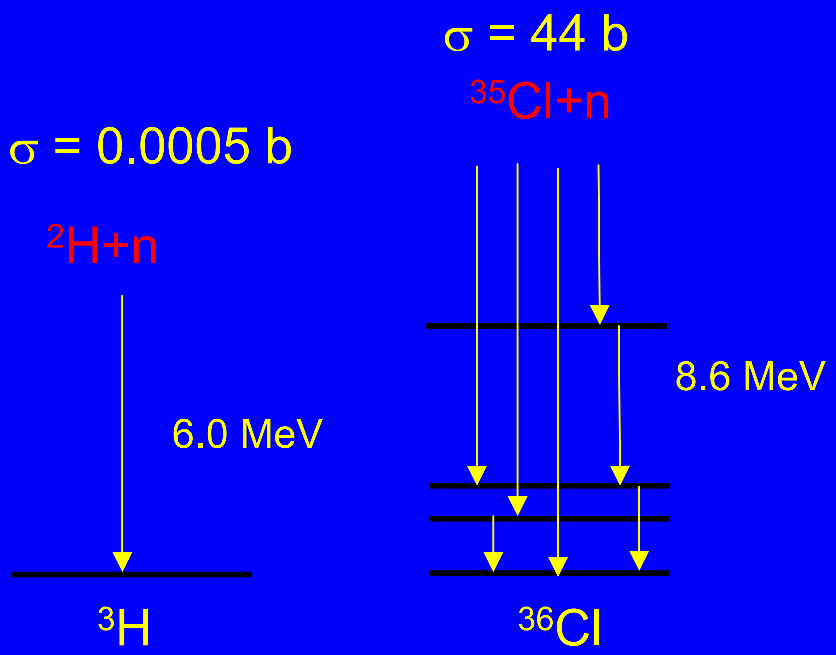
$$\phi_{ES}^{SNO} = 2.39^{+0.24}_{-0.23}(\text{stat})^{+0.12}_{-0.12}(\text{syst}),$$

$$\phi_{NC}^{SNO} = 5.09^{+0.44}_{-0.43}(\text{stat})^{+0.46}_{-0.43}(\text{syst}).$$

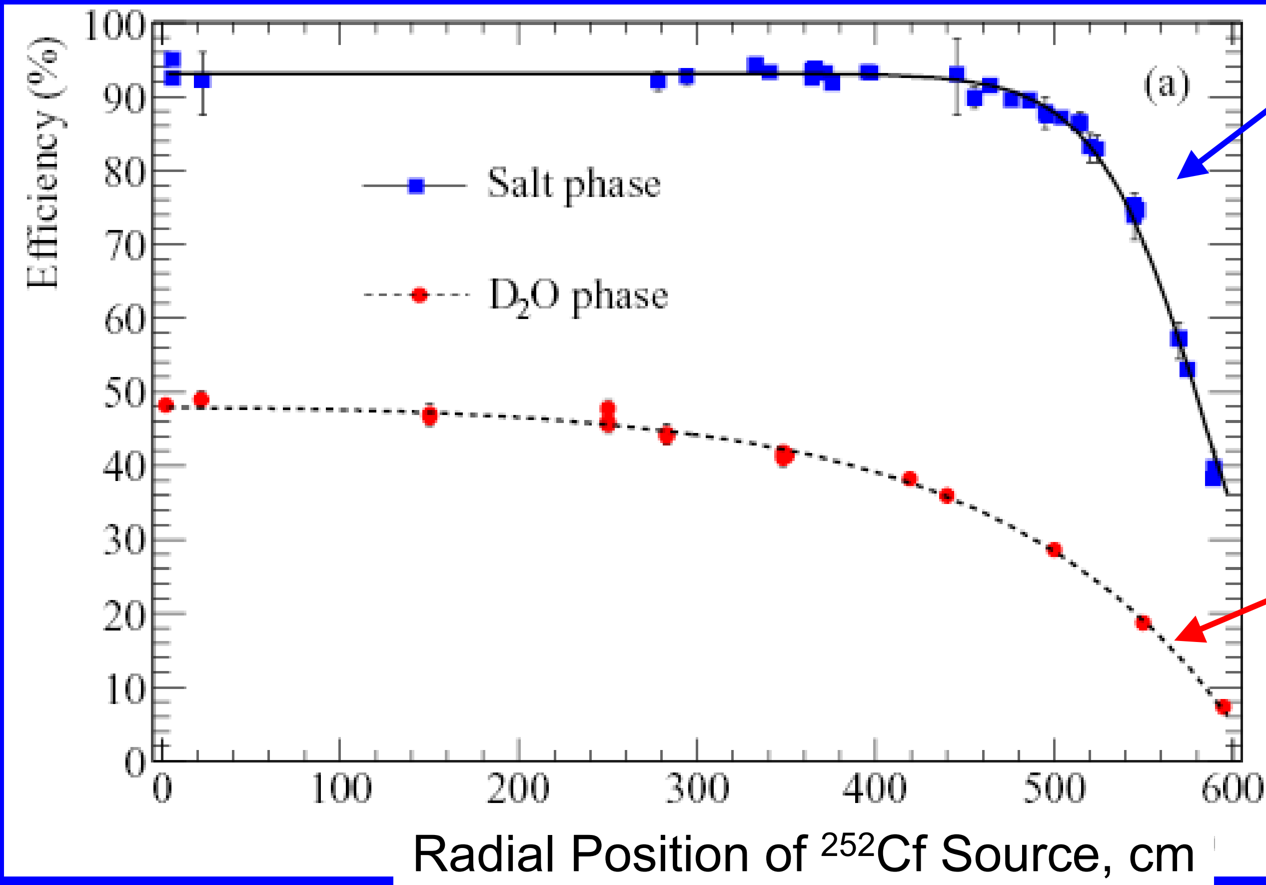
Advantages of NaCl for Neutron Detection

- Higher capture cross section
- Higher energy release
- Many gammas





Neutron Capture Efficiency in SNO



$^{35}Cl(n,\gamma)^{36}Cl$
Average Eff. = 0.399
$T_e \geq 5.5$ MeV and
$R_\gamma \leq 550$ cm

$^{2}H(n,\gamma)^{3}H$
Average Eff. = 0.144
$T_e \geq 5.0$ MeV and
$R_\gamma \leq 550$ cm

Salt allows NC-CC Separation based on Isotropy

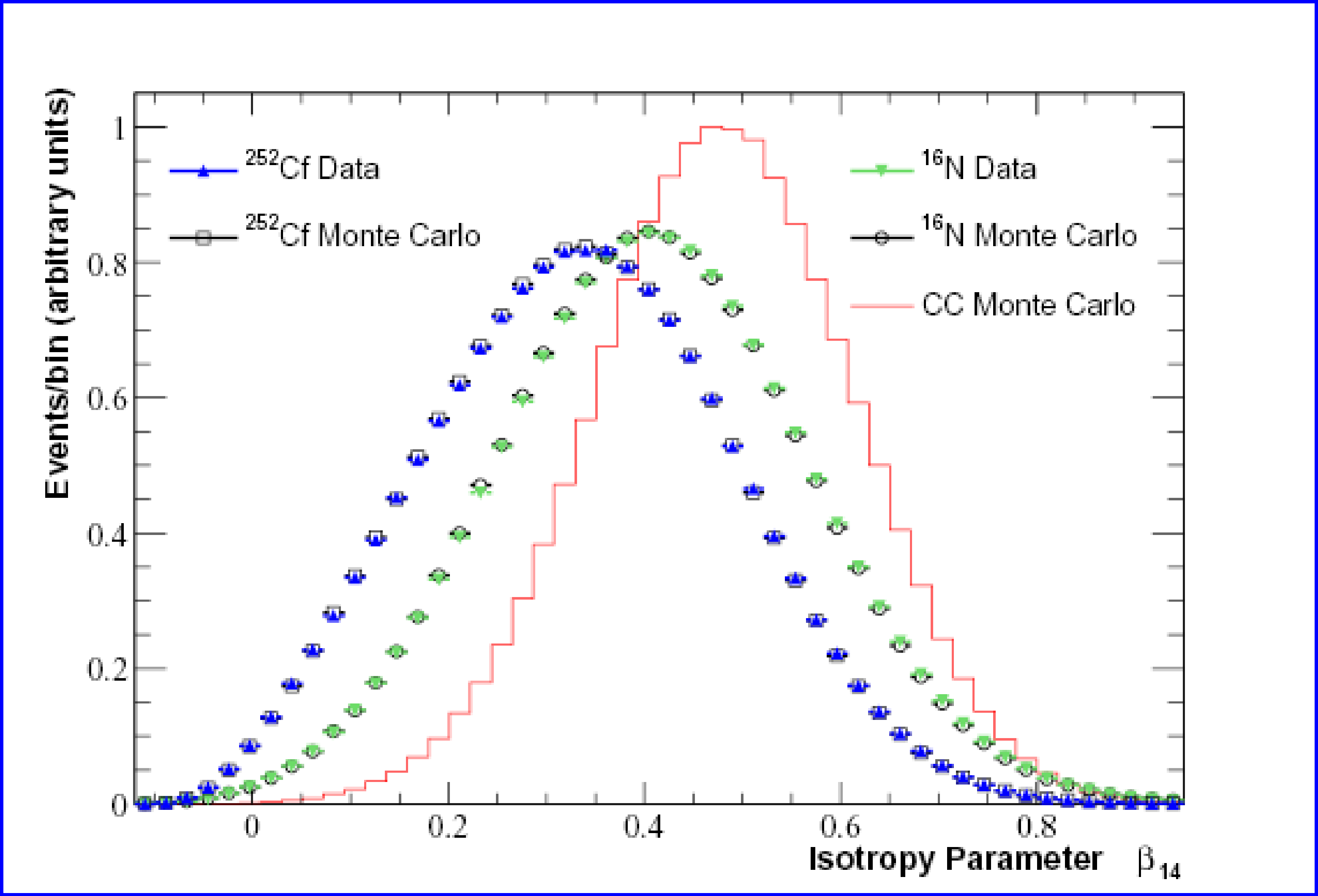
$$\beta_1 = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} cos\theta_{ij}$$

$$\beta_4 = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{1}{64}(9 + 20cos2\theta_{ij} + 35cos4\theta_{ij})$$

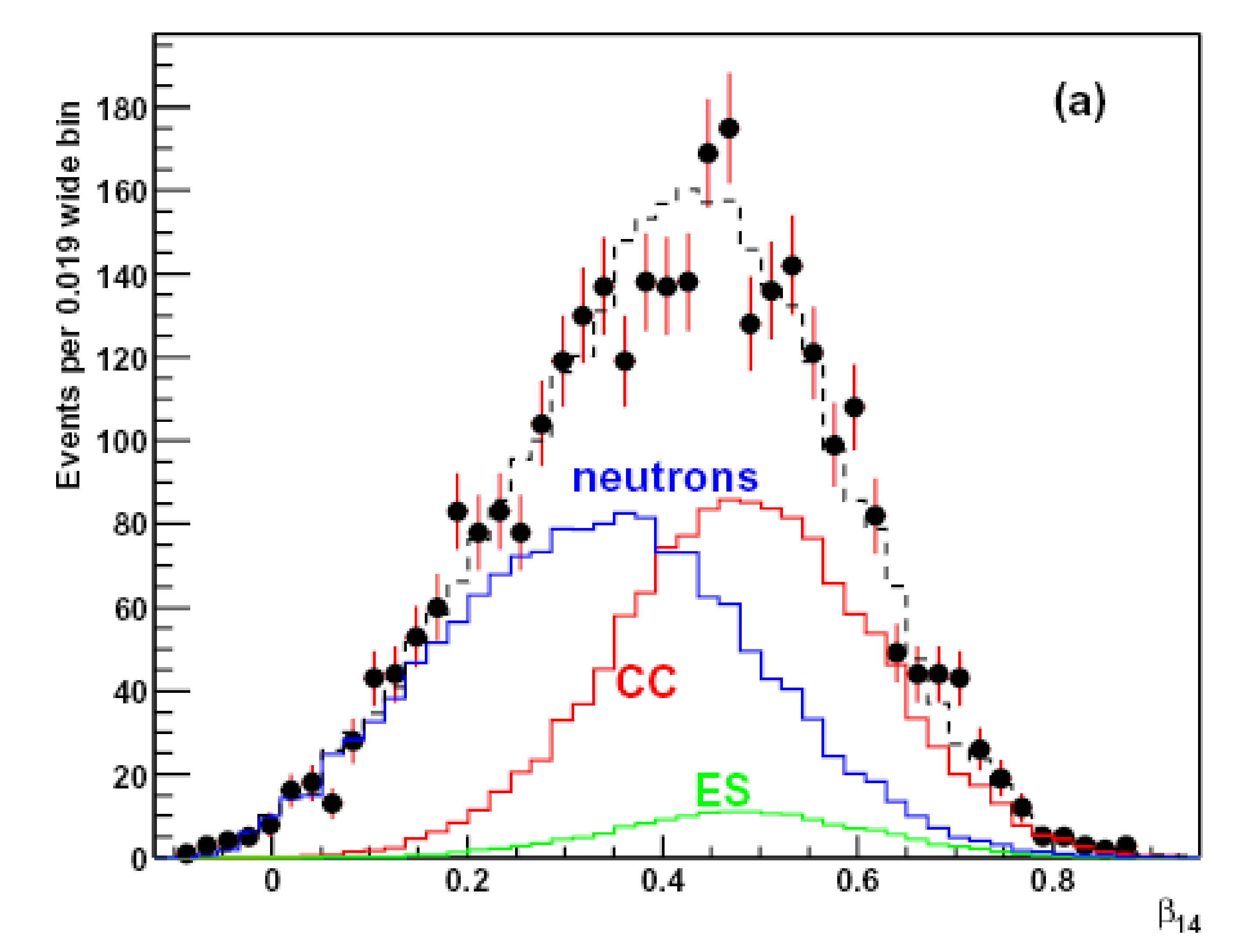
$$\beta_{14} = \beta_1 + 4\beta_4$$

Sum over all hit phototubes

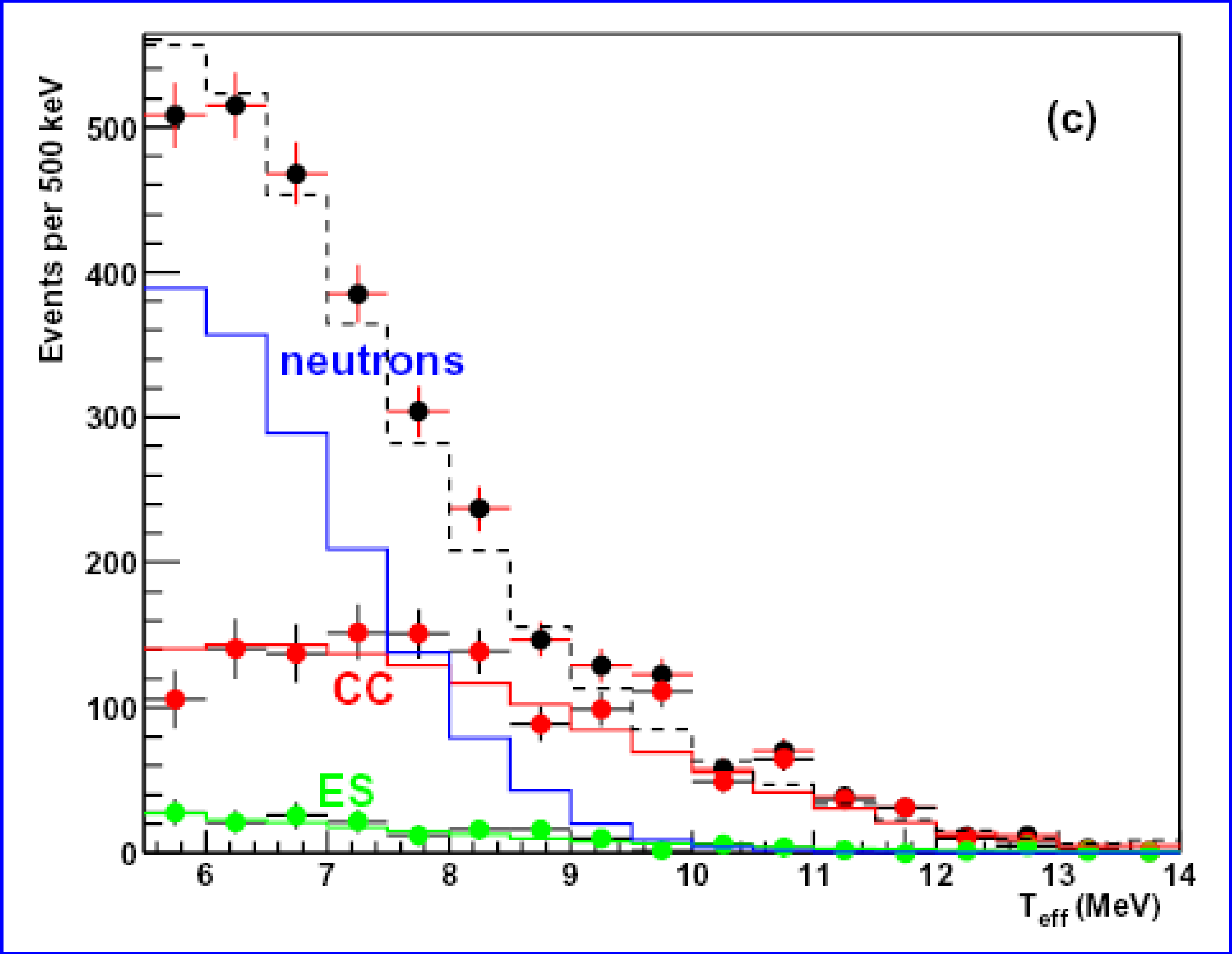
NC-CC Separation



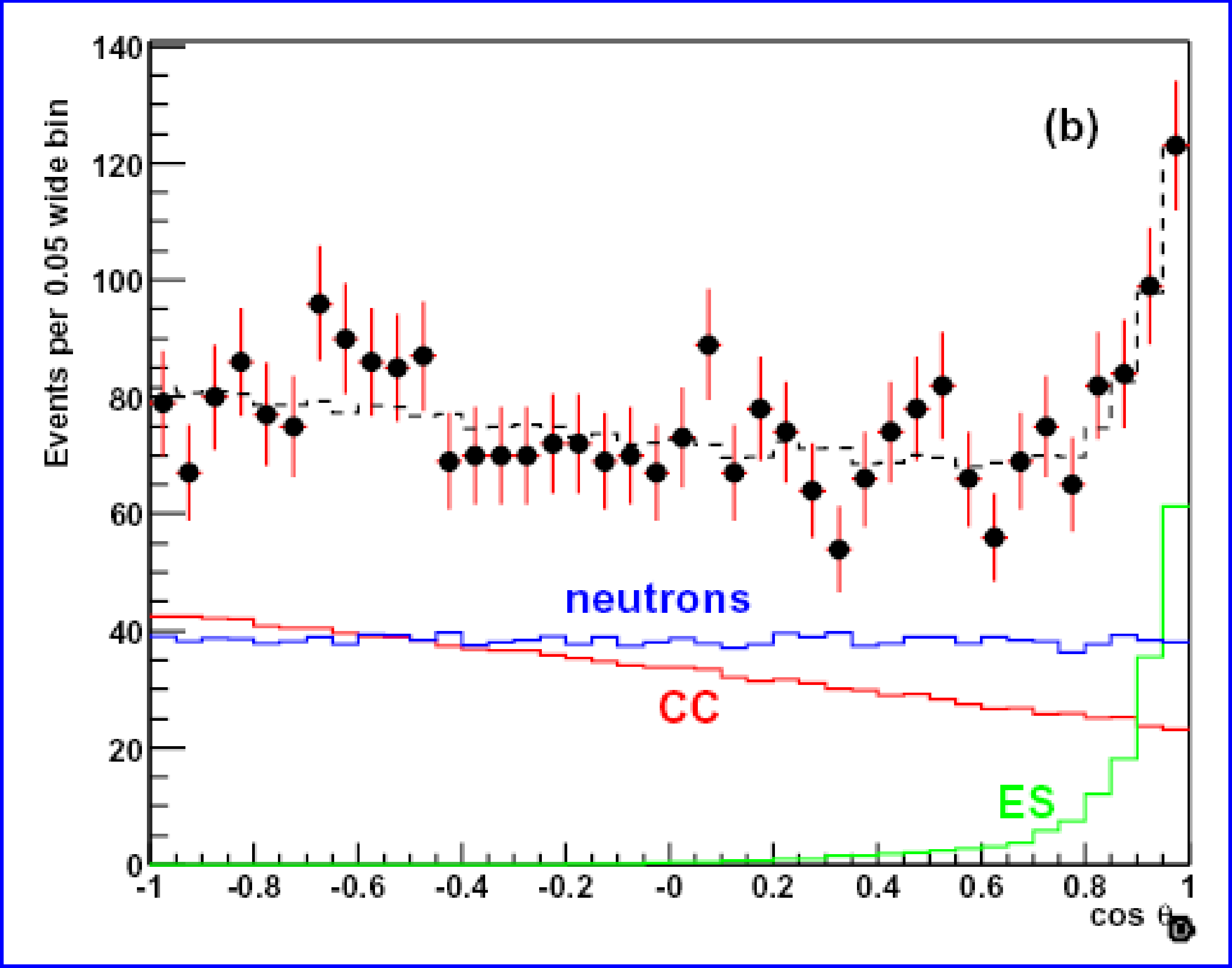
Isotropy Distributions for Salt Data



Energy Distribution for Salt



Directional Distribution for Salt



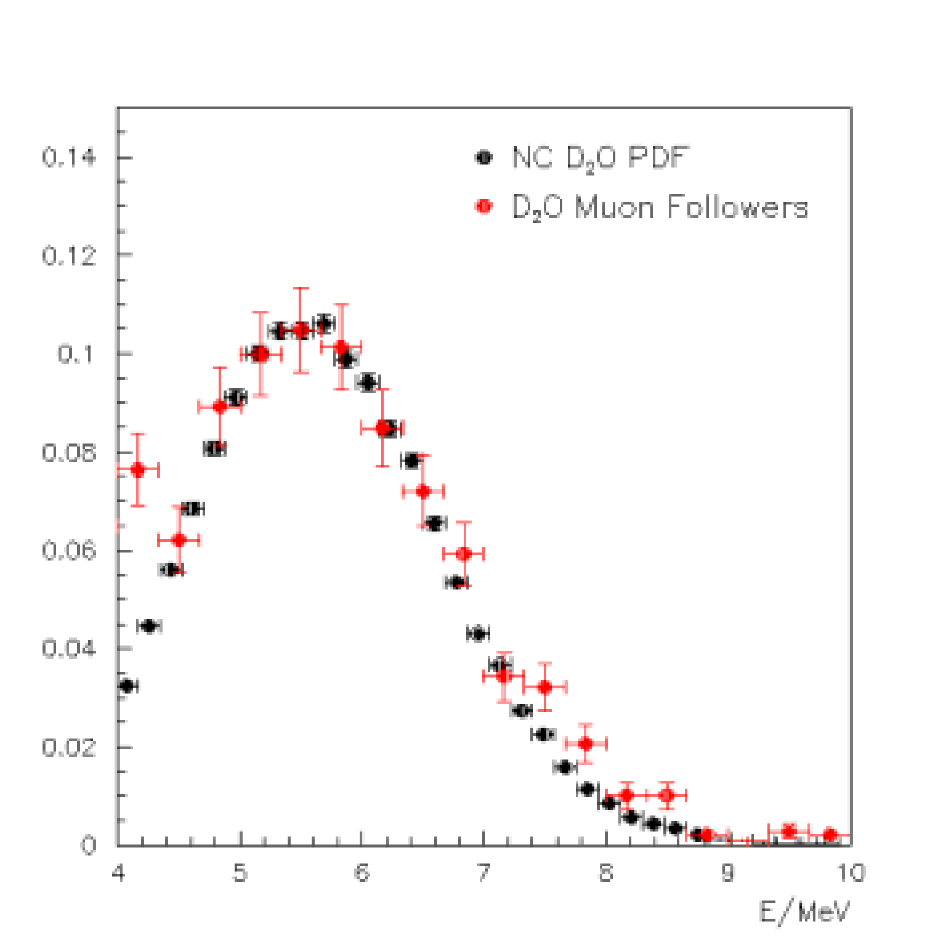
Blind Analysis

Three blindfolds for the analysts:

- Include unknown fraction of neutrons that follow muons

- Spoil the NC cross section in MC

- Veto an unknown fraction of candidate events



Backgrounds

Source	No. Events
Deuteron photodisintegration	73.1 +24.0,-25.5
$^{2}H(\alpha,\alpha)pn$	2.8 +/- 0.7
$^{17,18}O(\alpha,n)$	1.4 +/- 0.9
Fission, atmospheric ν's	23.0 +/- 7.2
Terrestrial and reactor ν's	2.3 +/- 0.8
Neutrons from rock	<1
24Na activation	8.4 +/- 2.3
Neutrons from CNO ν's	0.3 +/- 0.3
Total internal n background	**111.3 +/- 25**
Internal γ (fission, atm. ν)	5.2 +/- 1.3
^{16}N decays	< 2.5 (68% CL)
External-source neutrons (from fit)	84.5 +/- 34
Cherenkov events from β-γ decays	<14.7 (68% CL)
"AV events"	< 5.4 (68% CL)

Salt Results

Shape of ^{8}B spectrum in CC and ES not constrained:

$$\phi_{CC}^{SNO} = 1.59^{+0.08}_{-0.07}(\text{stat})^{+0.06}_{-0.08}(\text{syst})$$
$$\phi_{ES}^{SNO} = 2.21^{+0.31}_{-0.26}(\text{stat}) \pm 0.10\,(\text{syst})$$
$$\phi_{NC}^{SNO} = 5.21 \pm 0.27\,(\text{stat}) \pm 0.38\,(\text{syst})$$

Standard (Ortiz et al.) shape of ^{8}B spectrum in CC and ES:

$$\phi_{CC}^{SNO} = 1.70 \pm 0.07(\text{stat.})^{+0.09}_{-0.10}(\text{syst.})$$
$$\phi_{ES}^{SNO} = 2.13^{+0.29}_{-0.28}(\text{stat.})^{+0.15}_{-0.08}(\text{syst.})$$
$$\phi_{NC}^{SNO} = 4.90 \pm 0.24\,(\text{stat.})^{+0.29}_{-0.27}(\text{syst.})$$

Salt – Pure D_2O

- Constrained

$$\phi_{CC}^{SNO} = 1.76^{+0.06}_{-0.05}(\text{stat})^{+0.09}_{-0.09}(\text{syst}),$$
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Not Constrained

$$\phi_{NC}^{SNO} = 6.42^{+1.57}_{-1.57}(\text{stat})^{+0.55}_{-0.58}(\text{syst})$$

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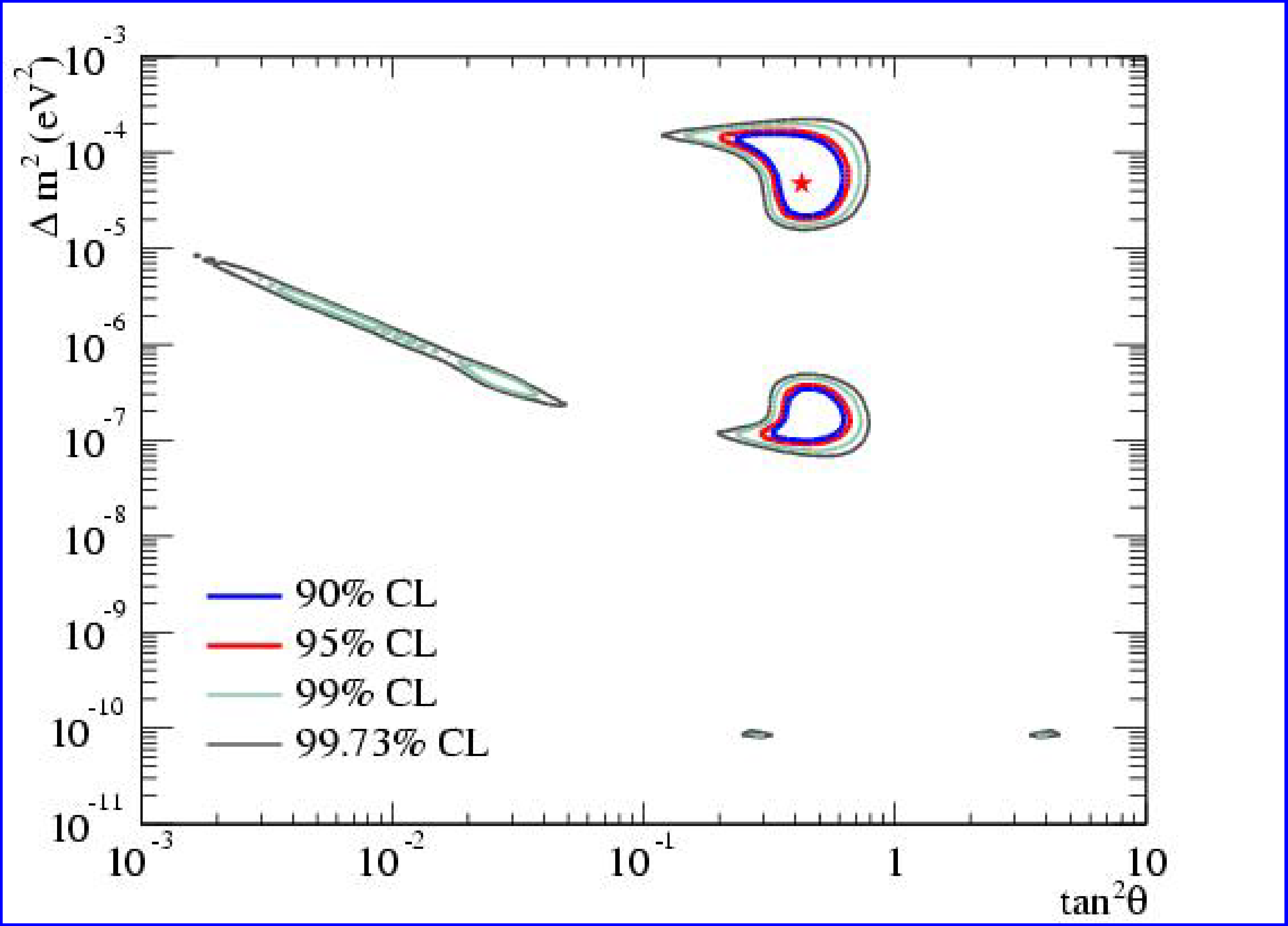
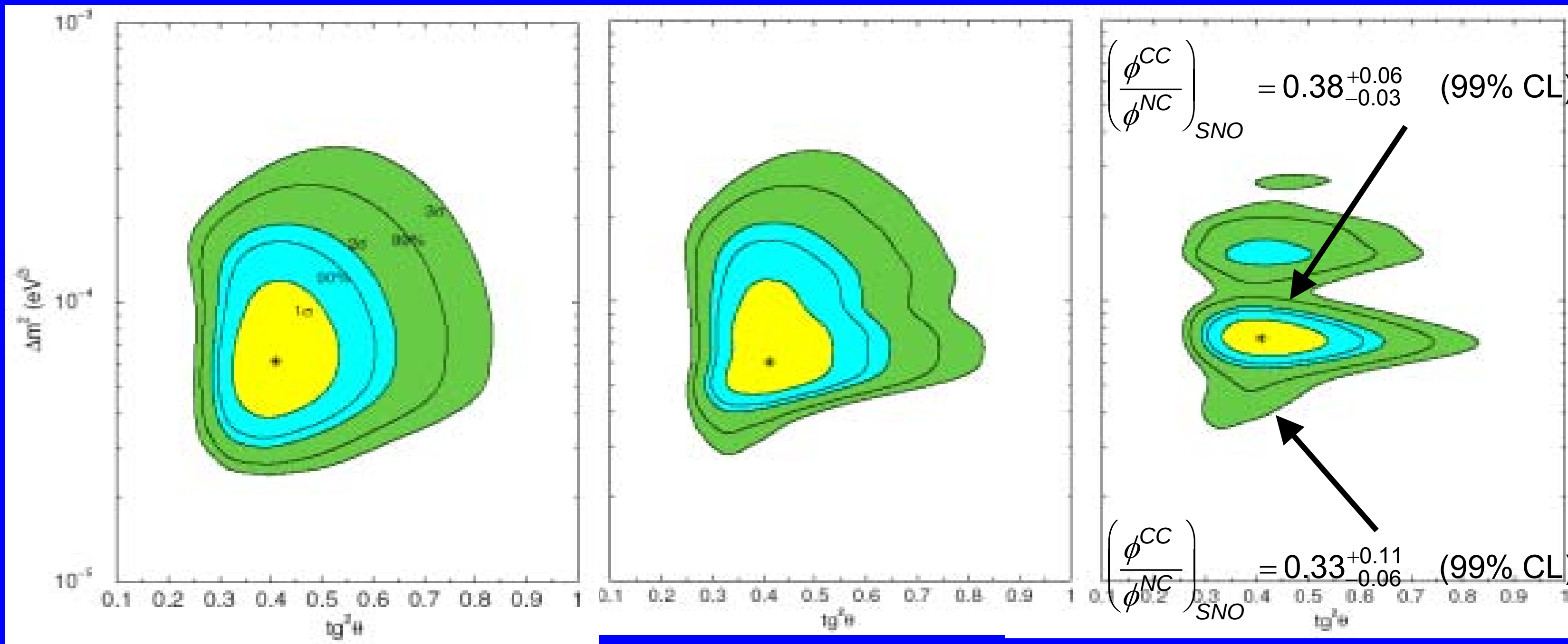
Pure D_2O

Salt

2-ν oscillation region defined by SNO



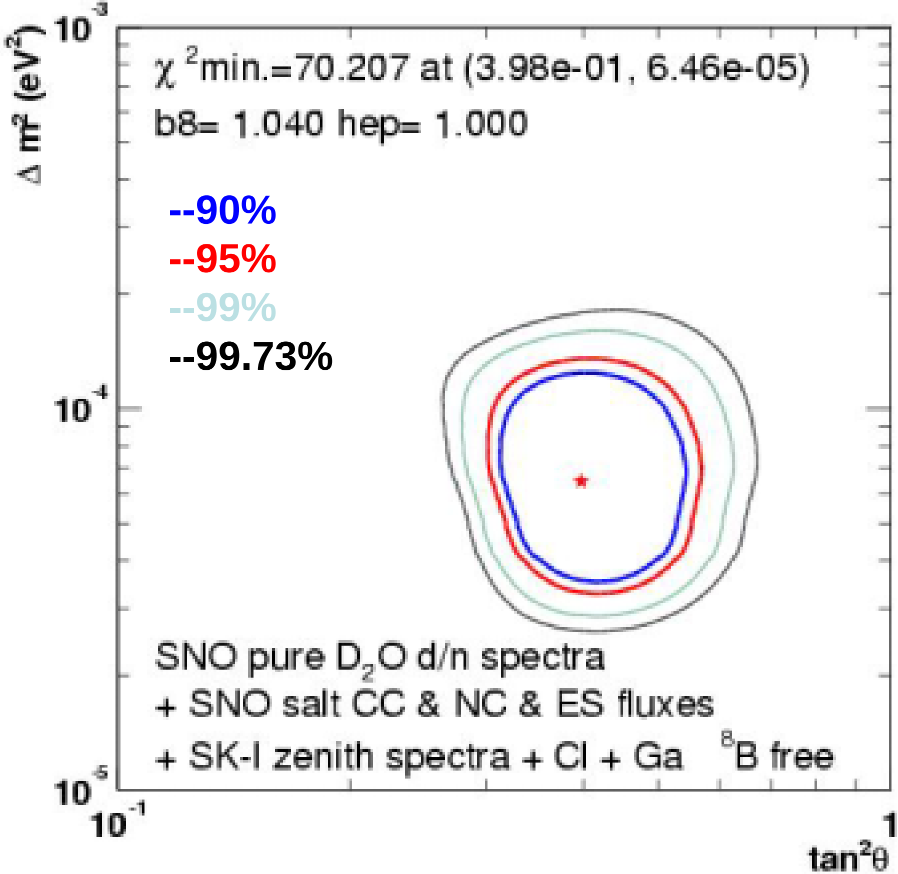
$\tan^2\theta_{12}$-Δm_{12}^2 before Salt Phase

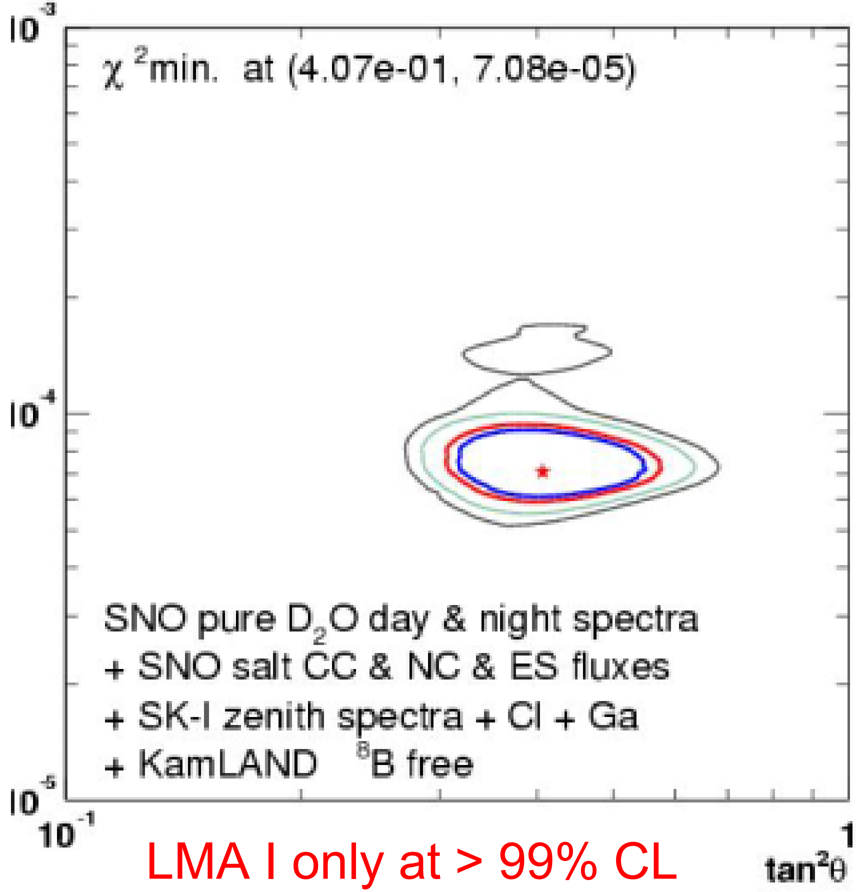


Solar Only | Solar+KL rate | Solar+KL spect.

de Holanda & Smirnov, hep-ph/0205241, hep-ph/0212270

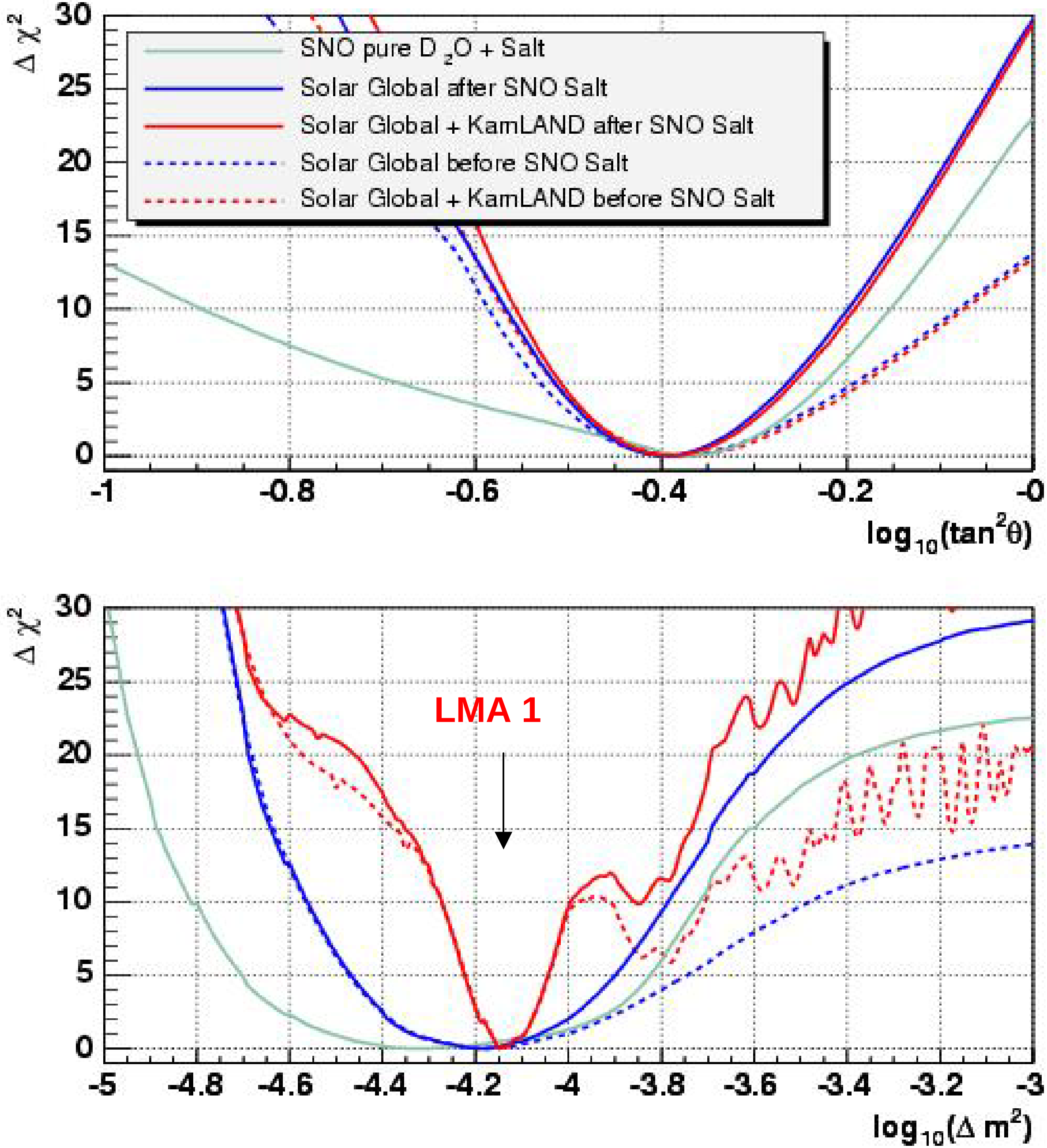
Closing in on Δm^2, θ





LMA I only at > 99% CL

Maximal mixing rejected at 5.4 σ



Results from SNO -- Salt Phase

Oscillation Parameters,
2-D joint 1-σ boundary

$$\Delta m^2 = 7.1^{+1.2}_{-0.6} \times 10^{-5}\ \mathrm{eV}^2$$
$$\theta = 32.5^{+2.4}_{-2.3}\ \mathrm{deg}$$

< 1% probability of LMA I

Marginalized 1-D 1-σ
errors

$$\Delta m^2 = 7.1^{+1.0}_{-0.3} \times 10^{-5}\ \mathrm{eV}^2$$
$$\theta = 32.5^{+1.6}_{-1.7}\ \mathrm{deg}$$

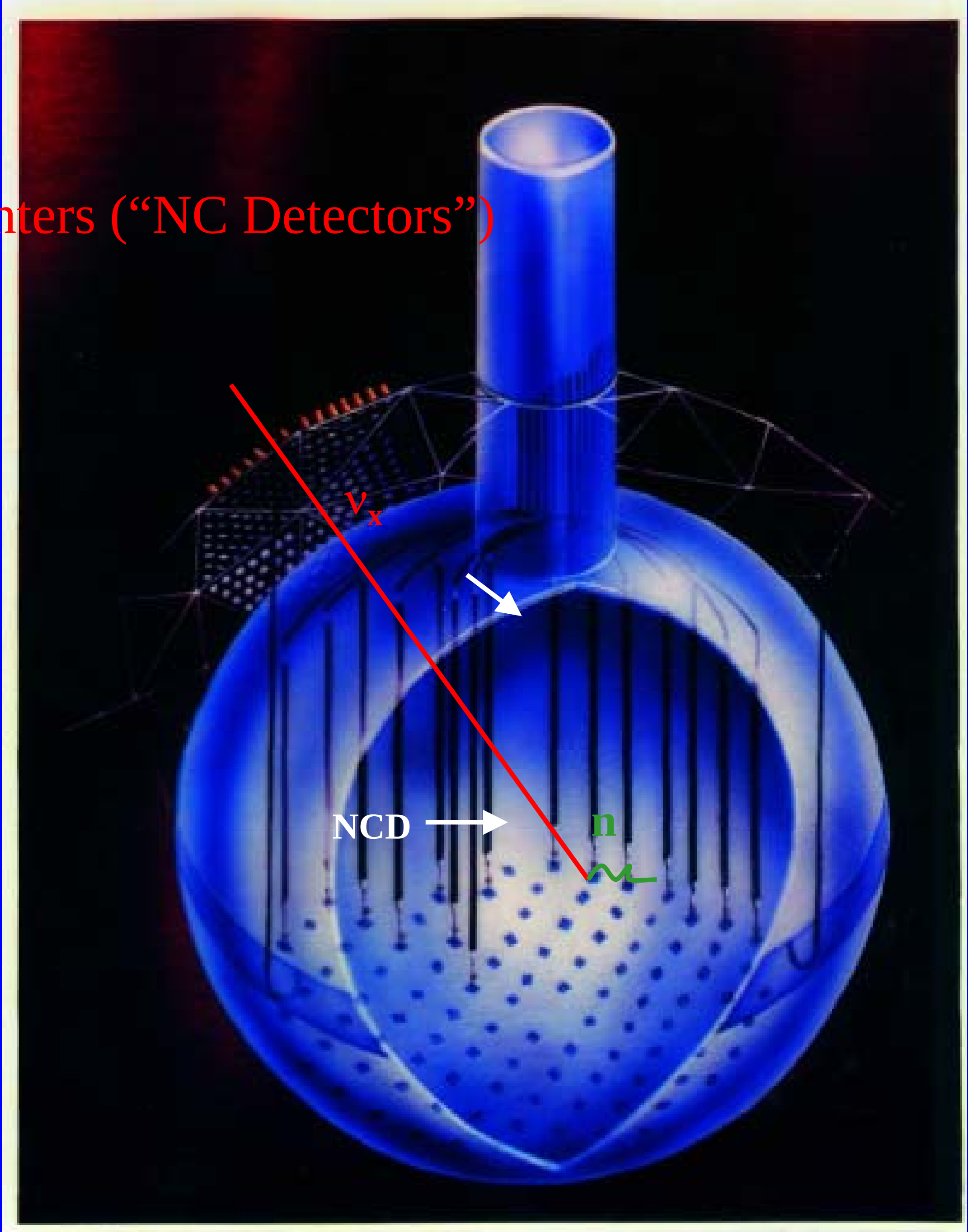
Maximal mixing rejected at 5.4 σ

➤ ^{3}He Proportional Counters (“NC Detectors”)

Current Status of SNO

NCD’s have been installed

Final commissioning in progress




Canadian SeeSaw