Recent results from the Sudbury Neutrino Observatory Experiment

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22nd Rencontres de Blois
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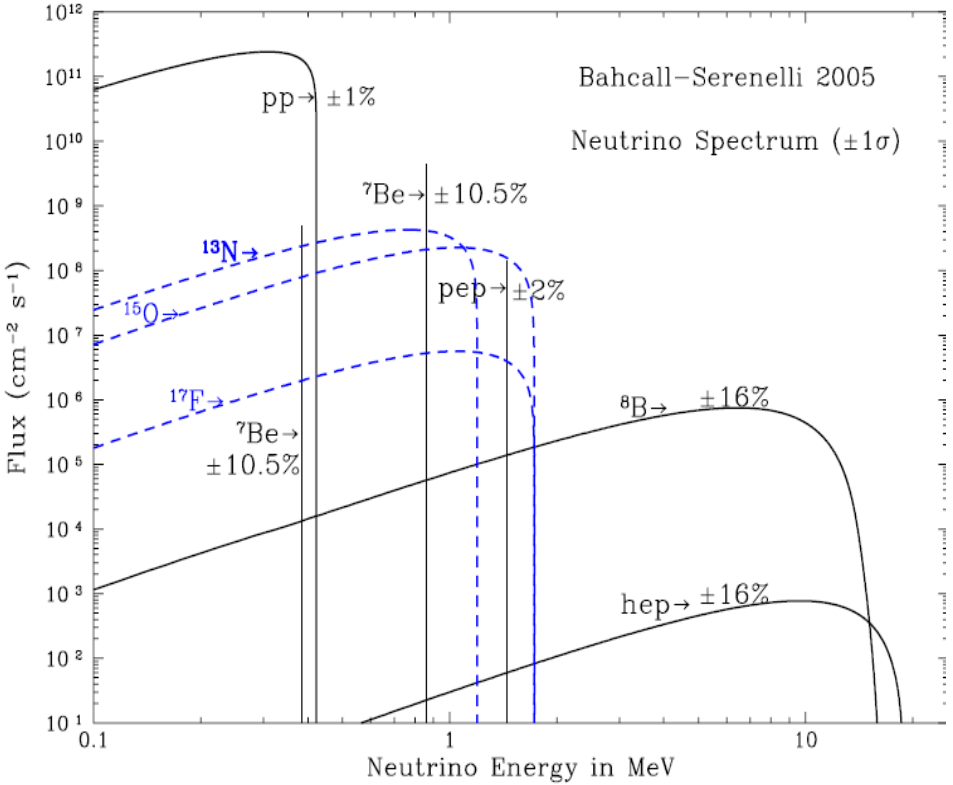
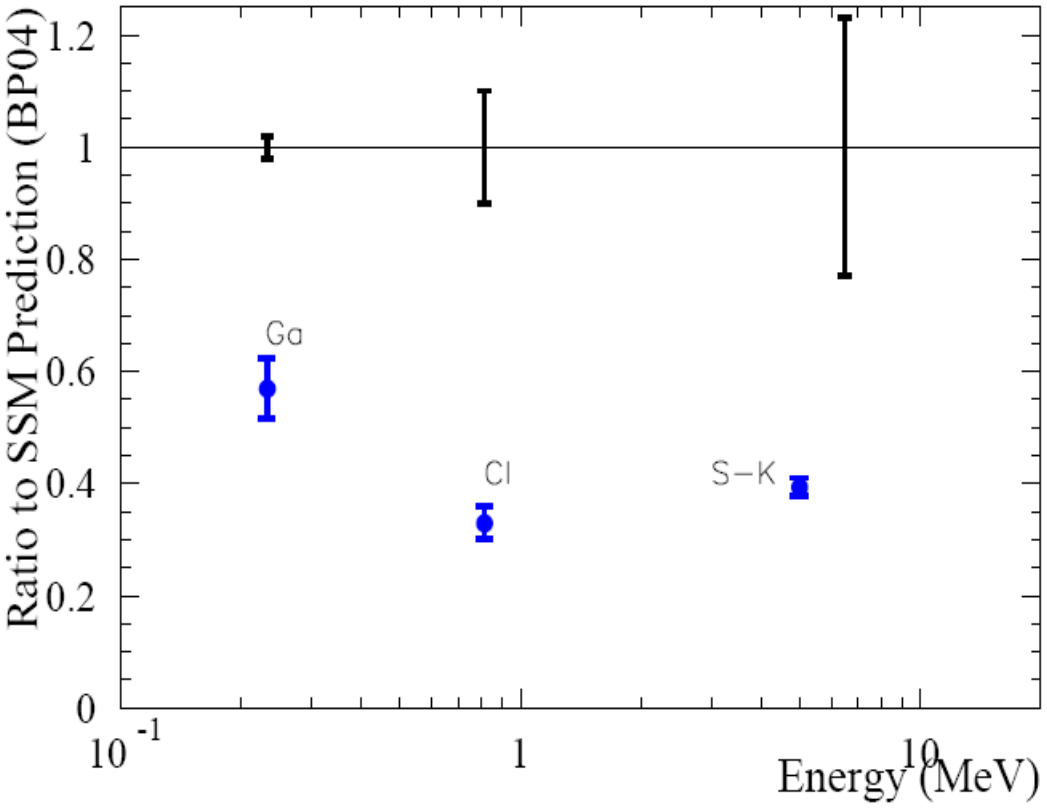
Solar Neutrinos – Pre 2001



Cherenkov →

Chlorine →

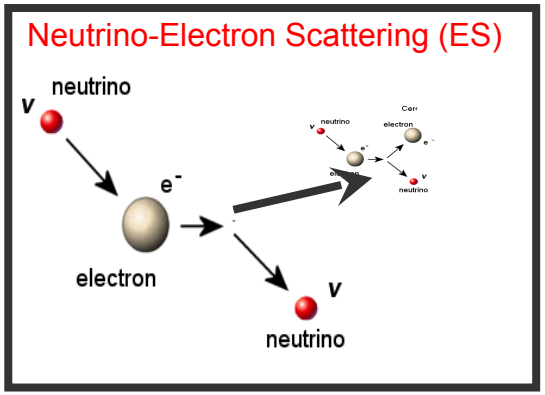
Gallium →



Experiment ≠ Theoretical predictions

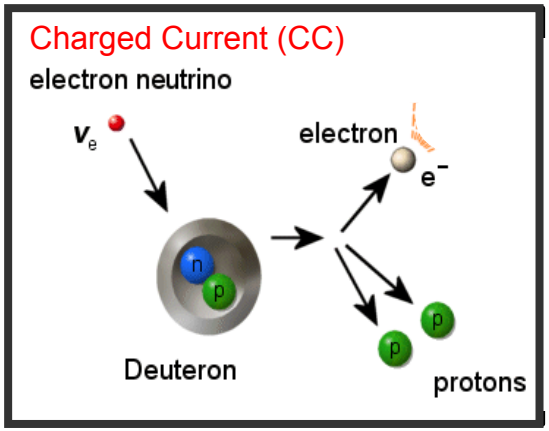
The Sudbury Neutrino Observatory

Located 6800 ft underground in Vale Creighton Mine, Sudbury, Ontario.



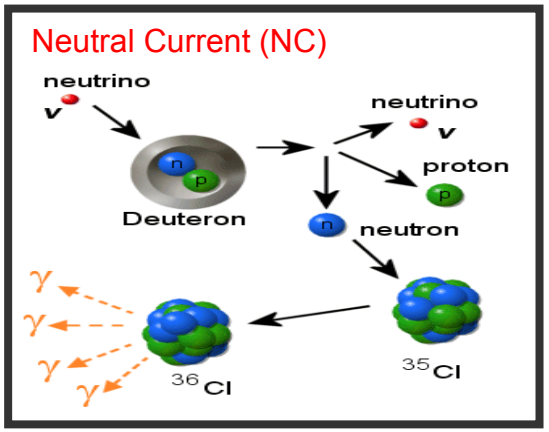
ES Reaction

- Primarily sensitive to ν_e.
- Sensitive to direction.



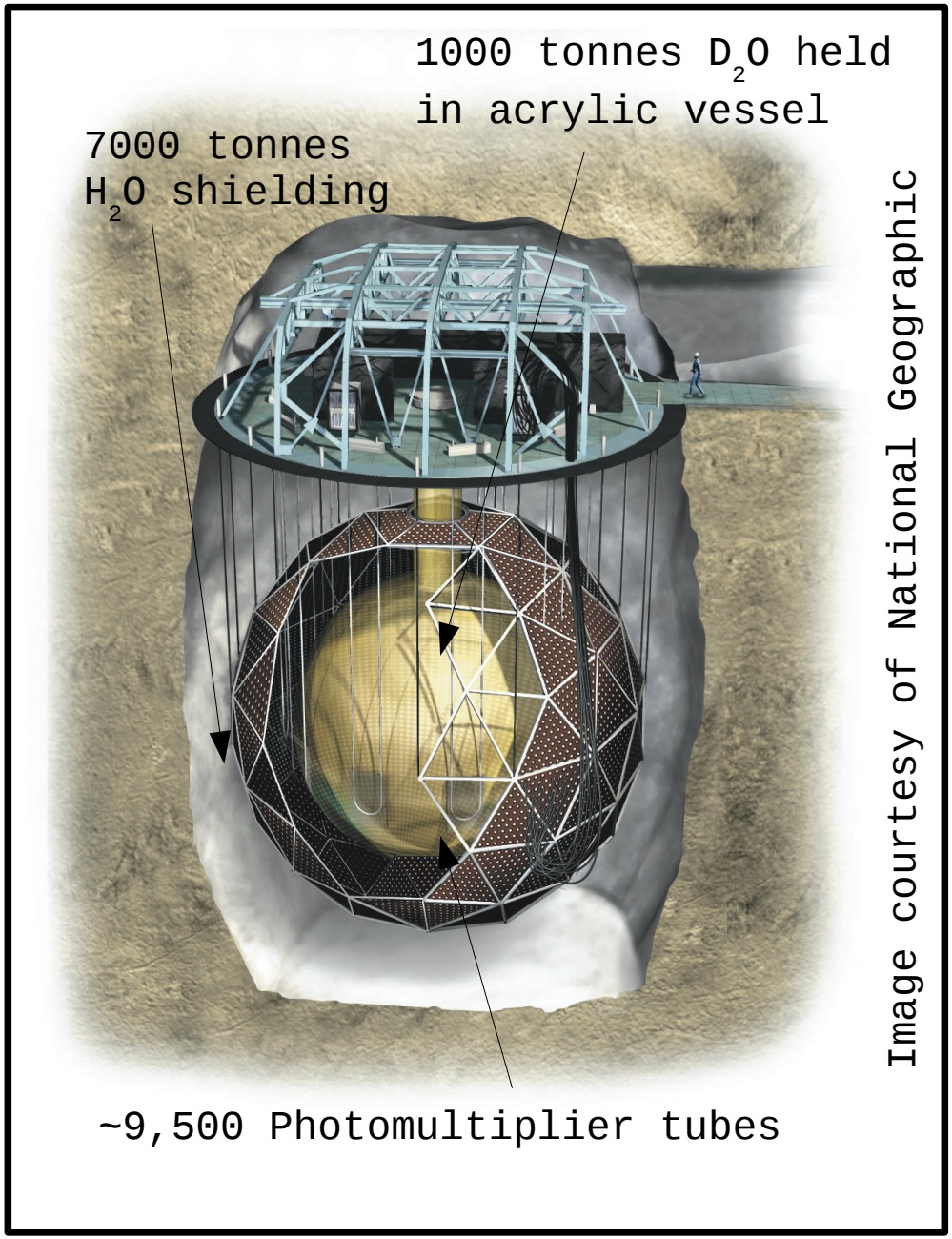
CC Reaction

- Sensitive to ν_e only.
- Can be used to obtain ν_e energy.



NC Reaction

- Sensitive to all active flavours.
- Measures total flux of ^8B solar neutrinos.



The Sudbury Neutrino Observatory

Three phases of operation

Phase I – Pure D_2O

1999 - 2001

- Simple detector configuration
- Low neutron detection
- Poor electron neutron discrimination

Phase II – Pure D_2O + NaCl

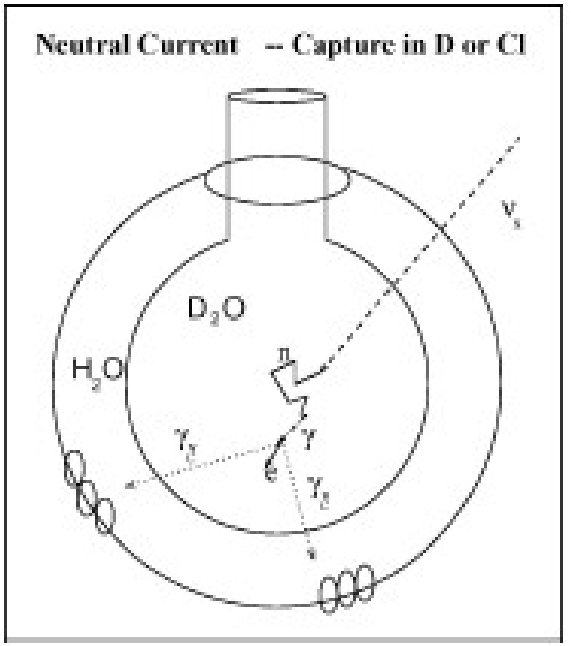
2002 - 2004

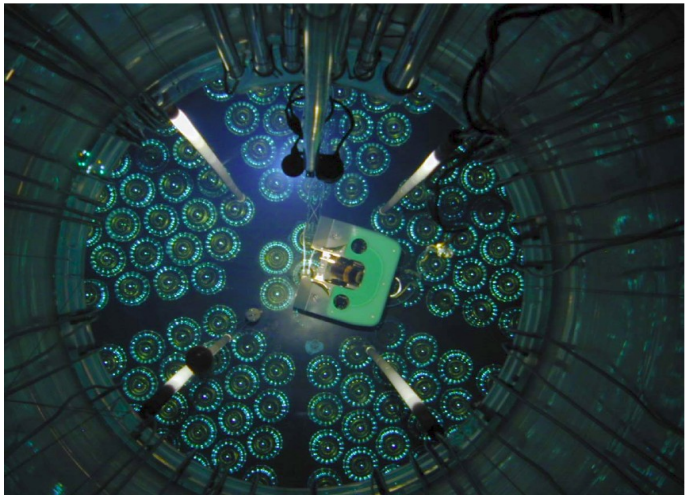
- Enhanced neutron detection
- Improved electron neutron discrimination

Phase III – Pure D_2O + ^3He Proportional counters

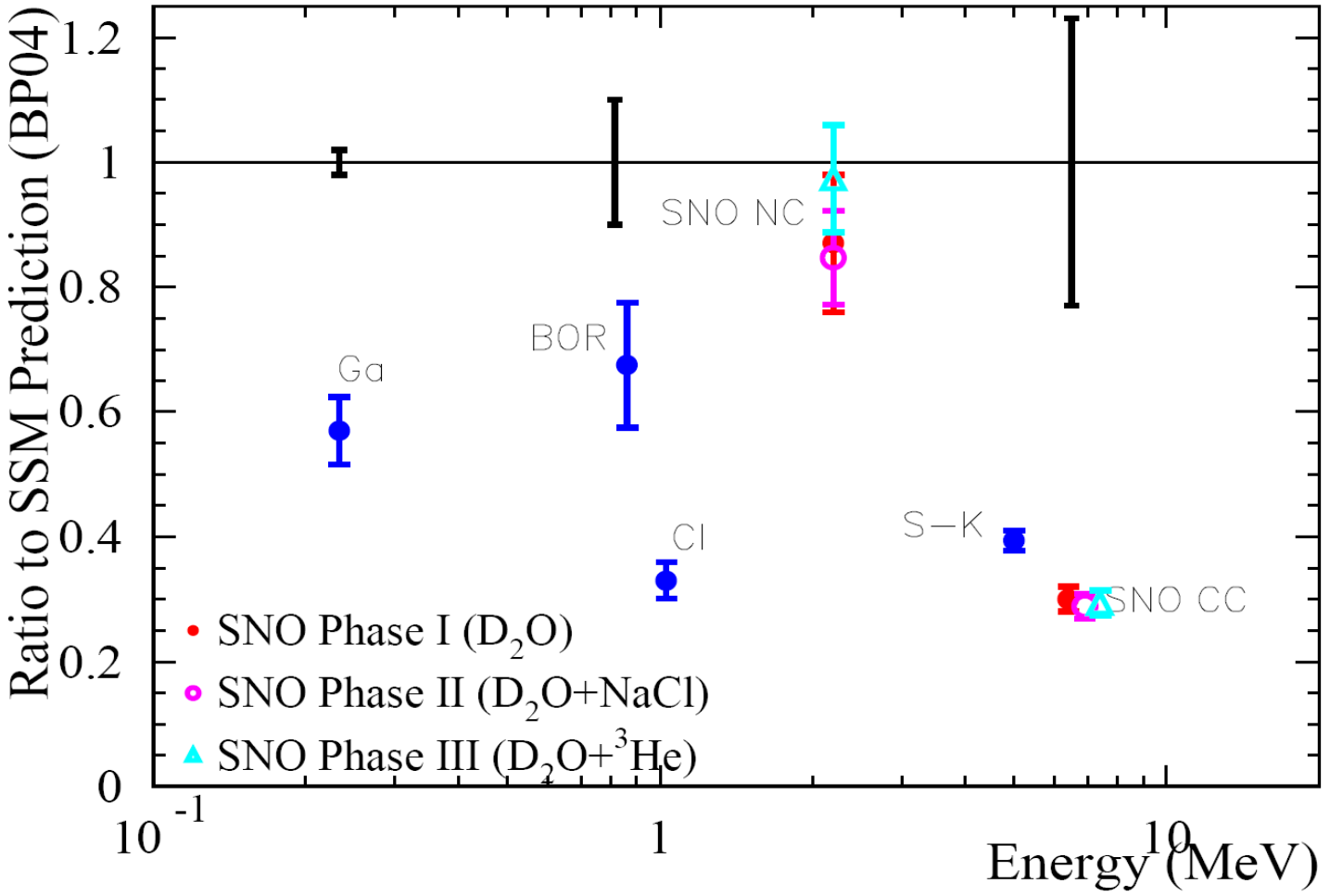
2004 - 2008

- Good neutron detection
- Excellent separation between neutrons and electrons





What do we know from SNO so far?



Flux of electron neutrinos is less than SSM prediction

Total flux of neutrinos is in agreement with SSM prediction

What else can be learned from SNO?

Low Energy Threshold Analysis

Basic overview

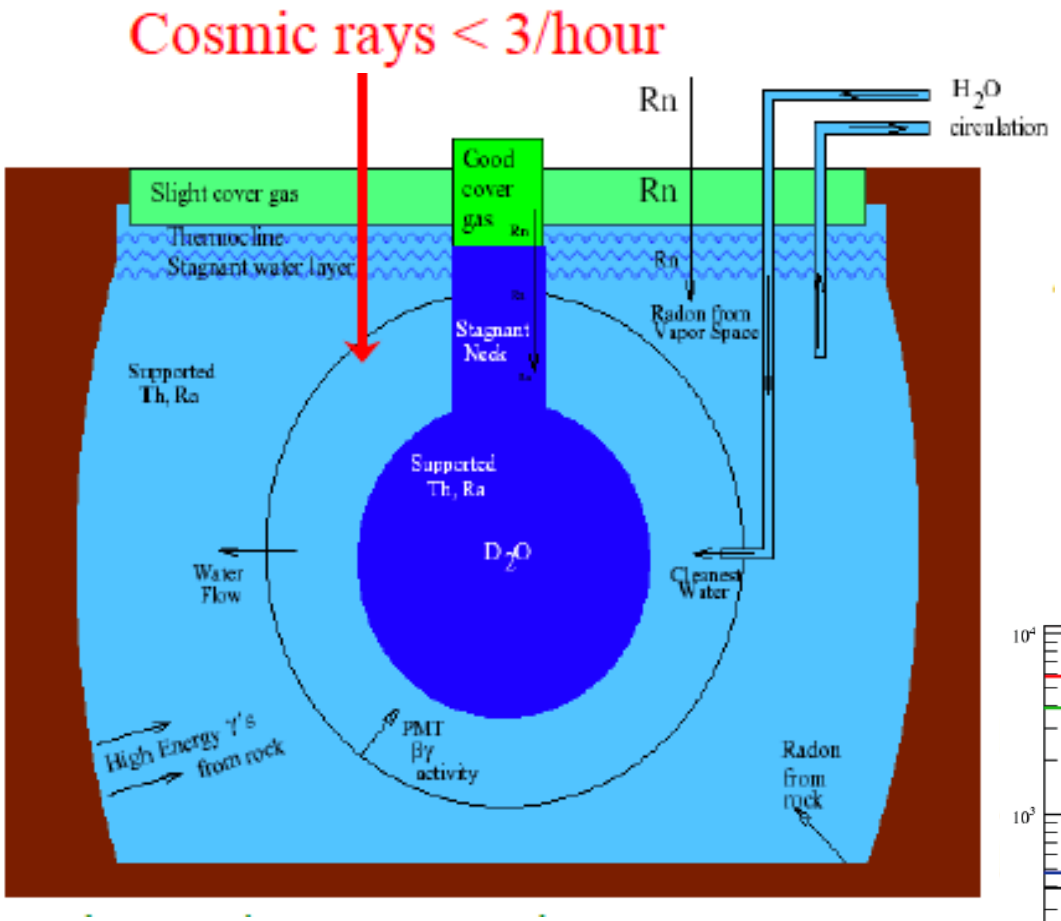
- Lower threshold to 3.5 MeV
- Combine data from phases I and II
- Fit for all signals and backgrounds
- Improvement of background exclusion
- Improve Monte Carlo simulation
- Reduction of systematic uncertainties
- Improved signal extraction methods
- Improved oscillation analysis

Results

- Measurement of 8B flux from NC rates
- Binned electron energy spectrum using CC and ES
- Two flavour and three flavour extraction of mixing parameters
- Parametrized survival probability

Low Energy Threshold Analysis

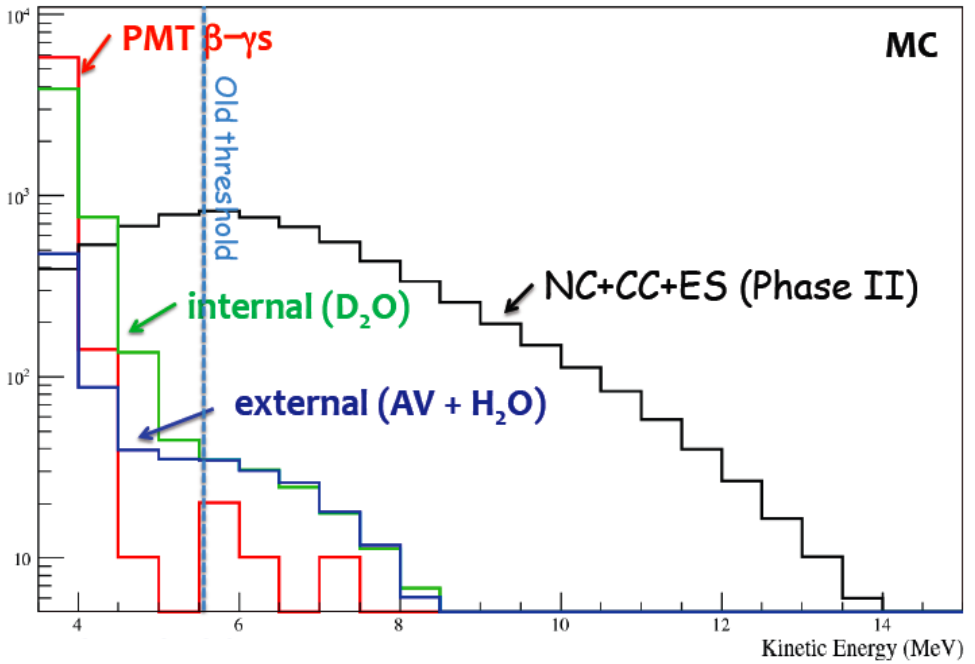
Radioactive backgrounds



Limited by backgrounds
- Naturally occurring radioactivity ^{238}U, ^{222}Rn and ^{232}Th
- Present in D_2O, Acrylic Vessel and H_2O shielding
- Main concern are ^{208}Tl and ^{214}Bi

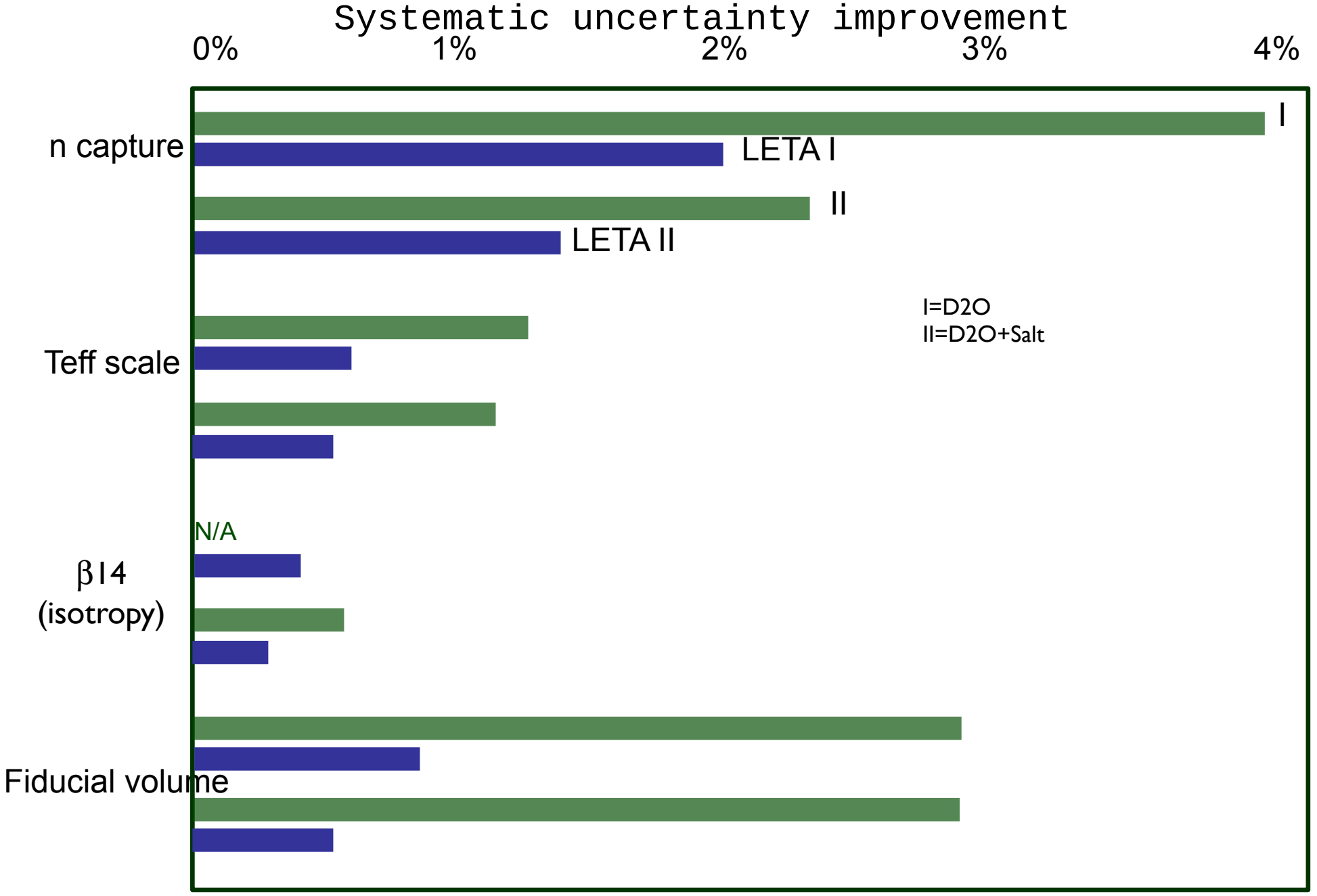
Can constrain using assay results

Kinetic Energy Spectrum



New energy estimator improved background rejection by around 60%.

Low Energy Threshold Analysis



Low Energy Threshold Analysis

Signal extraction

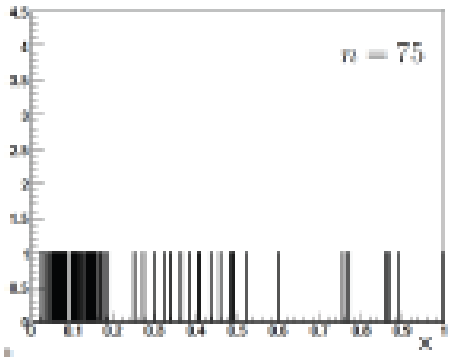
3 Neutrino signals + 17 backgrounds for EACH phase
Multidimensional pdfs

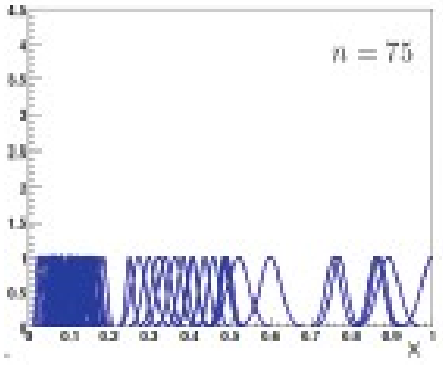
$P(\beta_{14}, R^3, \cos\theta_\odot)$ ES and CC

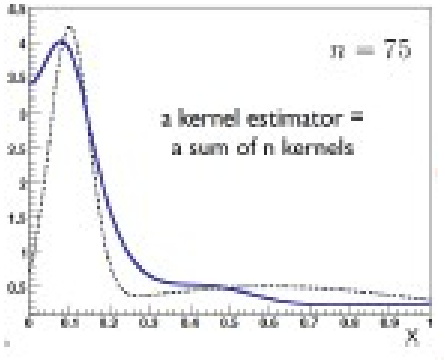
$P(T_{\rm eff}, \beta_{14}, R^3) \times P(\cos\theta_\odot)$ NC and backgrounds

Two distinct methods used

1. Maximum Likelihood approach using binned pdfs
   - Manual scan of likelihood space
   - Data assists with constraint of systematics
2. Kernel estimation
   - Essentially unbinned Maximum Likelihood approach
   - CPU intensive... use a graphics card!
   - Can float all systematics

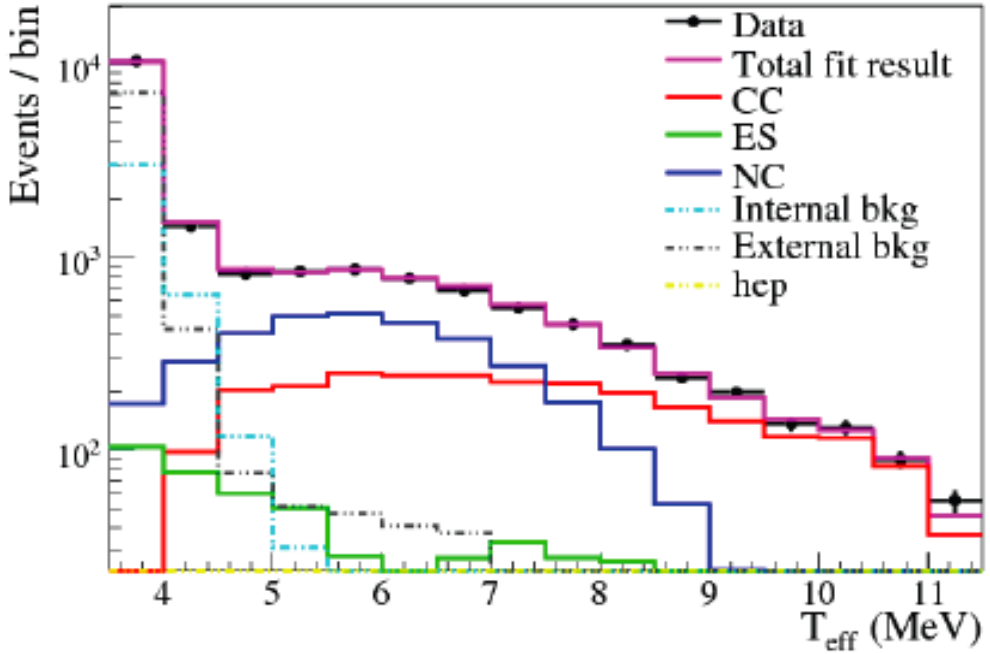


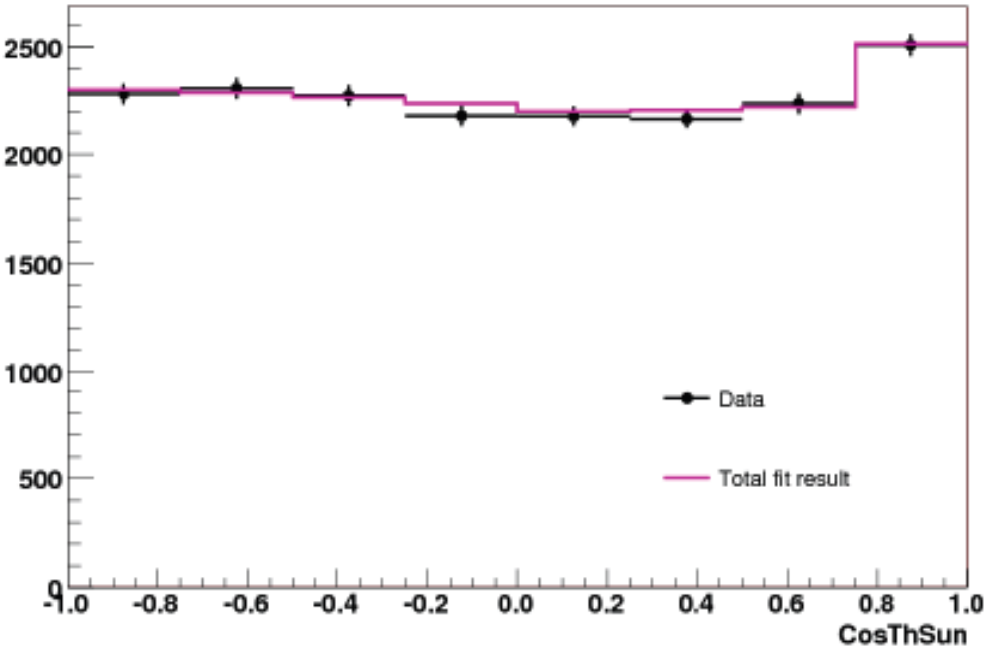


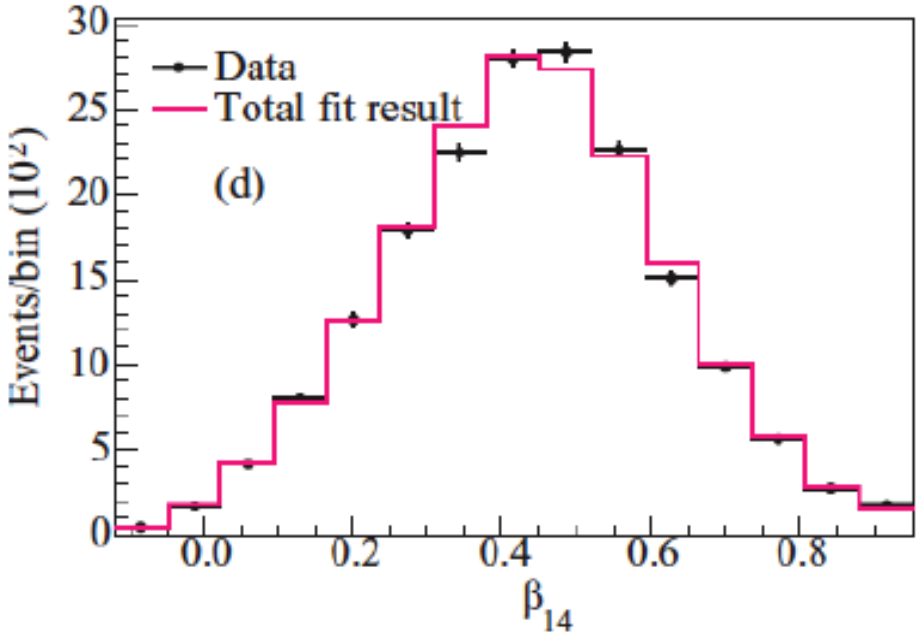


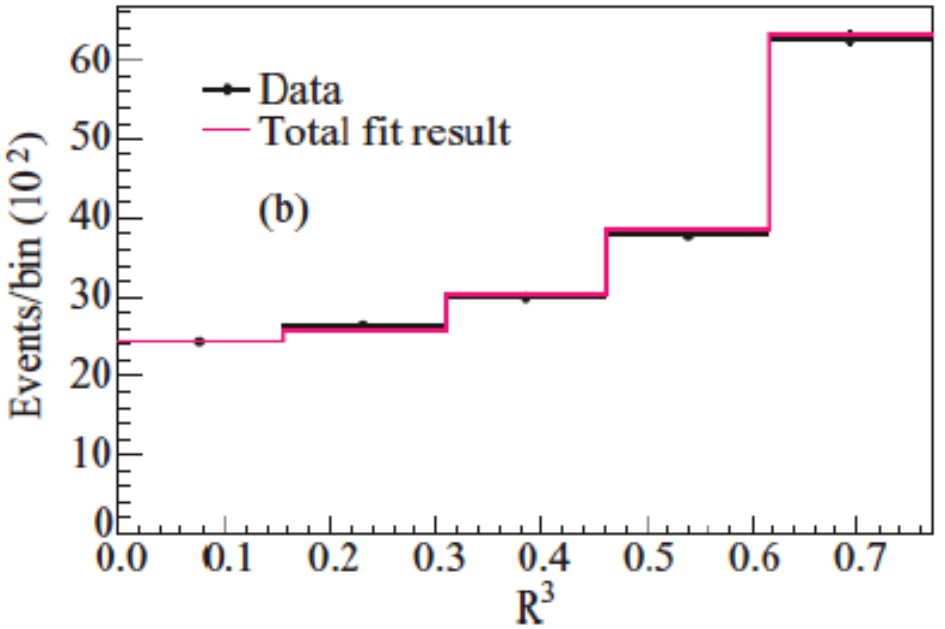
Low Energy Threshold Analysis

Signal extraction results – 1D projections



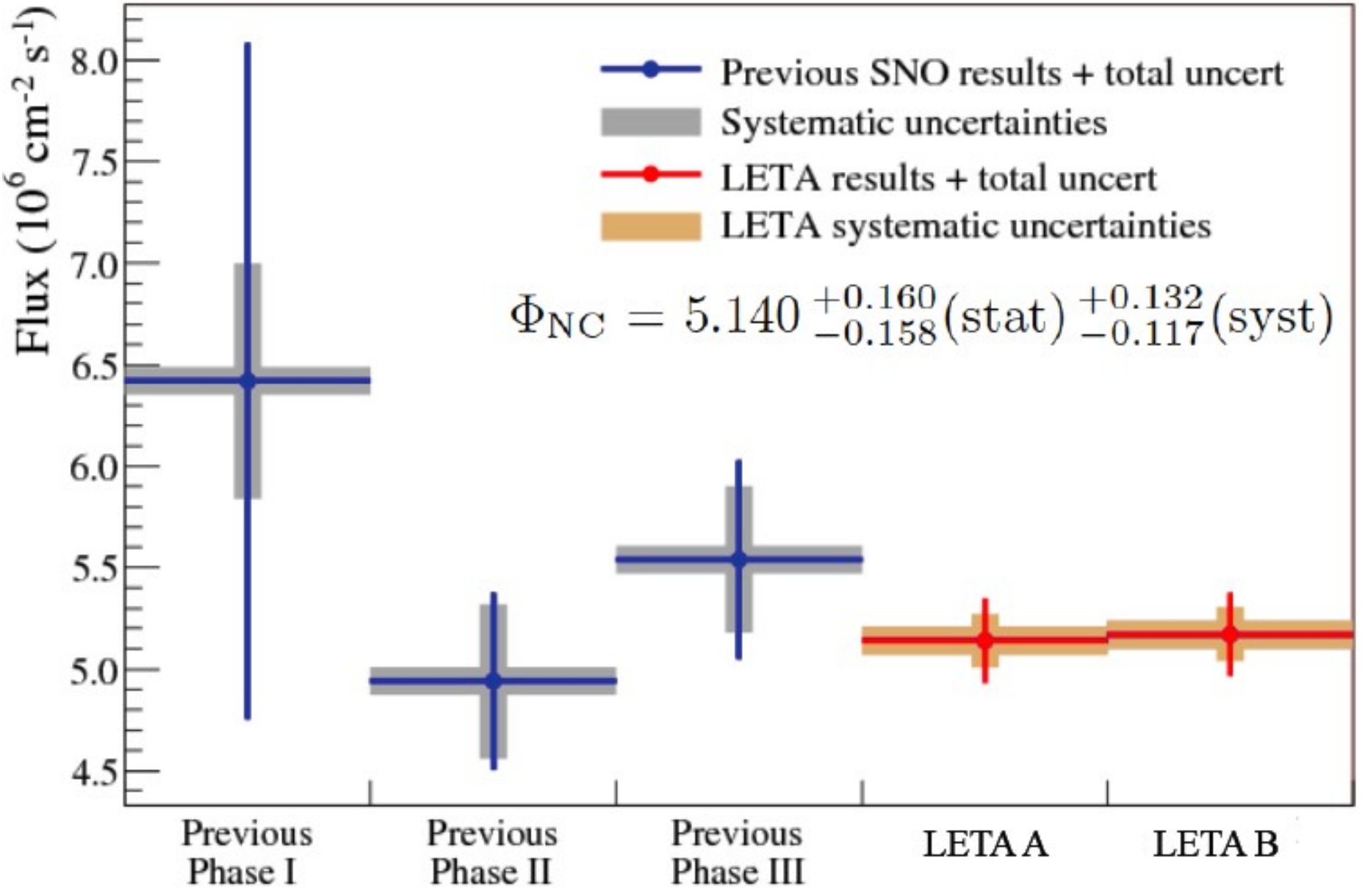






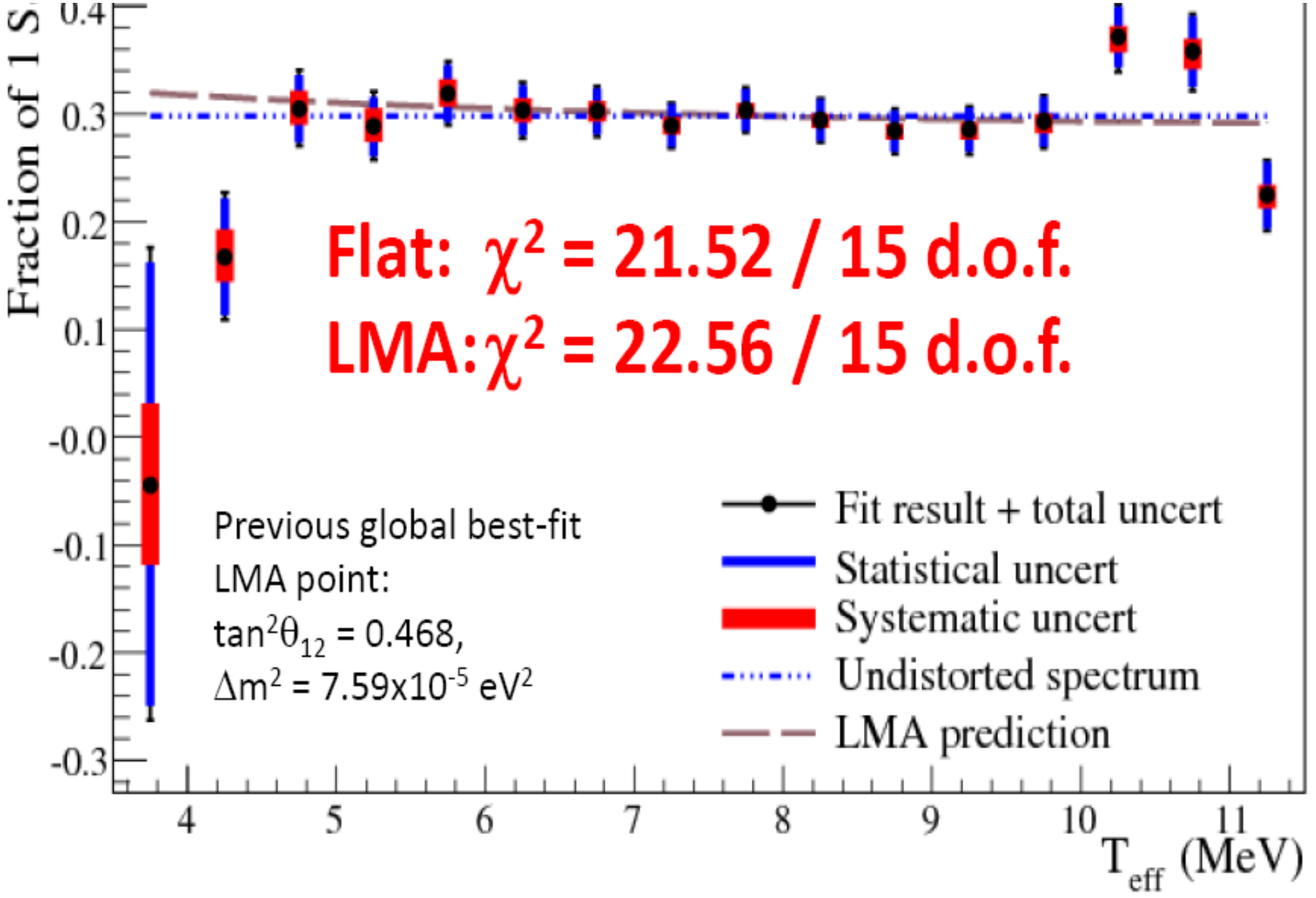
Low Energy Threshold Analysis

^{8}B Flux results using “unconstrained” cc spectrum



Low Energy Threshold Analysis

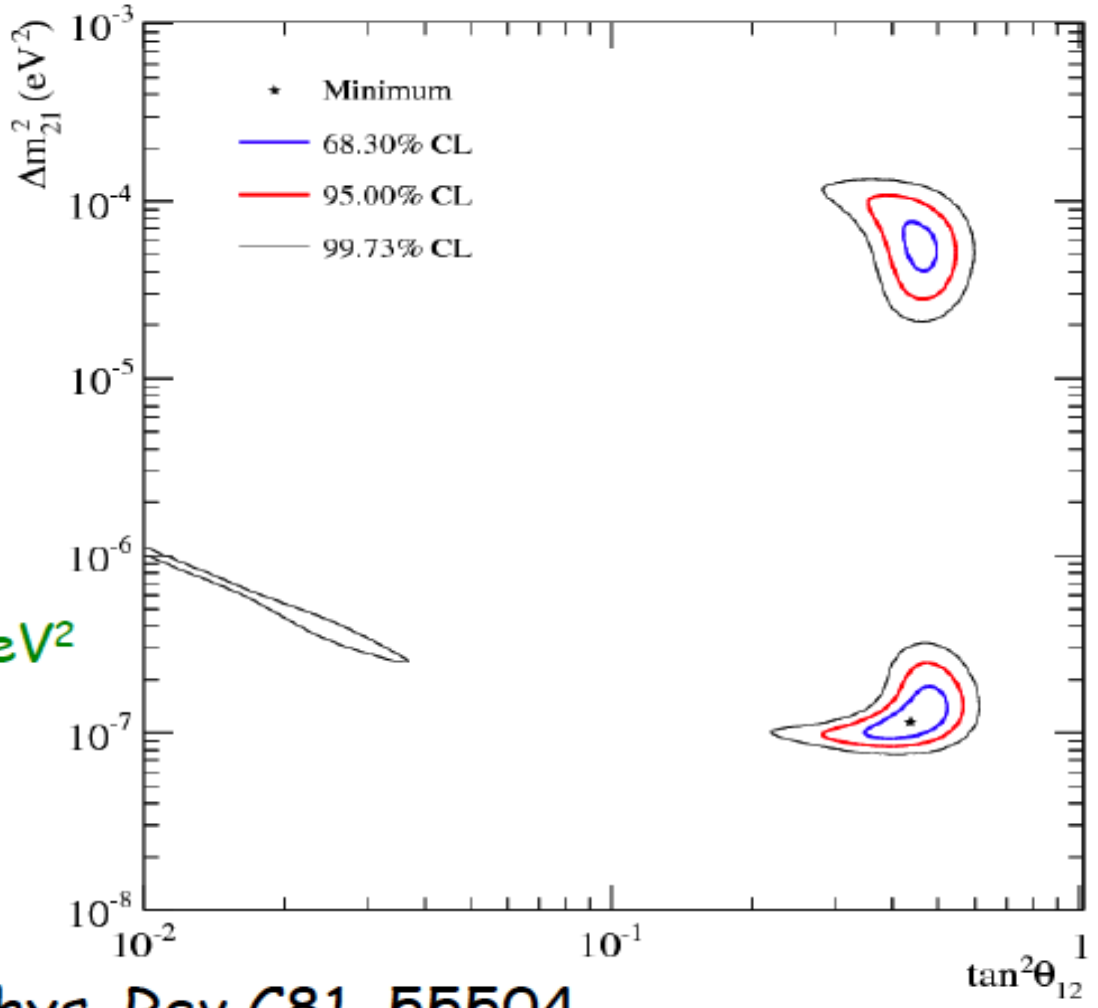
"unconstrained" CC electron spectrum



Low Energy Threshold Analysis

Oscillation analysis – SNO ONLY

LETA paper 2009:
LETA joint-phase fit
+ Phase III (^{3}He)



Best-fit point:

$\tan^2\theta_{12}=0.437\pm0.058$

$\Delta m^2=1.15\times10^{-7}\ ^{+0.438}_{-0.18}\ eV^2$

(LOW)

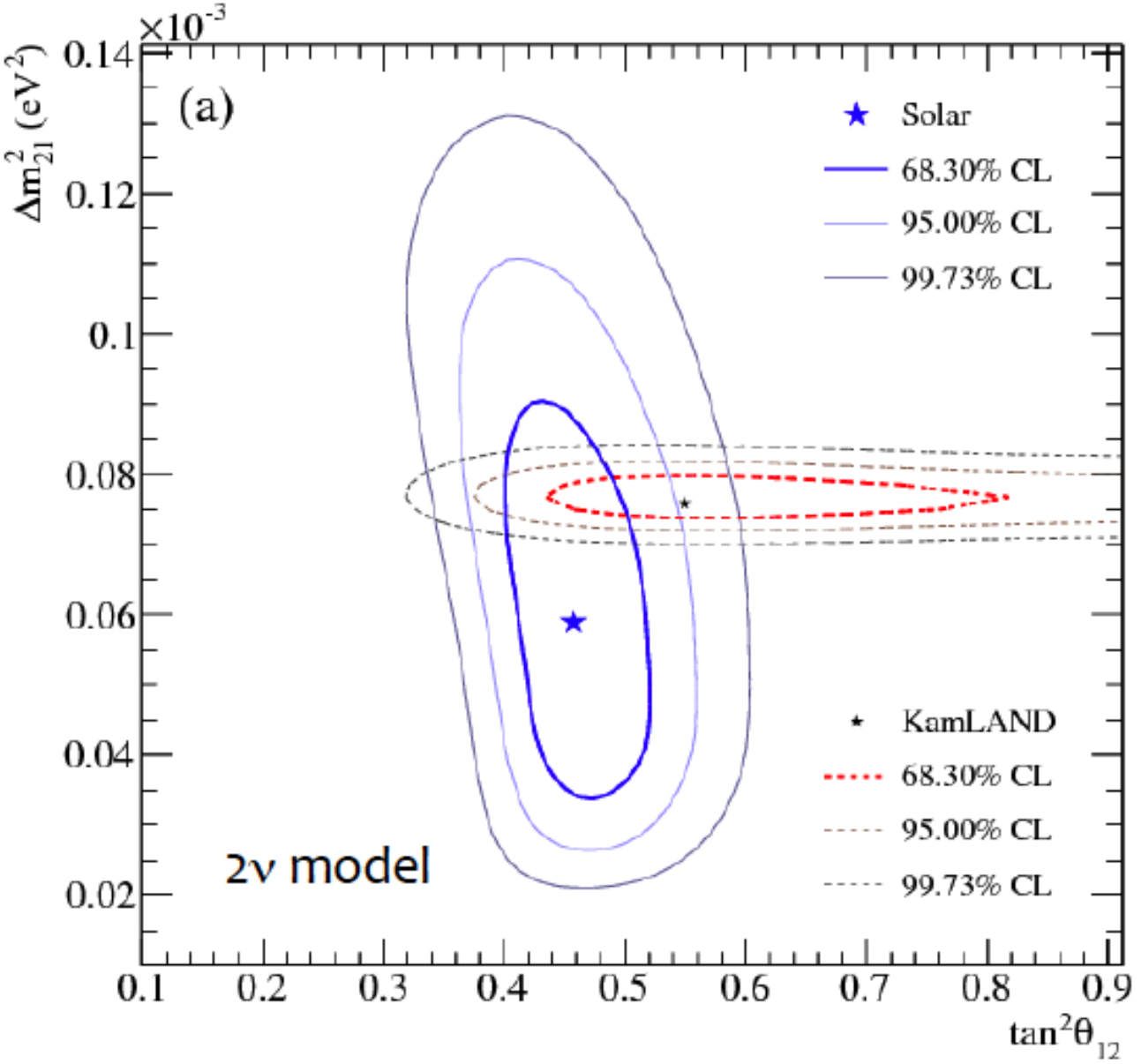
SNO Collaboration, Phys. Rev C81, 55504

Low Energy Threshold Analysis

Oscillation analysis – SNO + KAMLAND 2 Flavour

LETA paper 2009:
LETA joint-phase fit
+ Phase III
+ all solar expts
+ KamLAND

2 flavour overlay

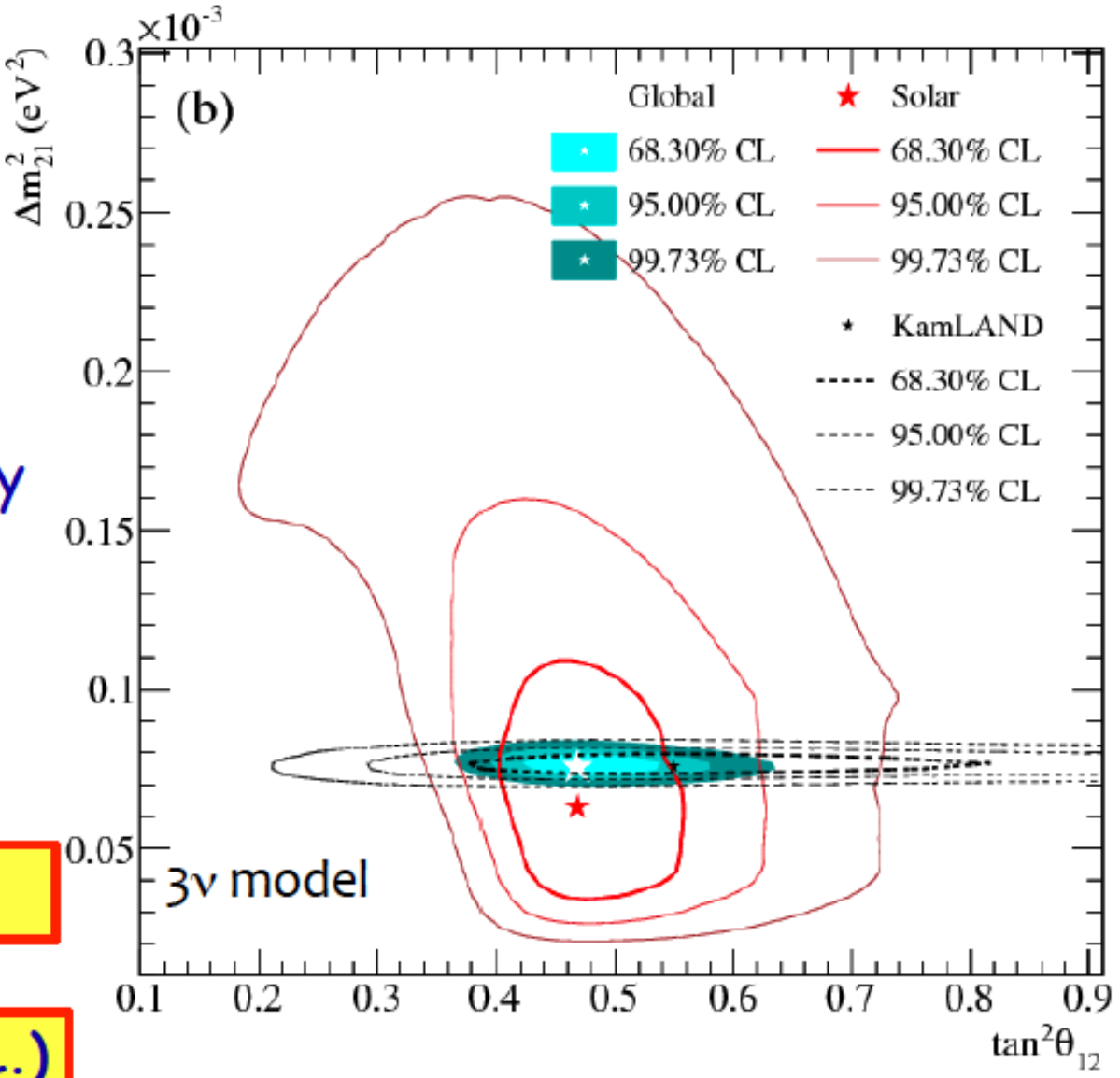


Low Energy Threshold Analysis

Oscillation analysis – SNO + KAMLAND 3 Flavour

LETA paper 2009:
LETA joint-phase fit
+ Phase III
+ all solar expts
+ KamLAND

3-flavor fit/overlay
->Pointed out by
many authors



Best-fit:

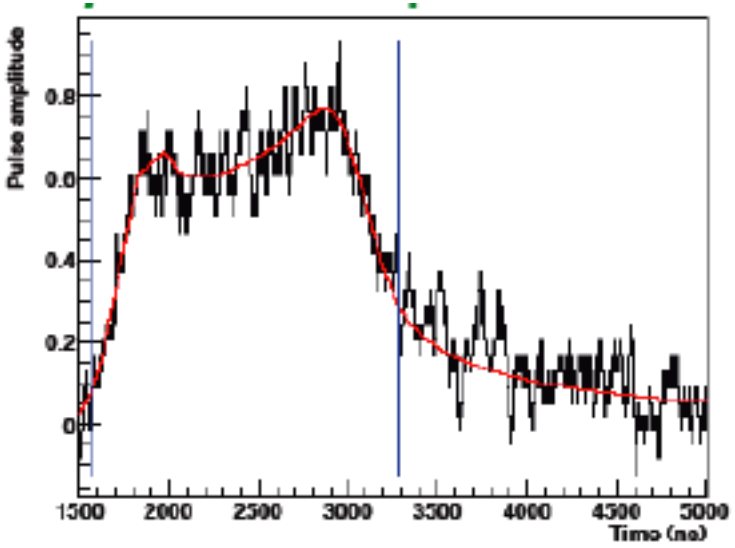
$\sin^2\theta_{13} = 2.00\ ^{+2.09}_{-1.63} \times 10^{-2}$

$\sin^2\theta_{13} < 0.057$ (95% C.L.)

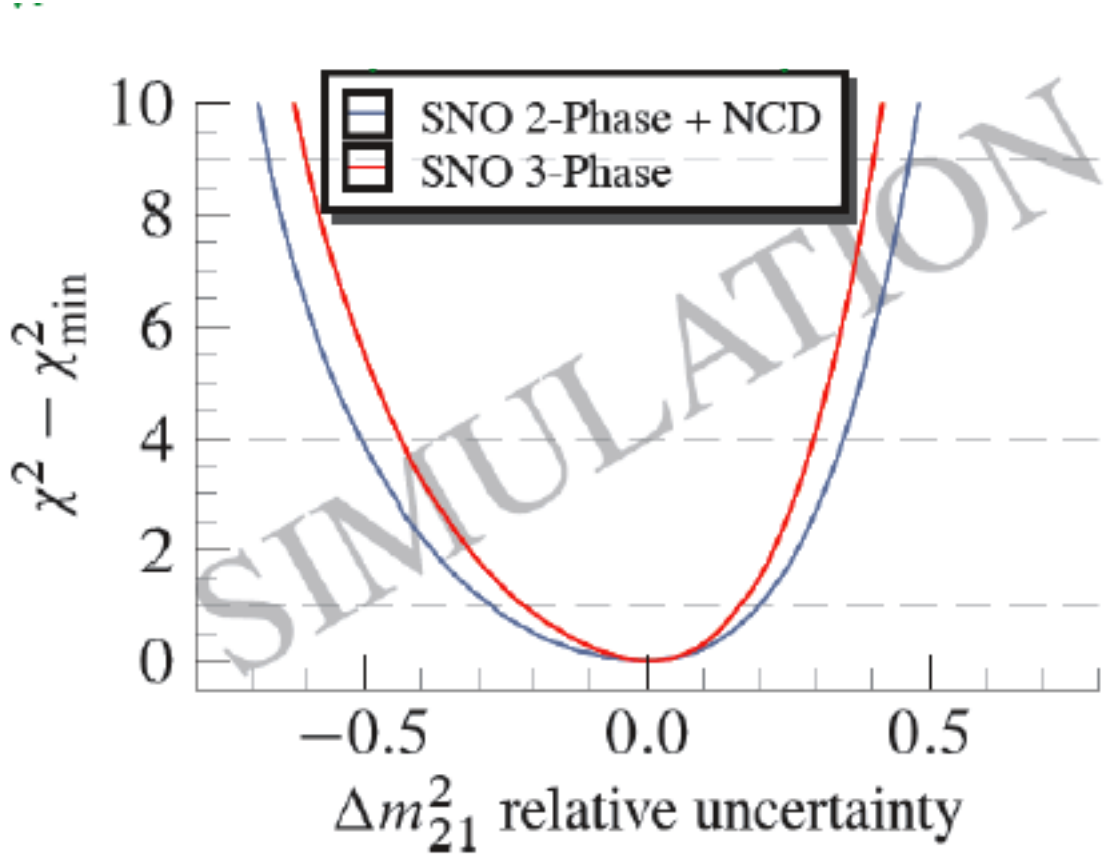
Full 3-Phase Analysis

Combine LETA and Phase III (NCD) in a single fit

Pulse shape analysis to separate ^{3}He signal from background

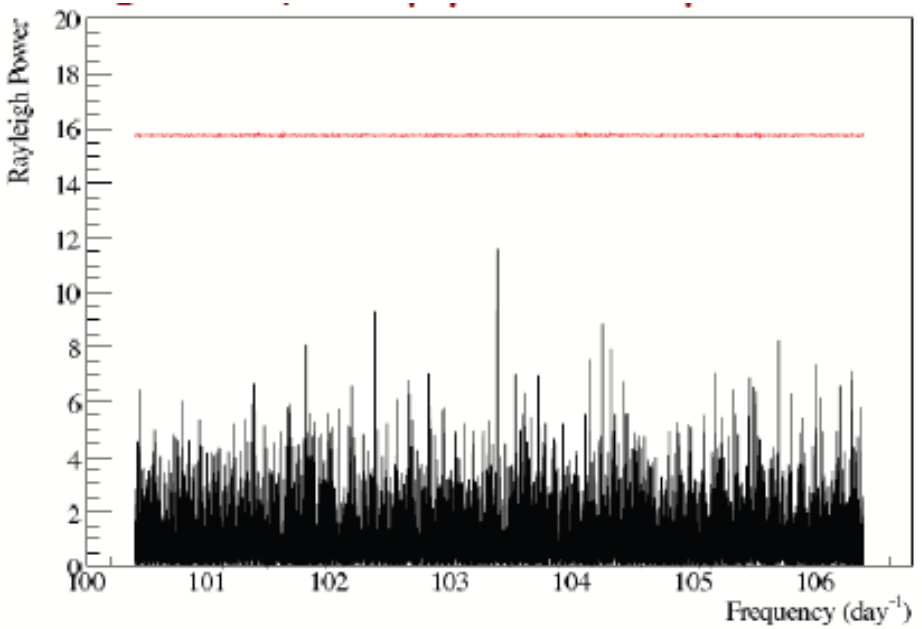


Number of neutrons determined by fitting to the counter energy spectrum.
Constrain 3-phase fit using ^{3}He count.

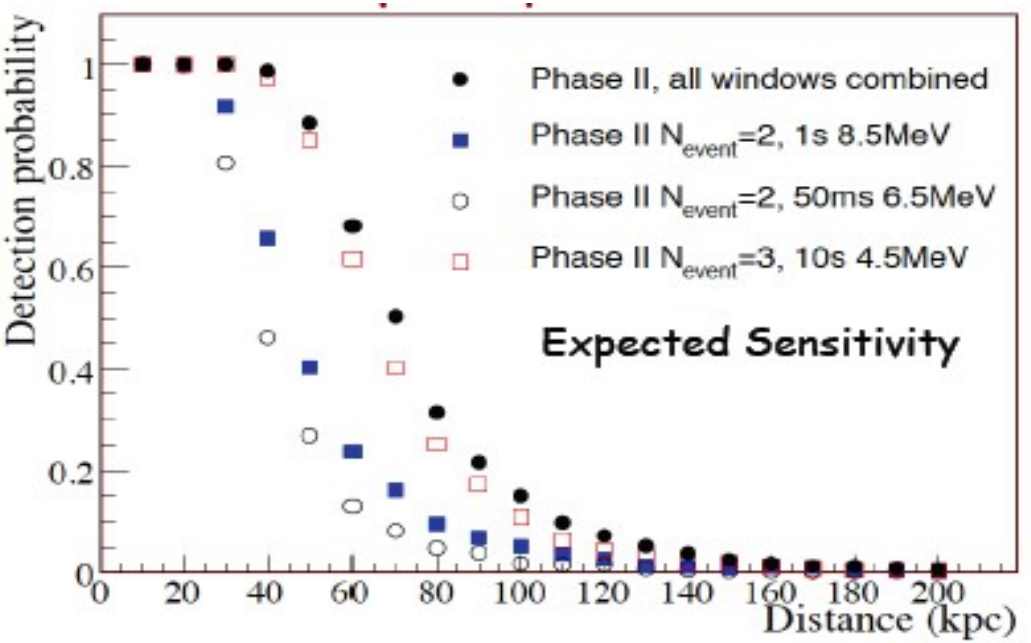


Expected improvement in Δm^2

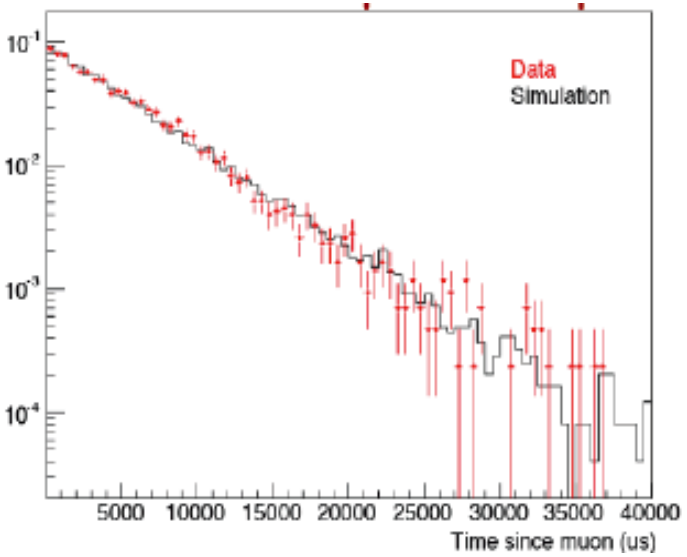
Other SNO results



High Frequency Periodicity Search
ApJ. 710:540-548



Low Multiplicity burst search
In Progress



Neutron and spallation product study
In Progress

Summary

- LETA analysis improved precision of SNO Neutral Current measurement by > factor 2

- LOWEST analysis threshold yet achieved using a water Cherenkov detector
- Low energy spectrum is consistent with NO distortion

- 3-Flavour analysis shows non-zero θ_{13} but consistent with $\theta_{13} = 0$

$$\sin^2\theta_{13} = 2.00\,^{+2.09}_{-1.63} \times 10^{-2} \qquad \sin^2\theta_{13} < 0.057\ (95\%\ C.L.)$$

- Expect further improvement with forthcoming 3 phase analysis

- Low multiplicity burst search paper expected soon

- Other “technical” papers expected soon – Spallation products, surface radioactivity measurements etc