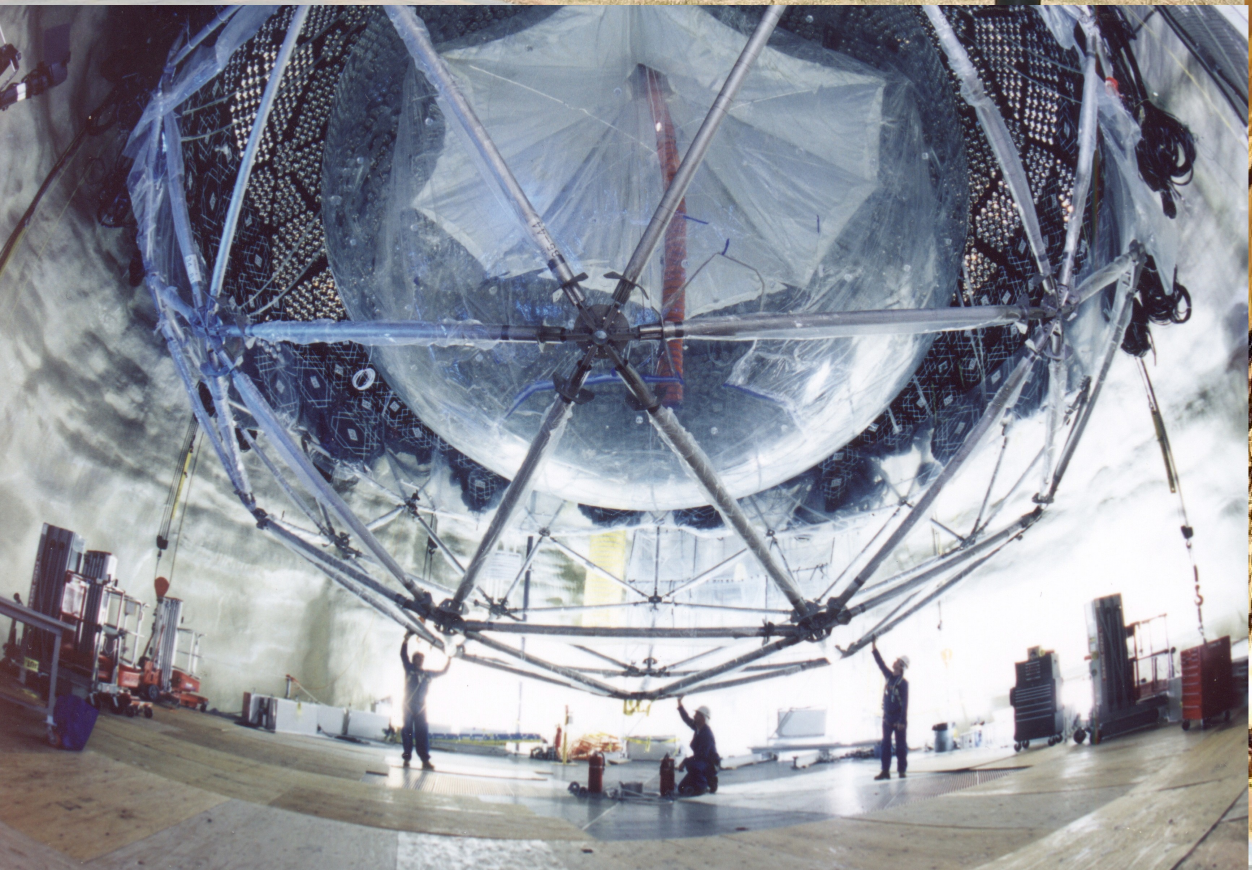
SNO Status update

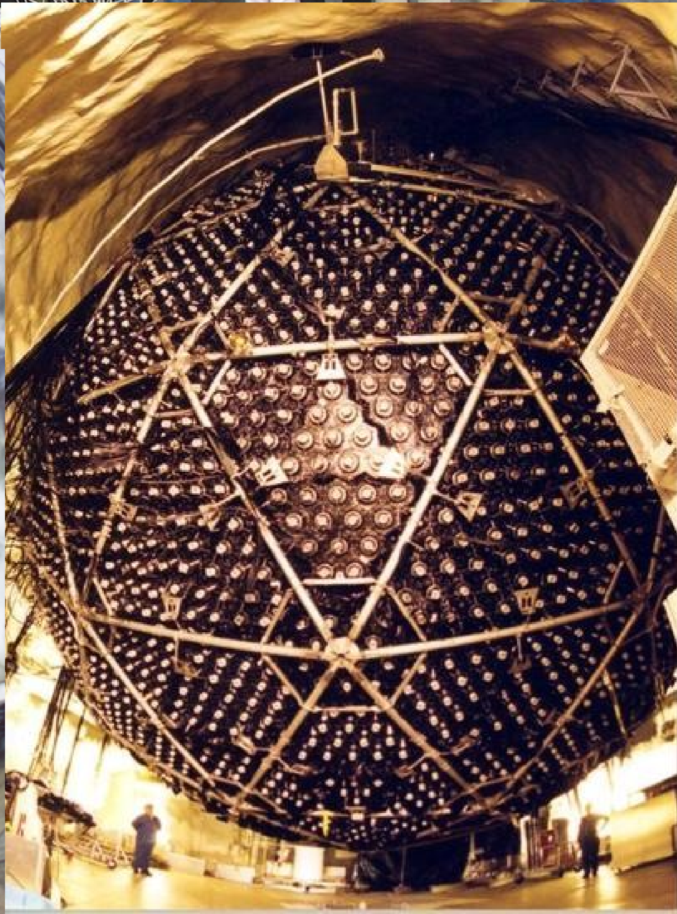
José Maneira, LIP-Lisboa
on behalf of the SNO collaboration
NWAP09, São Tomé
September 8, 2009

Outline

- Introduction
  - The Sudbury Neutrino Observatory
  - The three data taking phases
- Solar neutrinos, upcoming analyses
  - Motivation for a low energy threshold
  - Improving the energy response of SNO
  - Improving the background determination
  - Preliminary plots
- Cosmic rays and atmospheric neutrinos
  - New results from the full SNO data set

SNO Collaboration (and detector...)





Sudbury Neutrino Observatory

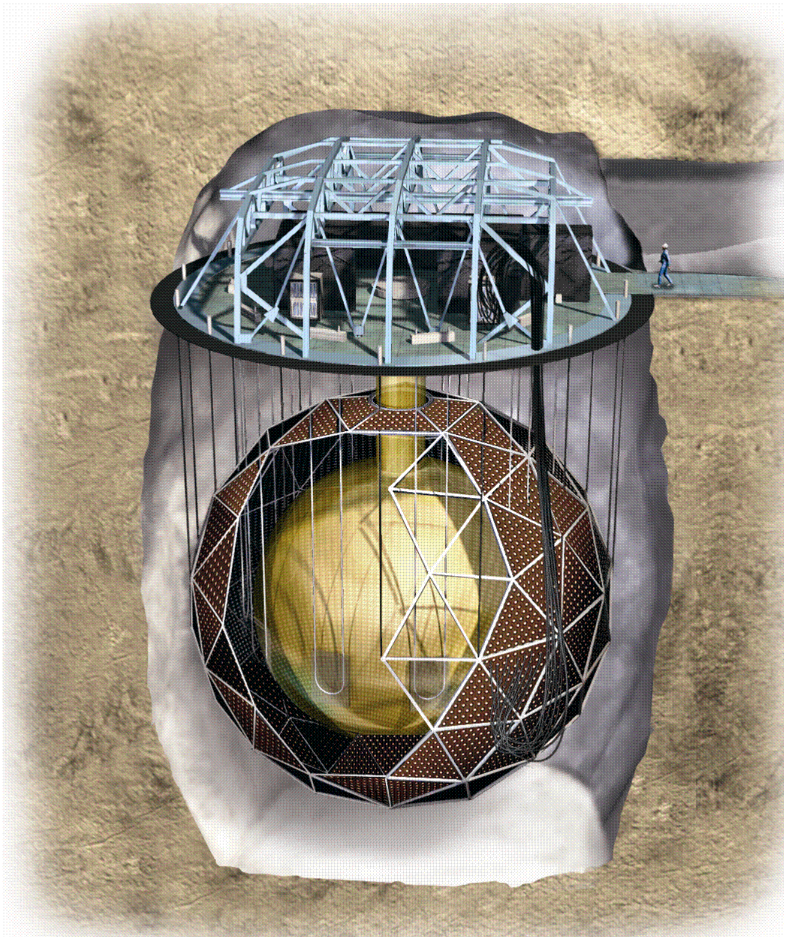
Acrylic vessel (AV)
12 m diameter

1000 tonnes D_2O
($300 million)

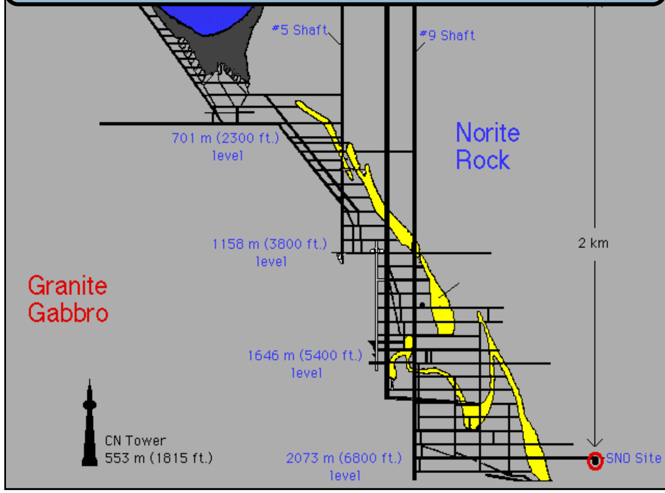
1700 tonnes H_2O
inner shielding

5300 tonnes H_2O
outer shielding

~9500 PMT's



2092 m underground



Creighton mine
Sudbury, CA

- Entire detector Built as a Class 2000 Clean room
- Low Radioactivity Detector materials

The heavy water has been returned to AECL.
Ongoing detector developments for SNO+.

The SNO 3-phase program

CC $\nu_e + d \longrightarrow p + p + e^-$

ν_e only

NC $\nu_x + d \longrightarrow p + n + \nu_x$

equally sensitive to all neutrino types

ES $\nu_x + e^- \longrightarrow \nu_x + e^-$

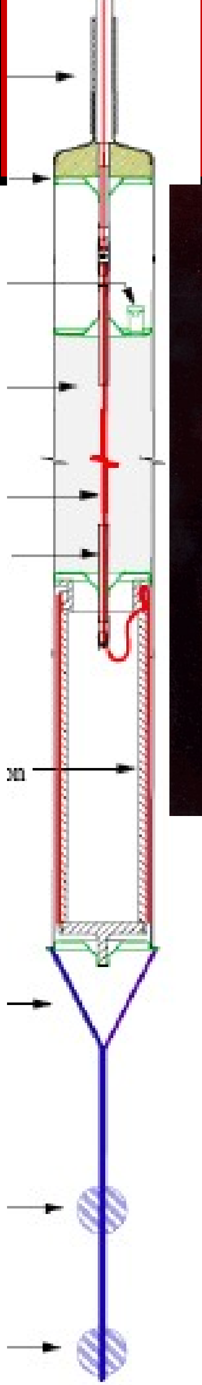
strong directional sensitivity

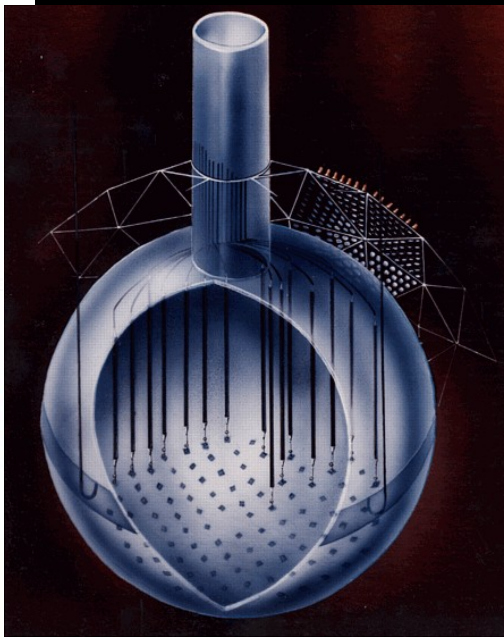
Statistical event separation

Independent detection

Phase I (D_2O) Nov 99 - May 01	Phase II (salt) July 01 - Sep 03	Phase III (^3He) Nov 04 - Nov 06
$^2H(n,\gamma)^3H$	2t NaCl	40 proportional counters
	$^{35}Cl(n,\gamma)^{36}Cl$	$^3He(n,p)^3H$
Good CC	Enhanced NC	Event by event NC

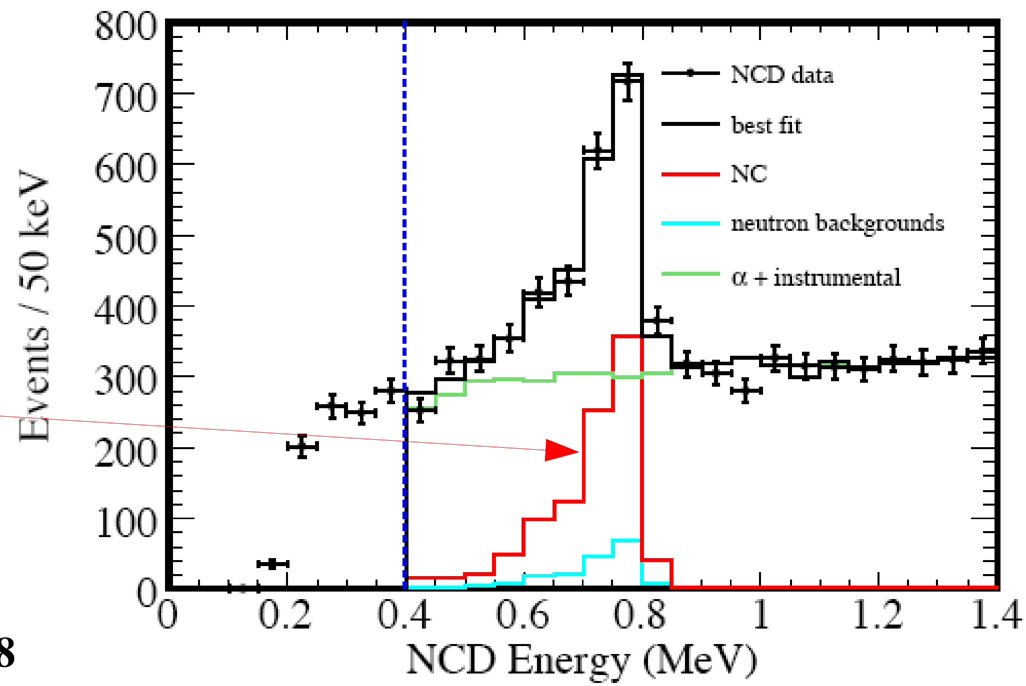
SNO Phase III





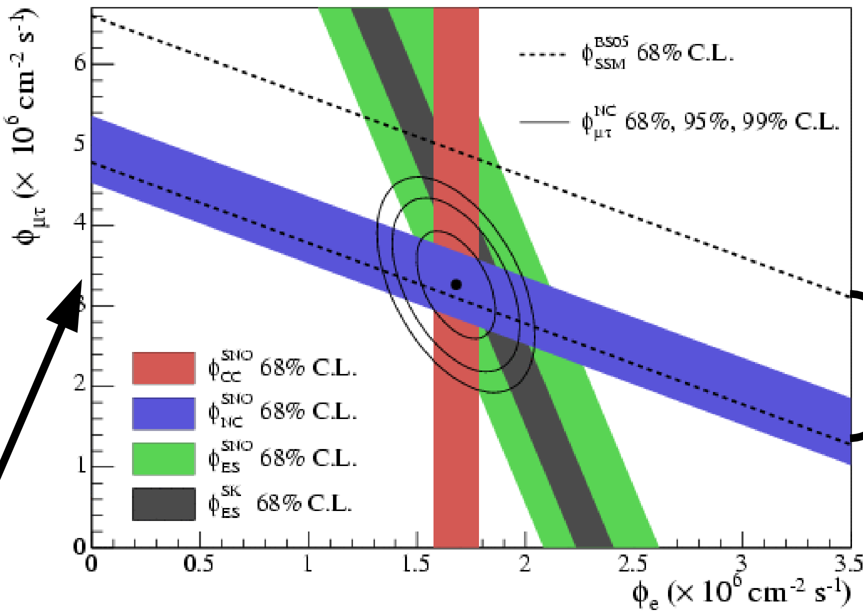
- Neutral-Current Detectors (NCD)
  - Proportional counters with ^{3}He, 40 tubes of ~10 m in a 1x1 m grid
  - Independent measurement of the NC flux
- Phase III
  - PMT signal reconstruction harder
  - Break the correlations between CC/NC

9% NC
uncertainty (total)



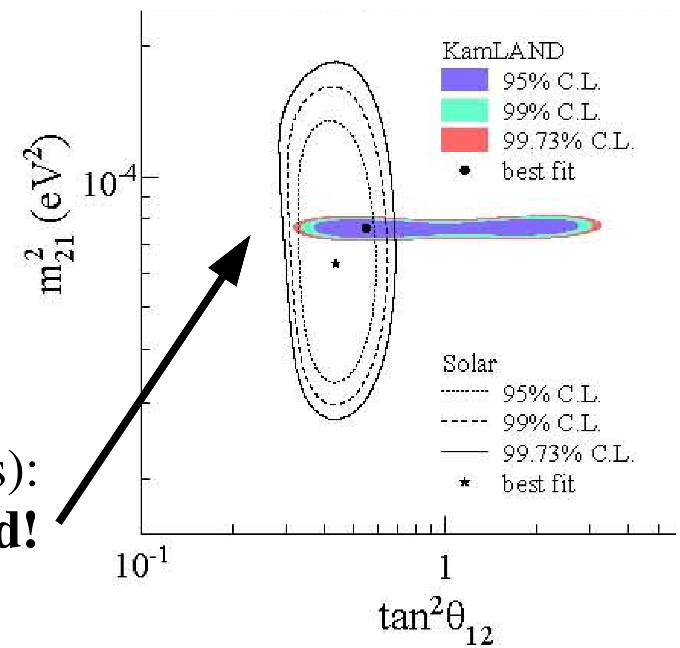
PAPER: nucl-ex/0806.0989v3
Phys.Rev.Lett.101:111301,2008

Summary of solar neutrino results



Agreement with solar models:
Solar neutrino problem solved!

Non-zero $\mu\tau$ neutrino flux:
flavor change!



Agreement with KamLAND (reactors):
Oscillations confirmed!

Solar neutrinos

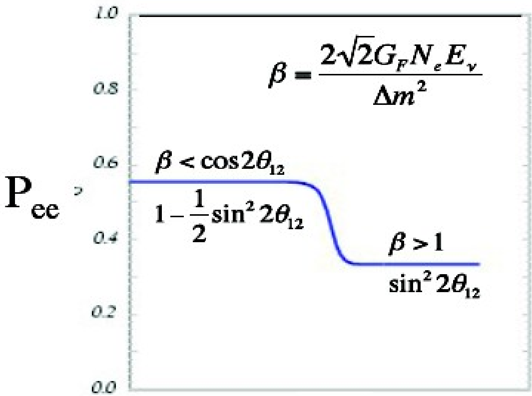
- No more data, so what's new?
- Many, many improvements to the analysis
  - Event reconstruction
  - Monte Carlo simulations
  - Background cuts and estimations
  - Combination of different phases
- What do we gain from these?
  - Lower energy threshold
    - Sensitivity to lower energy neutrinos
    - Increased statistics
  - Reduced systematics
    - Avoid double-counting of phase-correlated sources
    - Break correlations between CC and NC

Previous analyses
5.0/5.5/6.0 MeV
Phase I/II/III

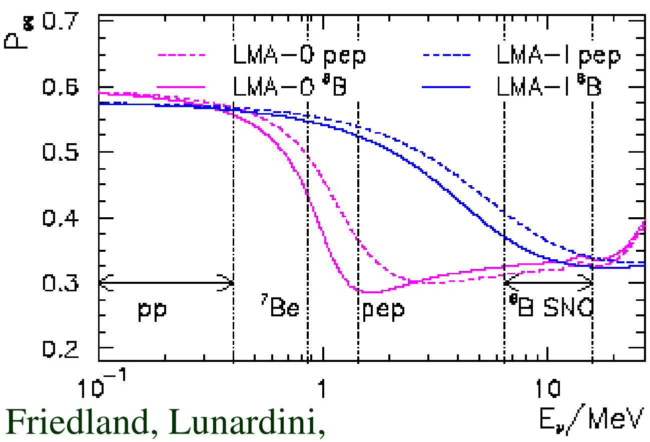
- Upcoming results: combined phase I+II with 3.5 MeV
- Later: combined phases I+II+III

Why lower threshold?

- Sensitivity to lower energy vs
  - Can we see the upturn in LMA survival probability?



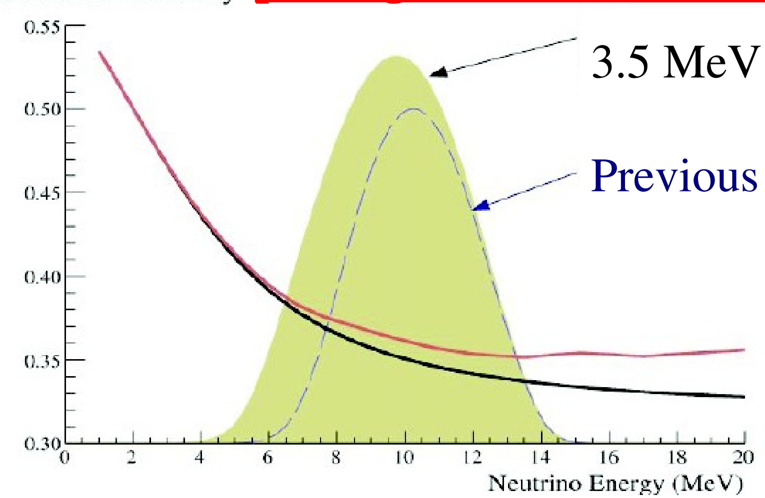
  - New Physics models



Friedland, Lunardini, Peña-Garay, hep-ph/0402266

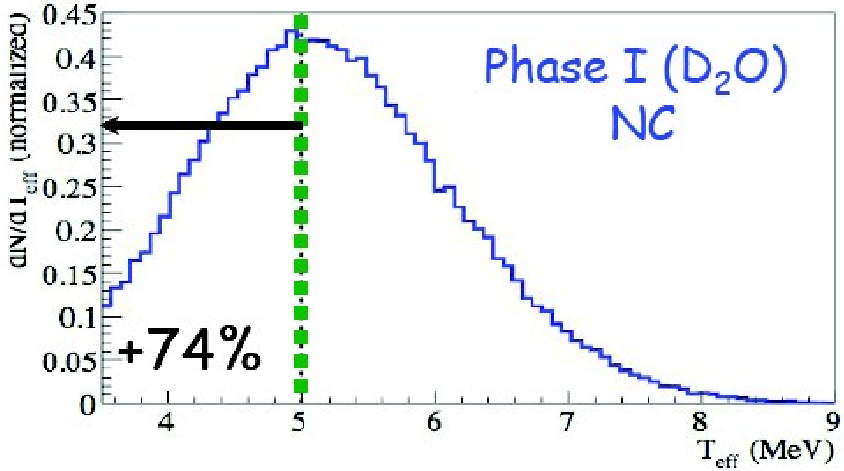
- Increased statistics
  - More neutrinos from the whole ^{8}B spectrum
  - Significant improvements in the errors of all signals (also NC!)

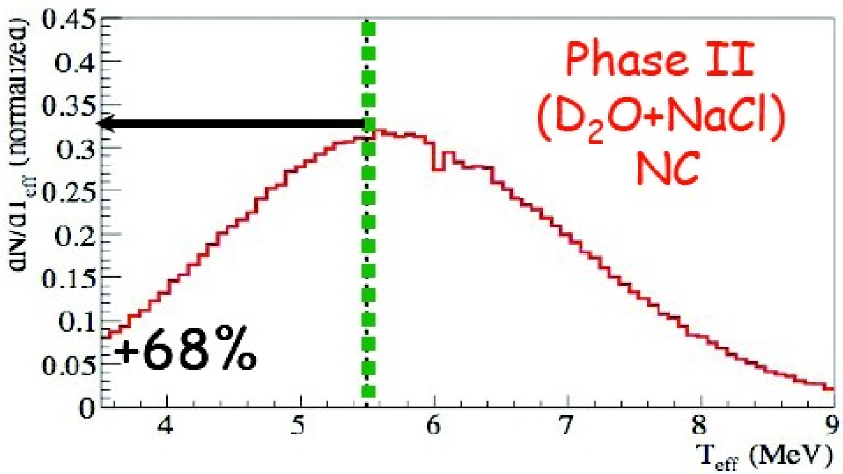
^{8}B neutrino events passing the electron energy threshold



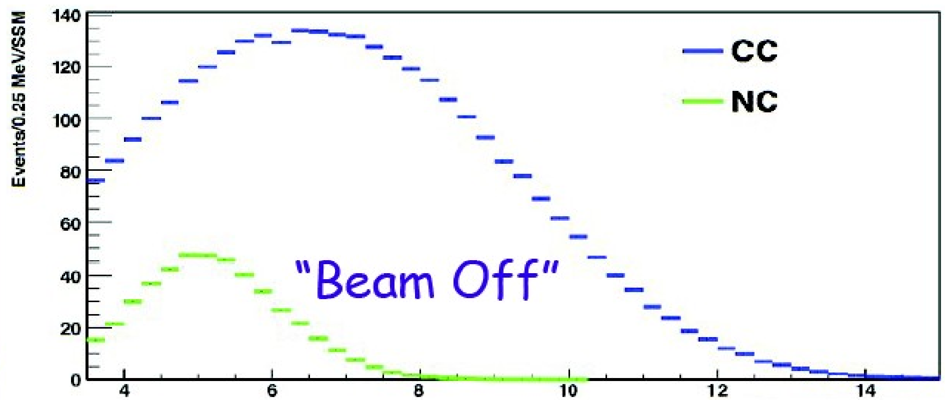
Advantages of new analysis

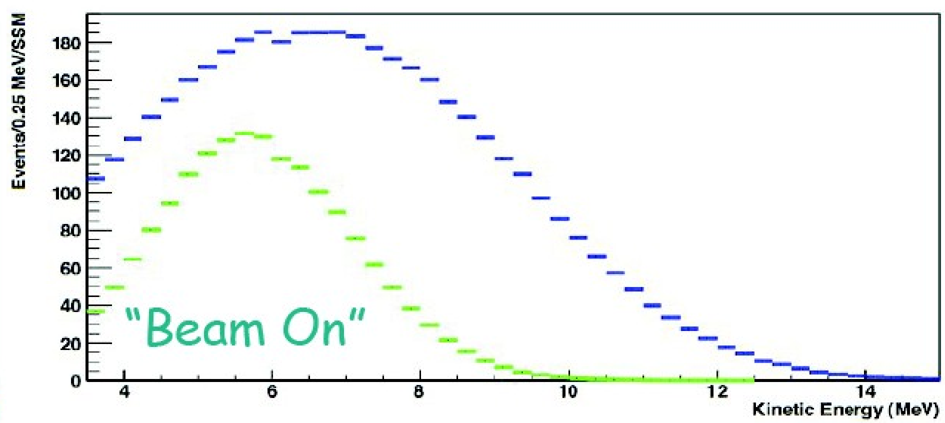
- By lowering threshold



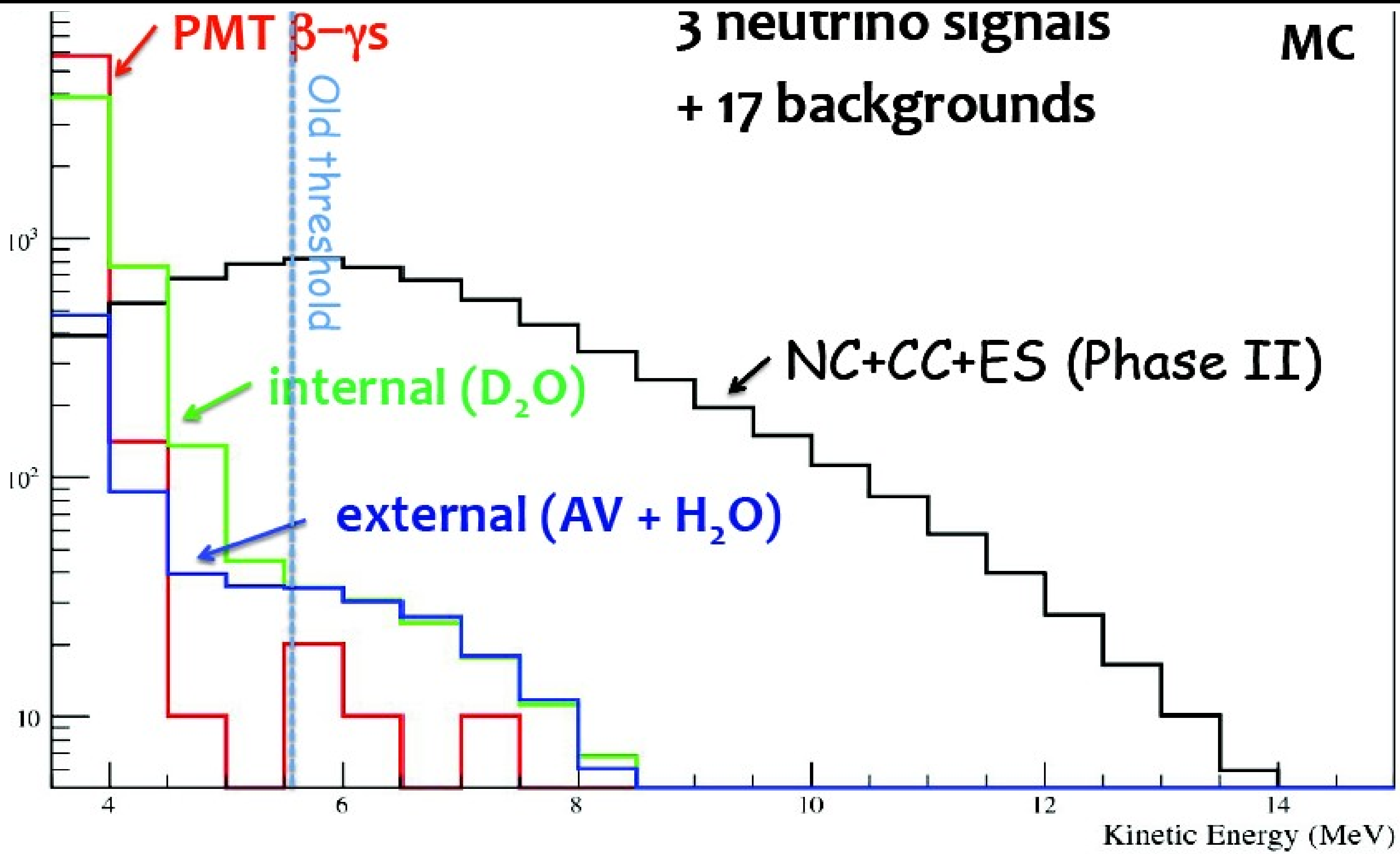


- By combining two phases
  - The same NC flux parameter is used, with different, known neutron efficiencies



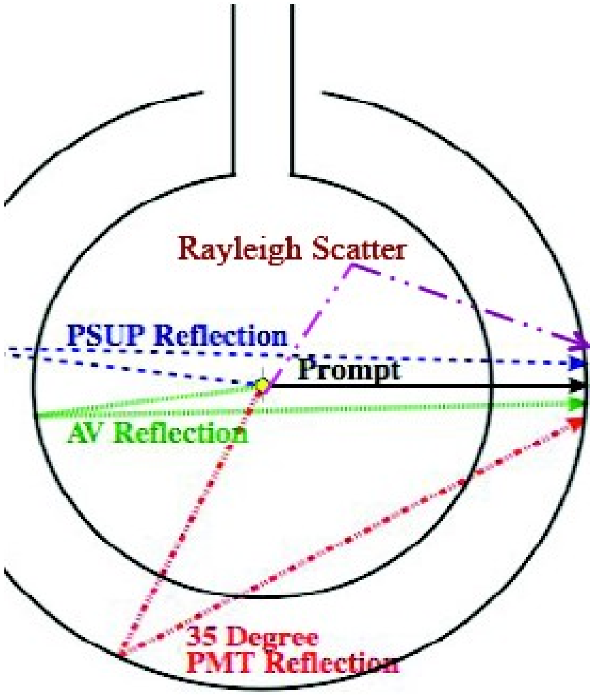


The expected spectrum



Signal extraction from max likelihood fit with
Multi-dimensional PDFs for signals and backgrounds
Dominant systematics can float in fit

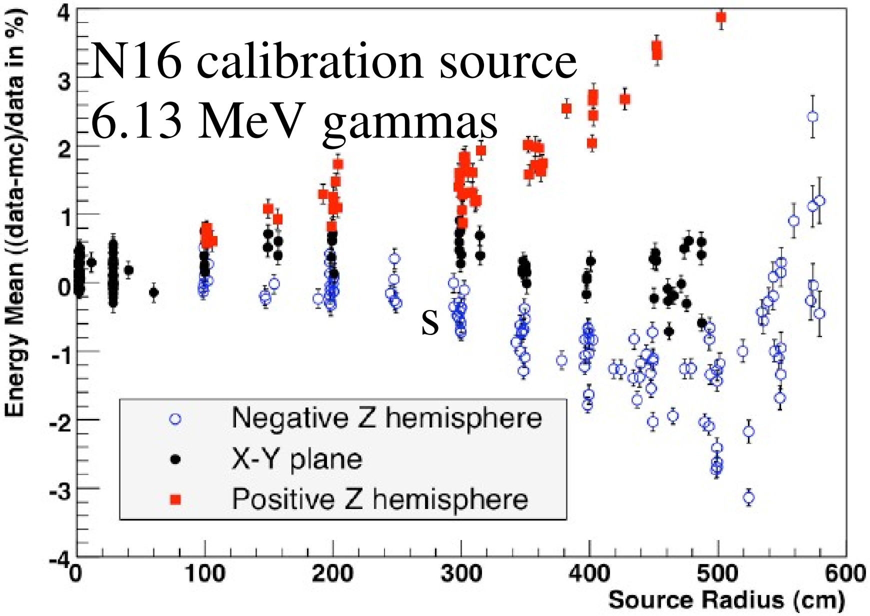
Energy response

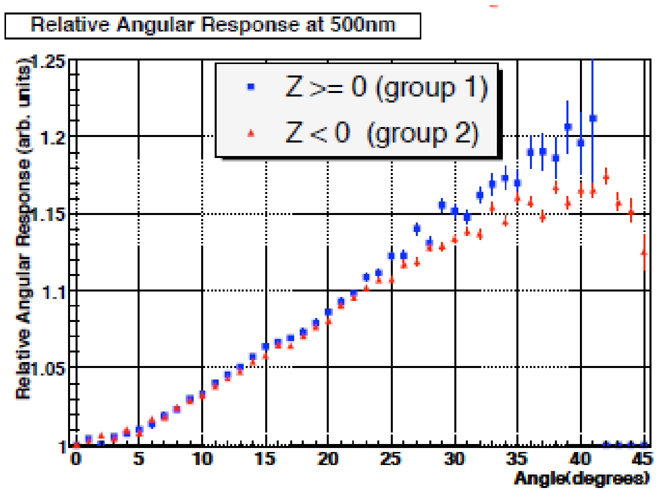


- Key to background reduction
  - Backgrounds are "only" tails from lower energy, so they depend strongly on resolution
- New energy estimator
  - Using both prompt and late light
    - More detailed detector model
  - Using improved 3D PMT model, channel-dependent PMT efficiencies
  - 12% more hits, 6% narrower resolution
    - 60% reduction of internal backgrounds!
- Volume-weighted uncertainties
  - Huge improvement

	Phase I	Phase II
Old	± 1.2%	± 1.1%
New	± 0.6%	± 0.5%

Bias correction

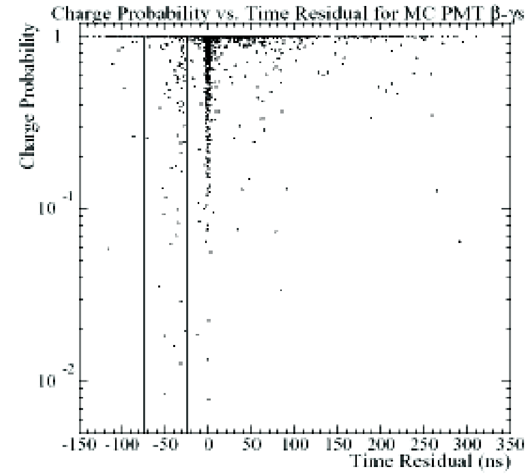


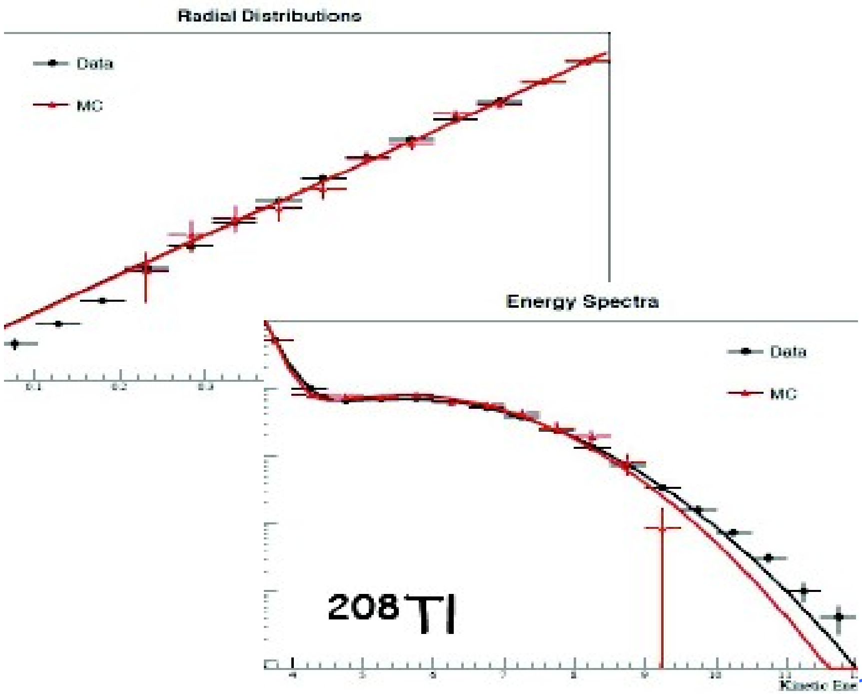


- Energy response bias with z
  - Also seen with optical source
    - Bias in PMT angular response in Z but not in other axes
  - Optics effects not in MC
    - Acrylic vessel (AV) neck, bottom of AV, non-uniformity of concentrator reflectivity...
    - Hard to disentangle
- Response correction
  - Based on position/direction
  - Derived from ½ of the N16 calibration data
  - Checks and systematics with:
    - Other ½
    - Neutrons, Rn spike

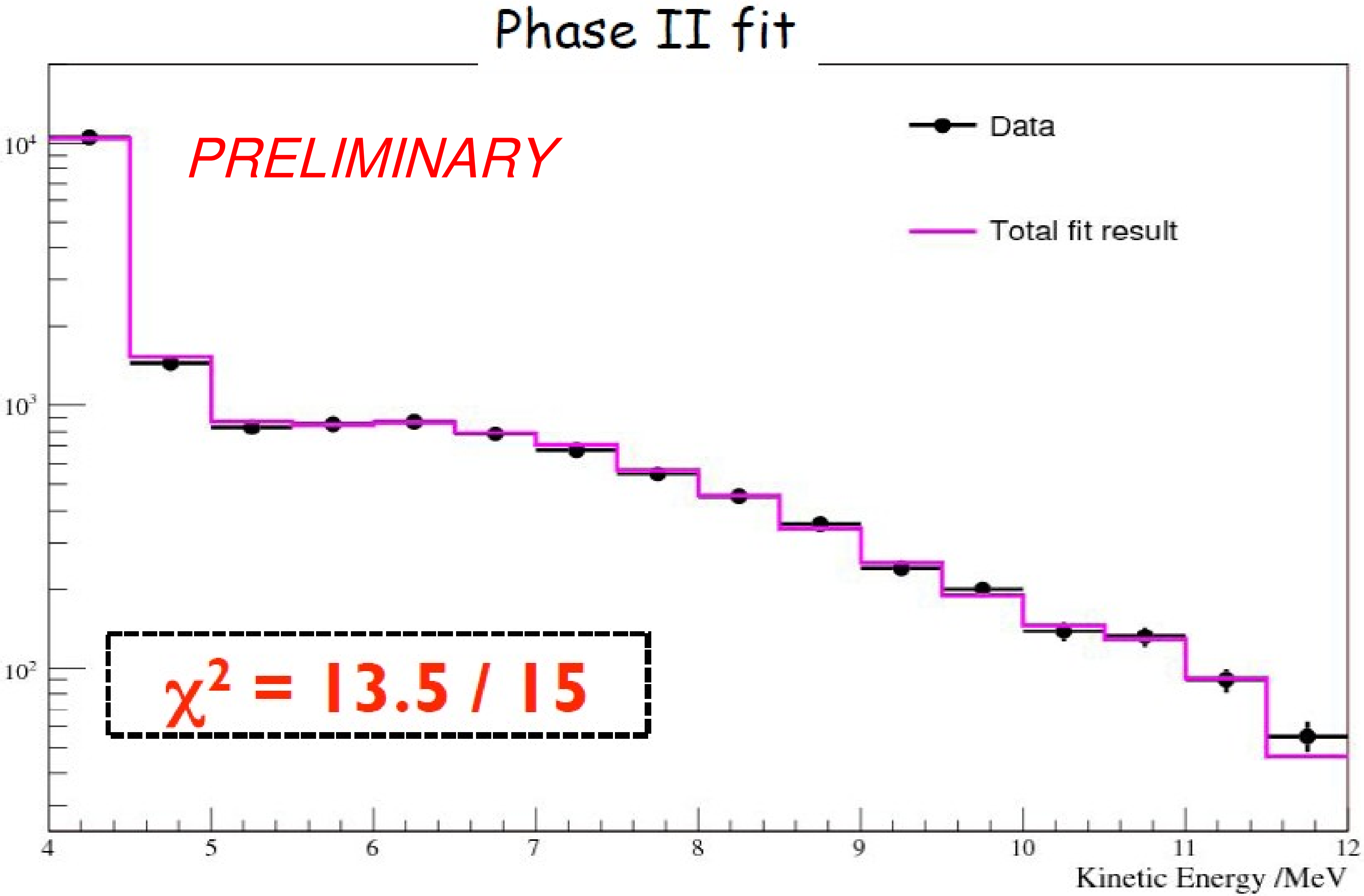
Backgrounds

- Need to disentangle several
  - D2O, H2O, AV, PMT
  - 214Bi, 208Tl
  - in- and ex-situ handles on D2O and H2O
  - PMT important for 3.5 MeV bin
- Example: PMT
  - Not enough CPU to simulate data sample
  - PDFs from data, using “bifurcated” analysis with high charge tag for part of the events
    - Decay is beta-gamma, PMT can see flash from beta at early times



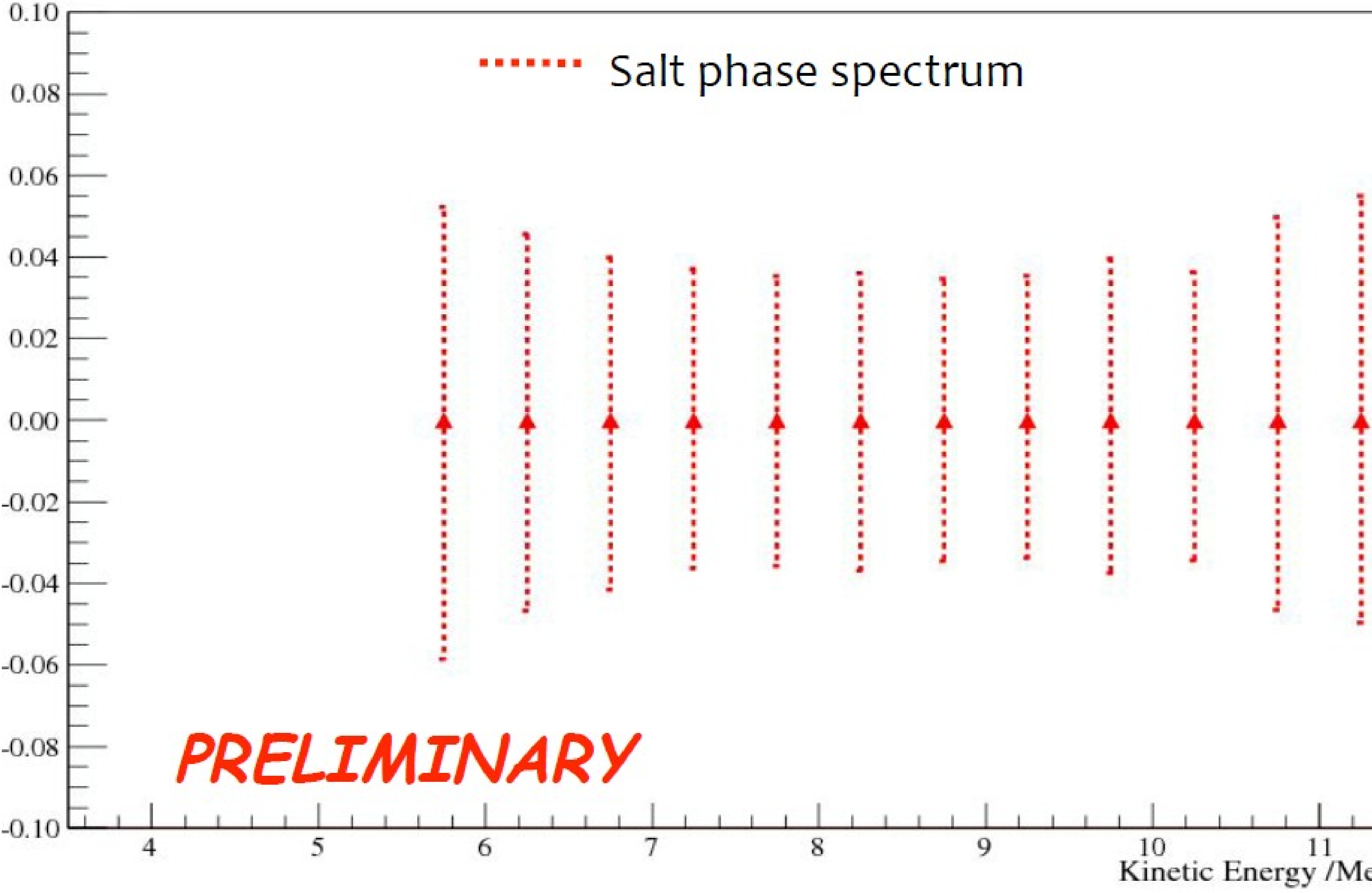


Preliminary results



Low Energy Threshold Analysis

➢ Uncertainties on CC Electron Recoil Spectrum



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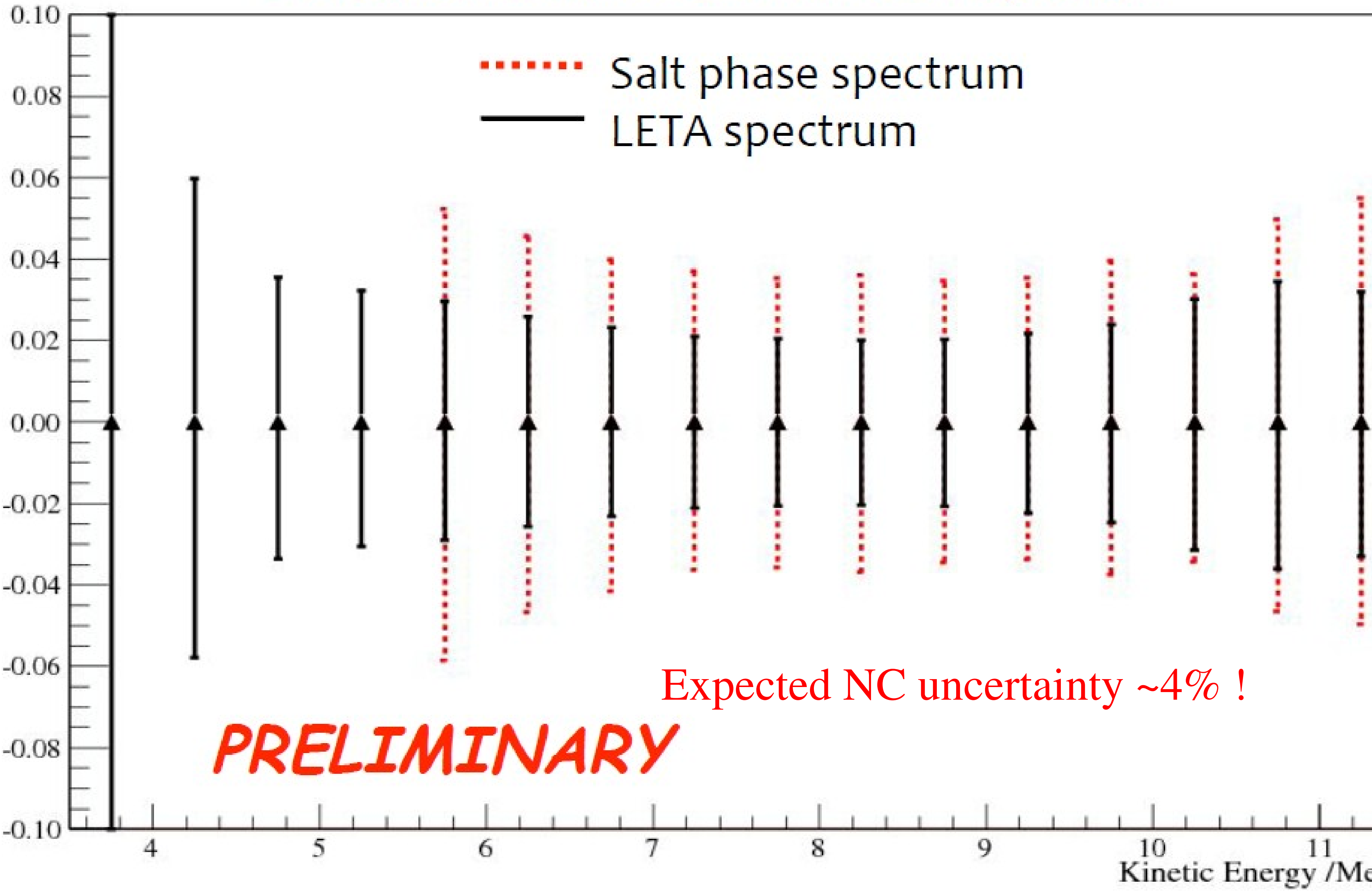
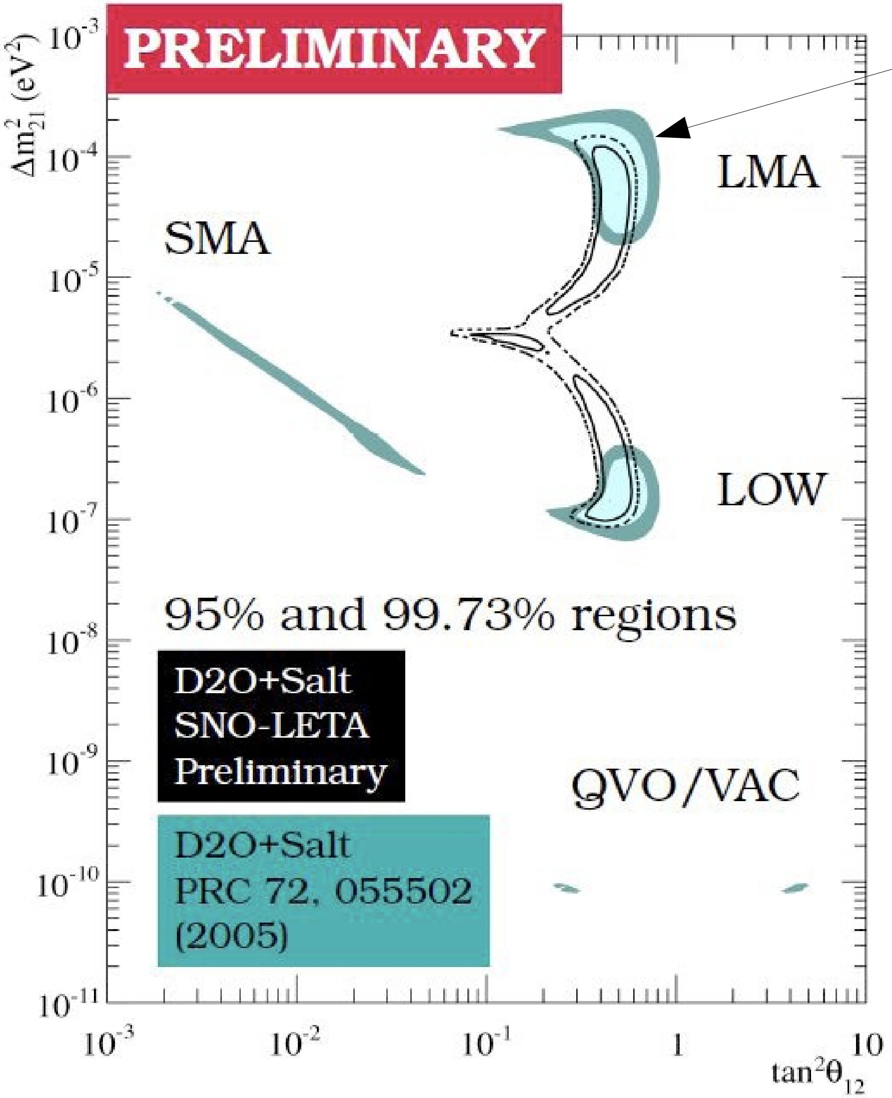
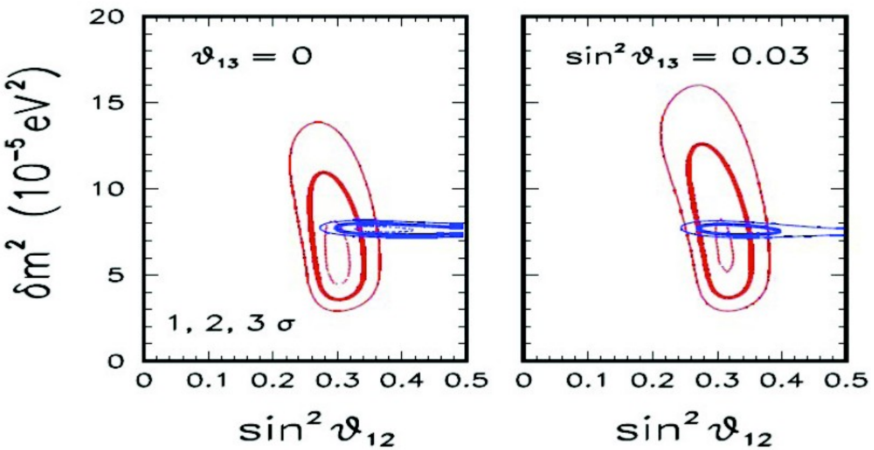


Physics reach



- Improve θ_{12}
- Combine with KamLAND for θ_{13} contours

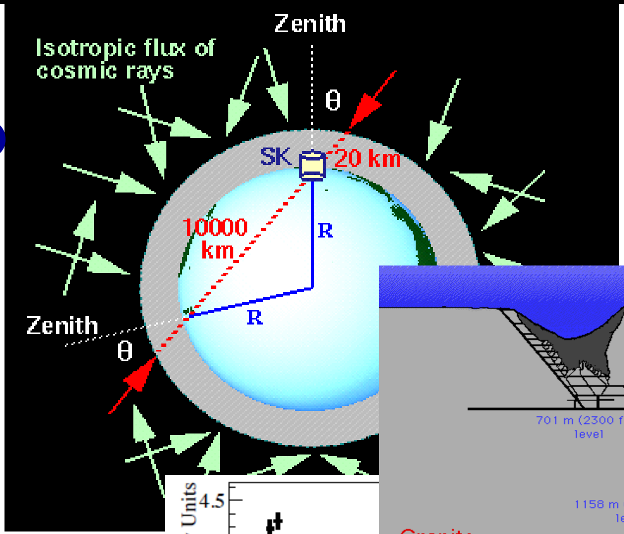


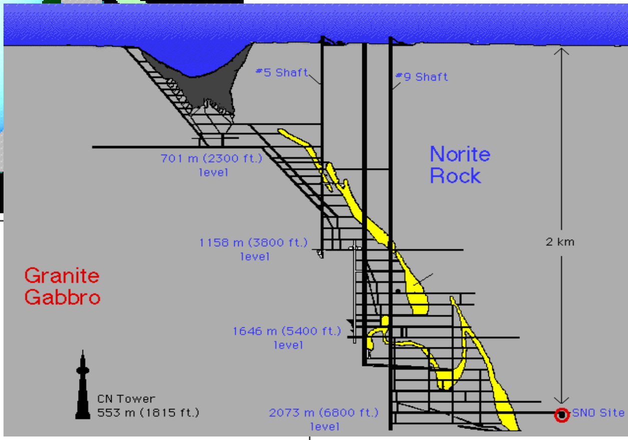
G.L. FOGLI [1,2*], E. LISI [2], A. MARRONE [1,2], A. PALAZZO [3], A.M. ROTUNNO [1,2]
arXiv:0905.3549v1

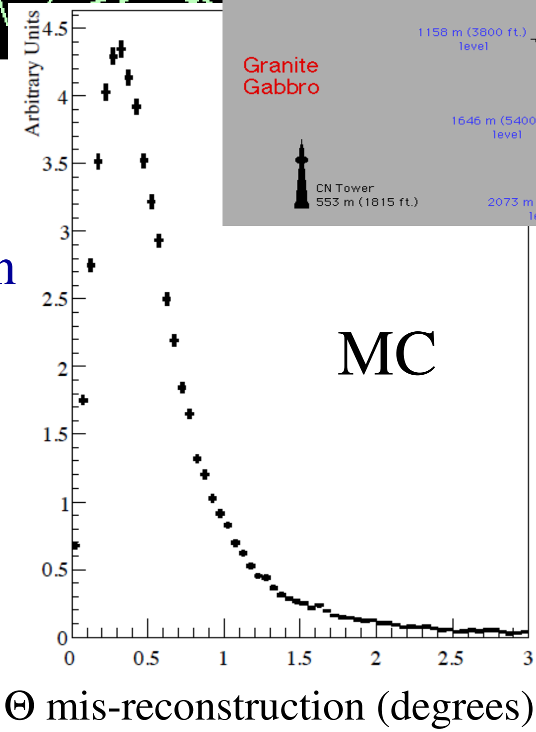
- Aiming also for a direct extraction of survival probability

Cosmic rays and atmospheric neutrinos

- **Disadvantages of SNO**
  - Small: 1kton D_2O + 1.7 kton H_2O
  - Only through-going muons
    - 96% of expected rate: 140 /yr
- **Advantages of SNO**
  - Depth of 5890 mwe
  - Flat overburden
- **Sensitivity to:**
  - Atmospheric neutrinos above the horizon
    - Cosmic muons only at $\cos\theta_{zenith} > 0.4$
    - Rate at $0 < \cos\theta_{zenith} < 0.4$ ~1/3 of total
    - Normalize the unoscillated flux
  - Cosmic muons at high slant depth





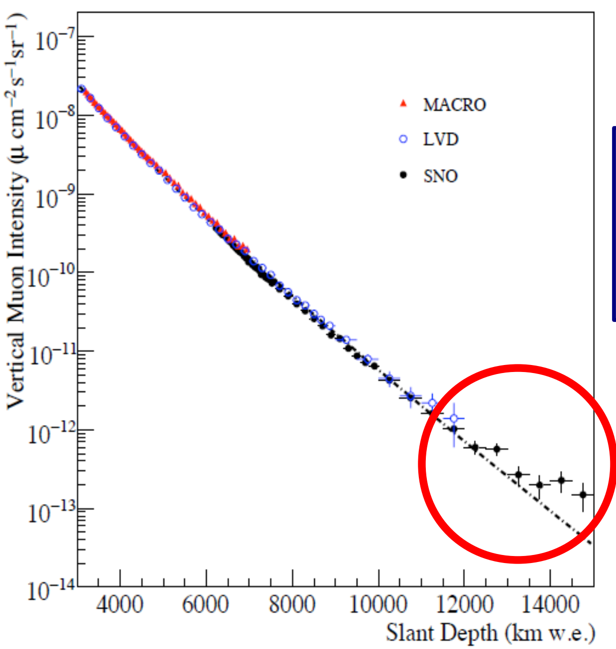


Results

Paper published:
SNO Collaboration, Phys.Rev.D80:012001,2009
hep-ex/0902.2776

Cosmic ray muon flux

3.31 ± 0.01 (stat.)± 0.09(syst.)$\times 10^{-10}$ μ/s/cm^2

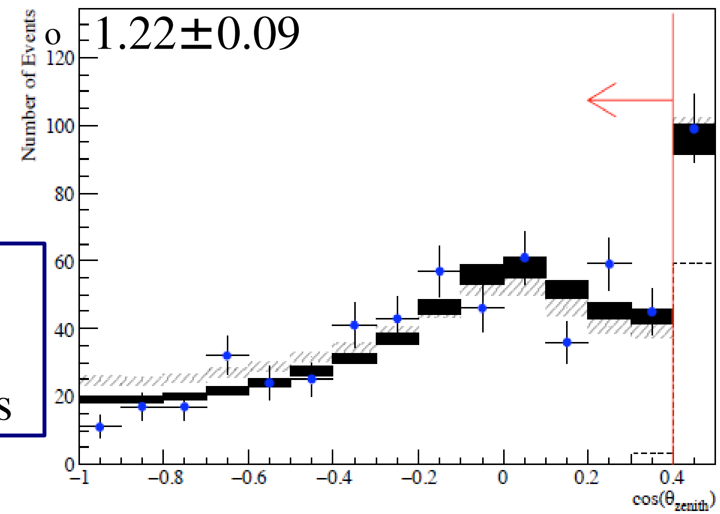


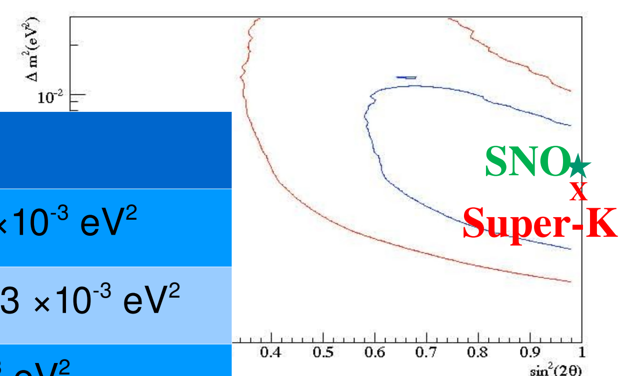
- Exposure
  - 1229 days, 2.30×10^{14} cm^{2}s

Measurement at the largest slant depths yet. Above 13.5 km we neutrino-induced muons become significant

Atmospheric neutrinos

- Cross-check of oscillations
- Normalization of the unoscillated flux from the 3D Bartol model:





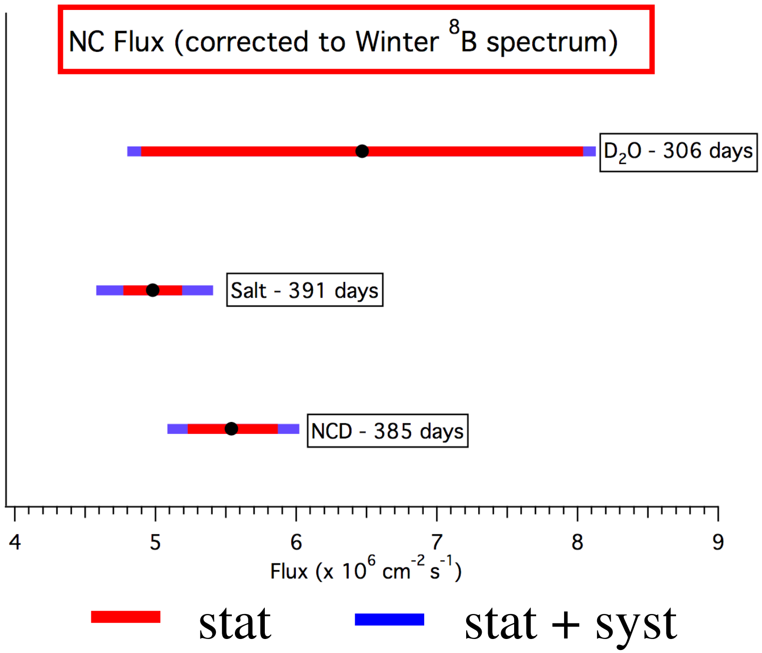
Experiment	Δm^2
Super-K	$2.1^{+0.6}_{-0.4} \times 10^{-3}$ eV^2
MINOS	$2.43 \pm 0.13 \times 10^{-3}$ eV^2
SNO	2.6×10^{-3} eV^2

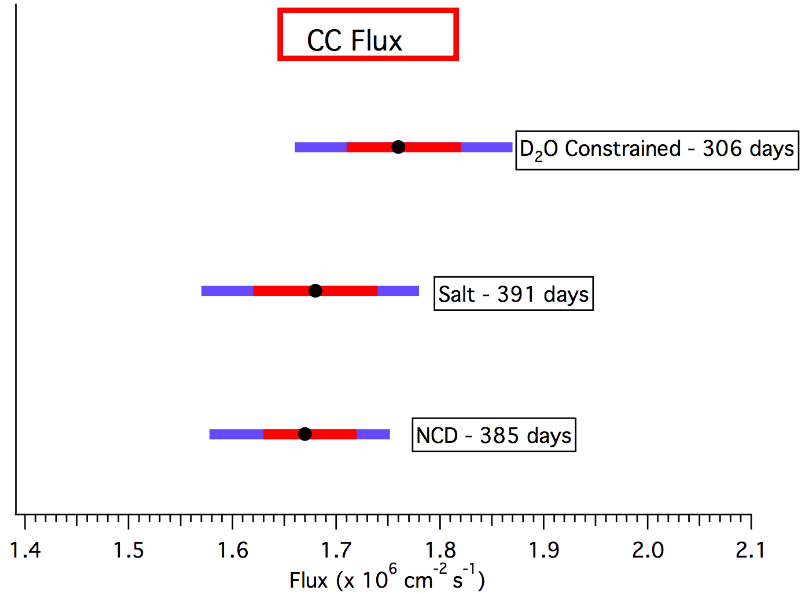
Conclusions

- SNO solar neutrino analyses
  - After data taking stopped, data analysis is ongoing with more sophisticated techniques, aiming for the best possible precision
  - Improvements in energy reconstruction and background analysis will allow for a low energy threshold of 3.5 MeV
  - This, plus a combined analysis of phases I and II will give unprecedented precision on the NC flux and CC/ES spectra
  - Stronger statements on the oscillation parameters
  - And it's still not the last word: improvements to SNO's phase III are also being prepared for a combined 3-phase analysis
- Other analyses
  - Combined 3-phase muon and atmospheric neutrino results published
    - Unprecedented sensitivity to region above the horizon
  - Searches for transient signals and “exotic” Physics ongoing

Extra

Flux measurements in the 3 phases





Consistency between all 3 phases