1. Rachel Carr (MIT). How are the error bars calculated for the coherent addition shown in Fig. 7? The righthand column on p. 5 says “of total 216 points [= 9 points in E * 24 points in L] each 8 points are averaged" and it would be helpful to understand how the error bars are combined in that averaging (i.e., assumptions about correlations).

To calculate values shown in fig.7 we average series of 8 experimental points of measured dependence of signal on parameter L/E. In calculations of average values and error bars shown in fig.7 we used expressions:

$$A^{k}_{average} = \frac{\sum_{i=8k}^{8k+7} \frac{A_i}{(\Delta A_i)^2}}{\sum_{i=8k}^{8k+7} \frac{1}{(\Delta A_i)^2}}, \Delta A^{k}_{average} = \sqrt{\left(\sum_{i=8k}^{8k+7} \frac{1}{(\Delta A_i)^2}\right)^{-1}}, k = 0 \ldots 26$$

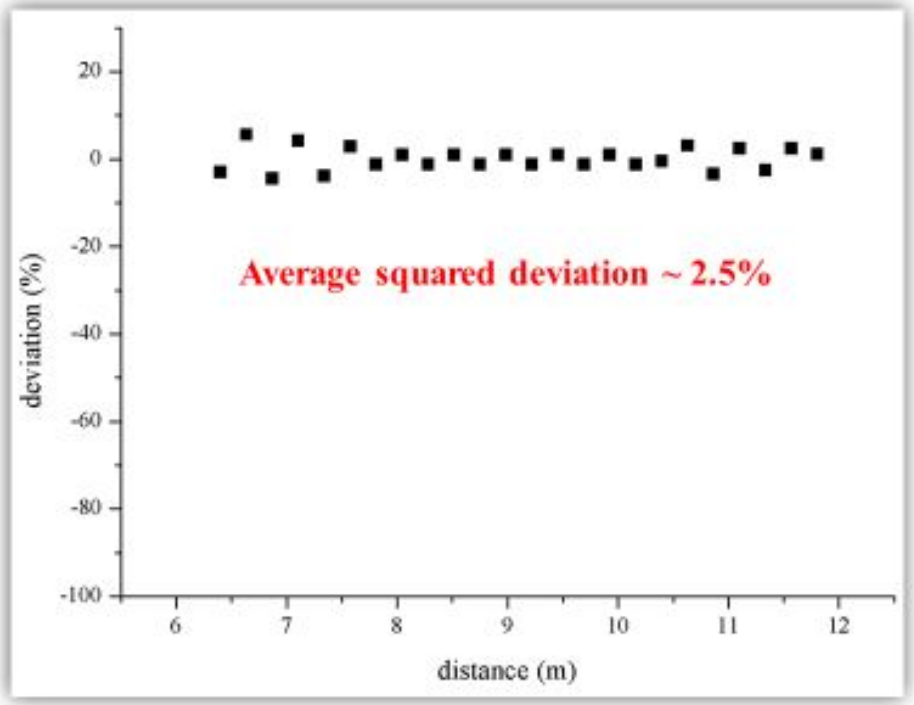
2. Pranava Surukuchi (IIT). How are correlated uncertainties between same segment but different baselines treated in the fitting procedure used to assess compatibility with the existance of a sterile neutrino?

In signal measurements we average results measured at the same distance by different rows (segments). Hence, we do not need to take the mentioned correlation into account. For more details refer slide 32.

Averaging of detector rows efficiencies due to movements (above estimation)

L(m)	Numbers of detector row				
6.4025	2				
6.6375	3				
6.8725	4	2			
7.1075	5	3			
7.3425	6	2	4		
7.5775	7	3	5		
7.8125	8	4	6	2	
8.0475	9	5	7	3	
8.2825	6	2	8	4	
8.5175	7	3	9	5	
8.7525	8	4	6	2	
8.9875	9	5	7	3	
9.2225	6	2	8	4	
9.4575	7	3	9	5	
9.6925	8	4	6	2	
9.9275	9	5	7	3	
10.1625	6	2	8	4	
10.3975	7	3	9	5	2
10.6325	8	4	6	3	
10.8675	9	5	7	4	
11.1025	6	8	5		
11.3375	7	9	6		
11.5725	8	7			
11.8075	9	8			

Average efficiency at various distances



3. Tom Langford (Yale), Pranava Surukuchi (IIT), Danielle Norcini (Yale).
Fig 4 compares the measured spectrum to that predicted, and finds poor agreement. Is this understood? Similarly, how would the predicted spectrum by altered by short baseline oscillation with your best-fit parameters, and how would this compare to the measured spectrum in Fig. 4.

Answer on the first part of the question one can find at slide 21. The point is that we do not need to compare measured spectrum with calculated one, because we perform model independent analysis and use only ratio of spectra at various distances to averaged spectrum.

Problems with energy spectrum

1. Calculations of reactor flux can be one of the possible reasons for discrepancy. Taking into consideration 0.934 deficiency for an experimental antineutrino flux with respect to the calculated one, we should discuss not the «bump» in 5 MeV area, but the «hole» in 3 MeV area.

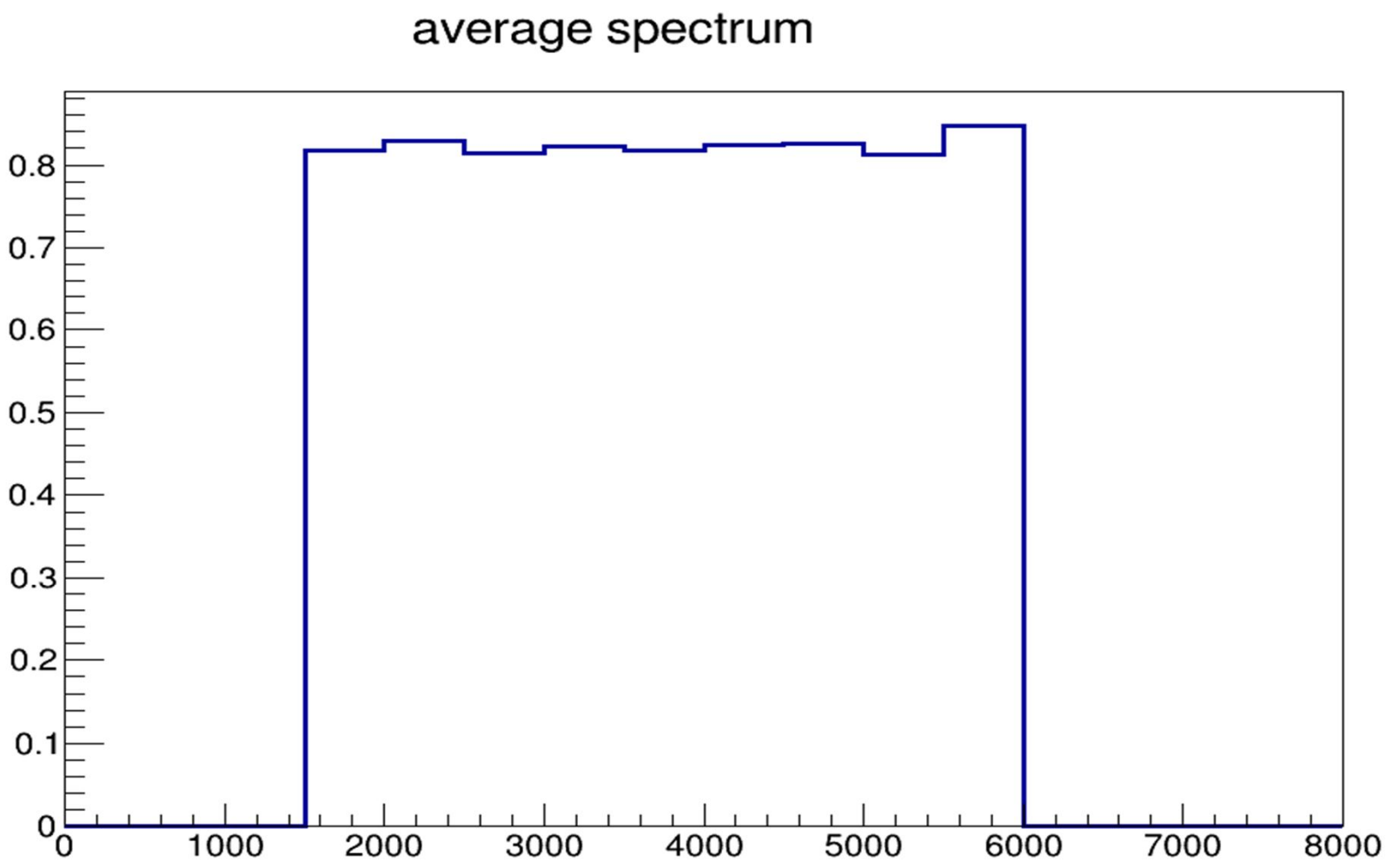
2. We should also consider possibility of systematic errors in calibration of energy scale or Monte-Carlo calculations of prompt signal spectrum in low energy region. There is a problem of precise registration of annihilation gamma energy (511 keV) in adjacent sections. Thus, energy point 1.5 MeV is the most problematic one.

3. Finally, one should take into account influence of oscillations with high Δm^2_{14} because we use 2m interval in analysis. Using such averaging, if $\Delta m^2_{14} > 5eV^2$ then spectrum would be suppressed by factor $1 - 0.5\sin^2 2\theta_{14}$ starting from low energies.

Conclusion: The method of the analysis of experimental data should not rely on precise knowledge of spectrum.

21

The correction of averaged predicted spectrum which appears if we take into account oscillation parameters corresponding to the best-fit.



4. Tom Langford (Yale), Danielle Norcini (Yale). Neutrino-4 uses Gd-doped liquid scintillator (GdLS) similar or identical to that used in the Daya Bay experiment. This GdLS is known to have a non-linear response (i.e. the amount of light produced is not linearly proportional to electron/positron energy deposition). This effect is of order 10-15% at low energies for this material, and is non-zero at all energies. This well establised property of all liquid scintiallators (and well measured for this particular material) is not evident in the calibration curve reported in Fig. 3. How is this explained, or the non-linearlity otherwise accounted for in the Neutrino-4 analysis?

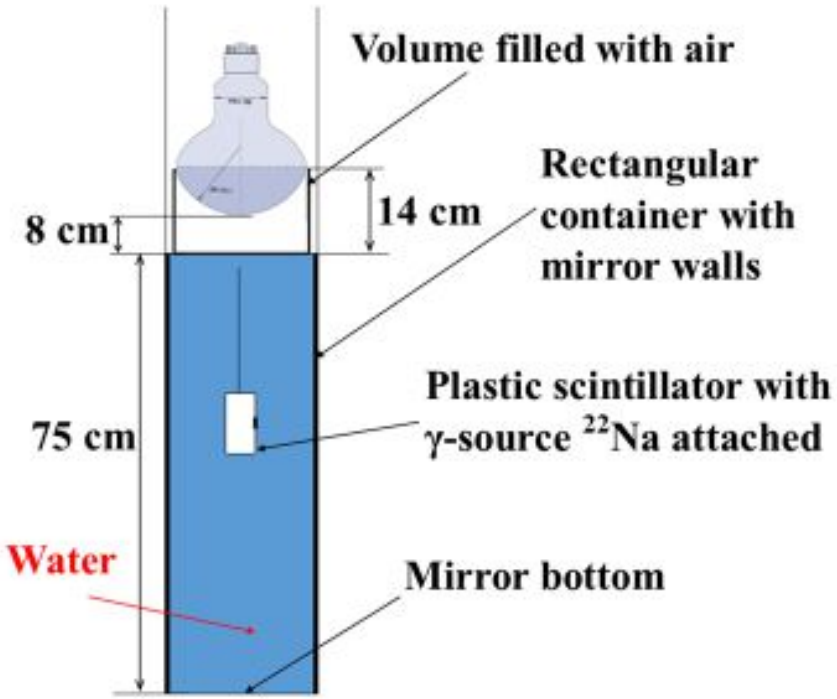
The discussed effect can be observed only with better accuracy of calibration procedure. In our measurements it cannot be observed due to insufficient accuracy.

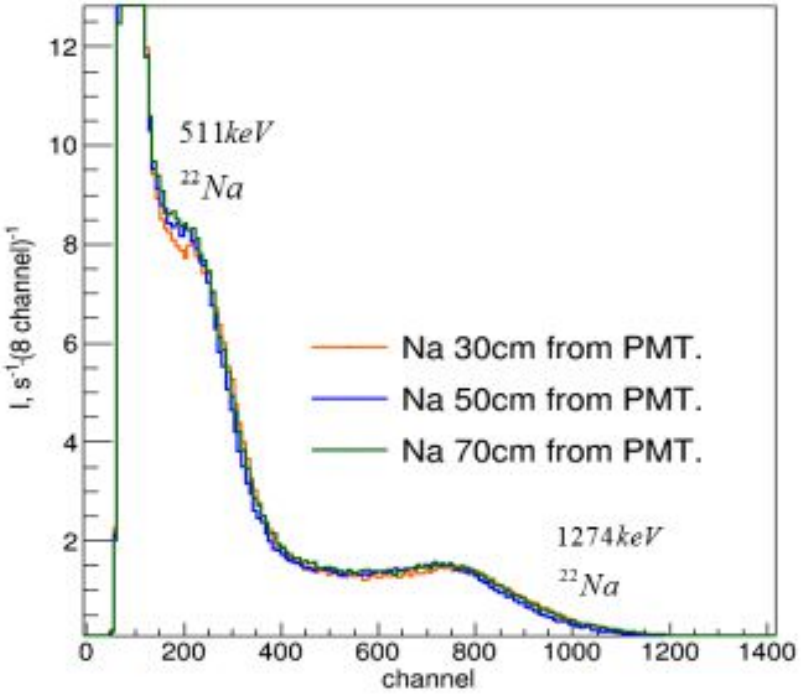
5. Pranava Surukuchi (IIT), Jeremy Gaison (Yale). Based on an oscillation analysis of Reactor OFF data it is stated that there are no instrumental systematic effects. However, no quantative limits are placed on such systematics based on direct studies of detector performance, calibration, detector stability, etc. For example, is the detector response non-uniform, e.g. due to reading out the scintilaltion light from only one end of the detector segments? Or due to the intrinsic non-linearity of the GdLS? Is it the case that no provision for such systematic uncertainties is incorporated into the fitting procedure used to assess compatibility with the existance of a sterile neutrino? How would the chi-squared values be affected if such effects (based on your best estimate) were incorporated in the fitting procedure?

The result of measurements at a distance is an average value of measurements with various rows (segments) and averaged square deviation is 2.5% and this is our instrumental systematic. Problem with one-side readout is solved, more information in slide 13.

Energy calibration on model of single section

We use effect of full internal reflection of light on the border scintillator - air at small angeles to improve the light collection from different distances. Therefore calibration can be done using the sources located outside – above section.



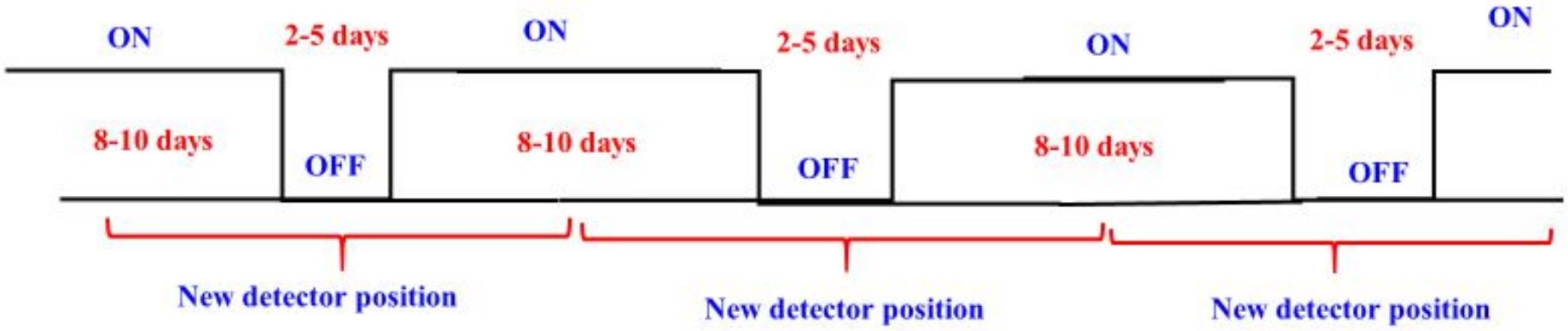


13

Schedule of reactor operating determines the time intervals of measurements at the same position and periods of background measurements, it is shown in slide 18. Frequent cycles of signal and background measurements minimize the effects of background instability.

ON
90 MW

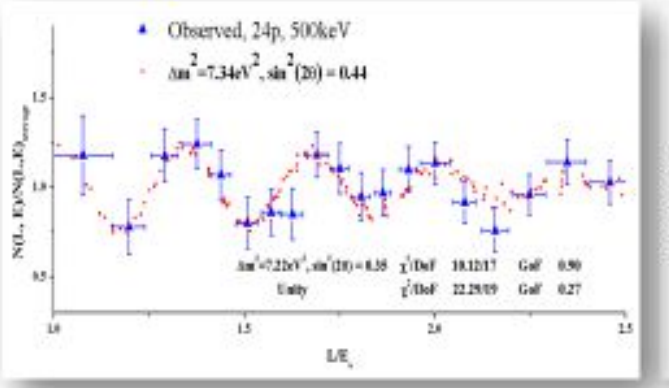
Measurements with the detector have started in June 2016. Measurements with the reactor ON were carried out for 480 days, and with the reactor OFF- for 278 days. In total, the reactor was switched on and off 58 times.

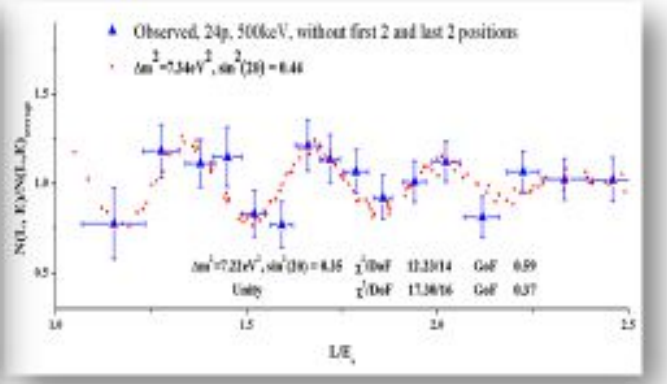


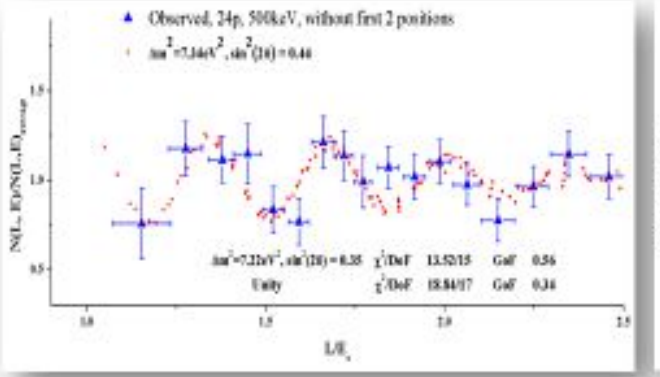
18

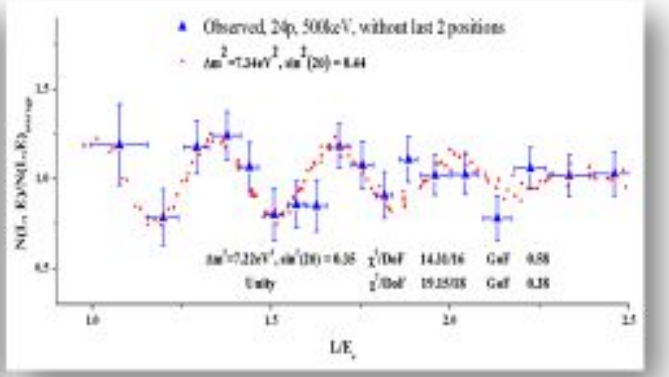
Moreover, we estimated the influence of systematic effects which potentially can simulate the oscillation effect. The result is shown in slide 33

Test of stability of the effect by means of removal of extreme positions









Conclusion

There is no reason to consider that the effect can be caused by structure of the detector. The possibility of averaging of efficiency of various sections by placing them at the same distance is the advantage of our experiment.

6. David Jaffe (BNL). What is the definition of E_i in Equation (2)

E_i – neutrino energy, which is connected to observable energy of prompt signals by equation

$$E_i = E_i^{prompt} + 0.8\mathrm{MeV}$$

7. David Jaffe (BNL). How do you evaluate confidence intervals?

In calculations of CI we use formula:

$$\Delta\chi^2(\sin^2(2\theta_{14}), \Delta m^2_{14}) = \chi^2 - \chi^2_{min} < A,$$

$$(A = 2.30(1\sigma), A = 6.18(2\sigma), A = 11.83(3\sigma))$$

8. Tom Langford (Yale). A comparison of measured and predicted neutrino spectrum in made in Fig. 4. If similar spectral comparison is made between each of the energy calibration sources used to generate Fig. 3, how well do the measurements and detector model predictions agree? How is the resulting energy scale systematic uncertainty incorporated into the fitting procedure used to assess compatibility with the existance of a sterile neutrino?

The method of comparison of measured values with expected within oscillation hypothesis values does not rely on MC calculated spectrum and hence we do not need to perform the comparison of measured and calculated spectra.

9. Seon-Hee Seo (IBS). We would like to know event selection criteria and detection efficiency for each criterion.

We use selection criteria listed below: occurring of two correlated signals – prompt signal in one or two adjacent sections, single delayed signal in interval of 300μs observed in 2-5 sections; total energy of prompt signal is in range 1.5-8MeV; total energy of delayed signal in range 3.2-8MeV. Accidental coincidence background is subtracted.

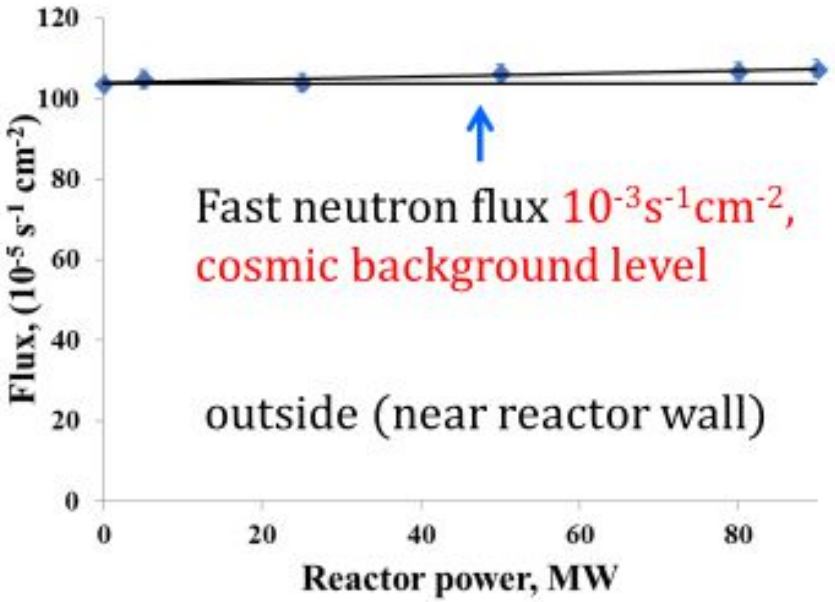
10. Seon-Hee Seo (IBS). Fig.3: no quenching effect is seen. Could you please explain this ?

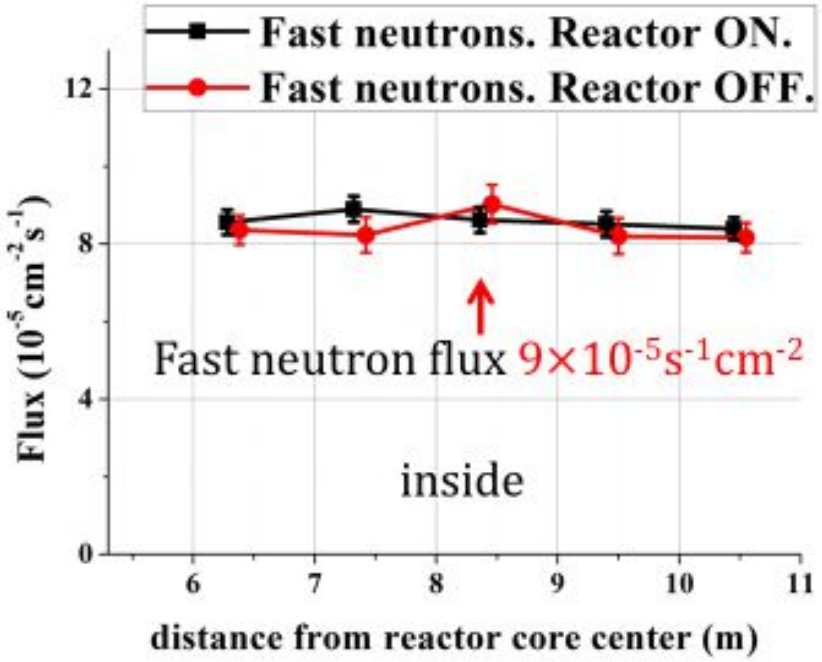
The discussed effect can be observed only with better accuracy of calibration procedure. In our measurements it cannot be observed due to insufficient accuracy.

11. Seon-Hee Seo (IBS). Fig.4: The prompt spectrum seems to contain some accidental background. You assume fast neutron background is the same for any distance, However, if you get close to the reactor, then you would get more fast neutrons (like PROSPECT), and therefore more accidental backgrounds.

We do not observe the difference in fast neutrons background at various distances measured within passive shielding (slide 7).

The background of fast neutrons in passive shielding does not depend neither on the power of the reactor nor on distance from the reactor





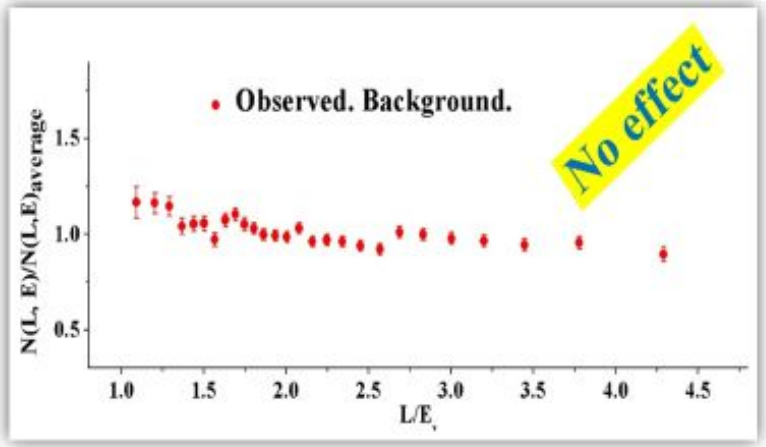
The background of fast neutrons in passive shielding is 10 times less than outside.
The background of fast neutrons outside of passive shielding is defined by cosmic rays and practically does not depend on reactor power.

7

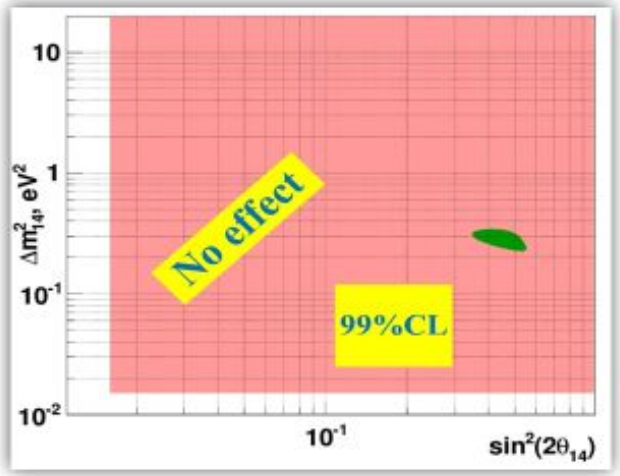
Distribution of fast neutrons background depends on building construction and we can observe it. That fact determines the form of L/E dependence in slide 30. Anyway, both fast neutrons and accidental coincidence backgrounds are measured for each detector position and subtracted. The reason of divergence between MC calculated and measured spectra is not important because we perform model independent analysis.

Test of systematic effects

To carry out analysis of possible systematic effects one should turn off antineutrino flux (reactor) and perform the same analysis of obtained data



data analysis using coherent summation method



analysis of the results on oscillation parameters plane

Thus no instrumental systematic errors were observed.

30

12. Seon-Hee Seo (IBS). Fig.4: What is the corresponding background distribution ?

Spectrum of correlated background is shown in slide 17

Energy spectrum and signal /background ratio

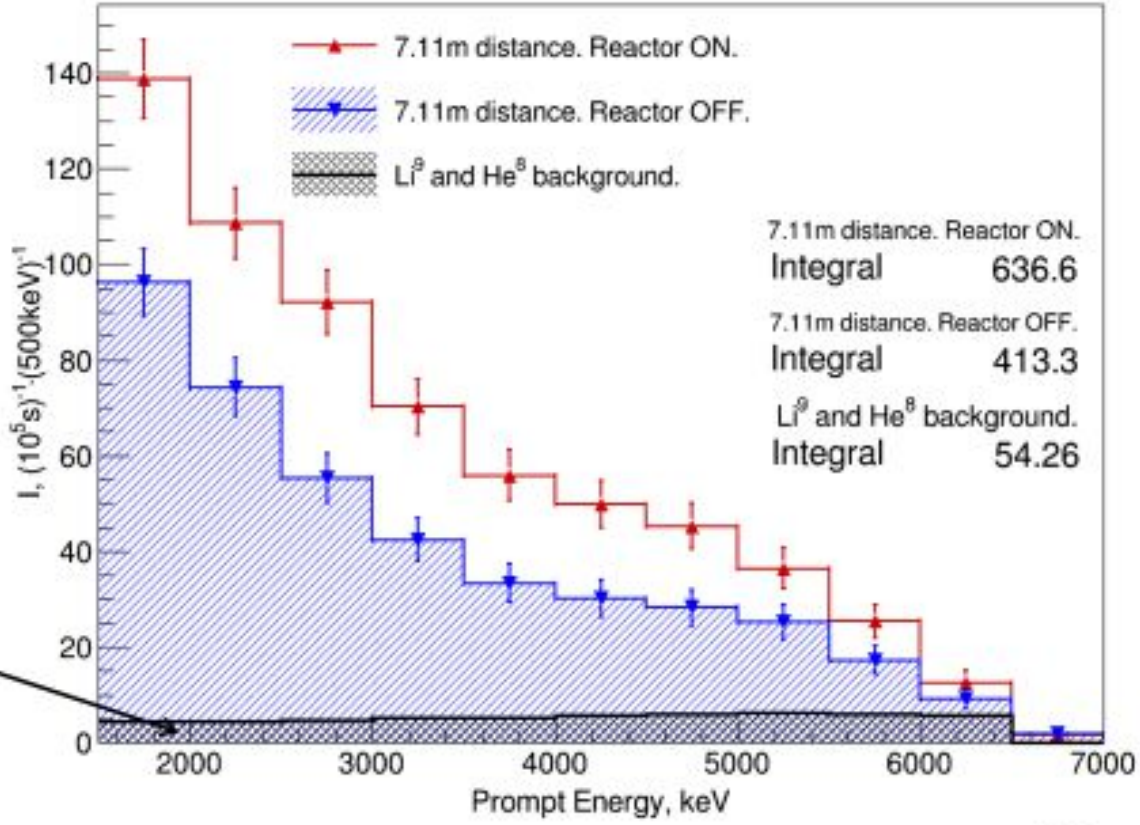
Reactor ON and OFF spectra after 2 months exposition at 7.11m

213 neutrino events/10^5 s

(ON - OFF)

signal /background ratio 0.54

Unavoidable background of Li^9 and He^8 is 54 events/10^5s



17

13. Seon-Hee Seo (IBS). Fig4. I do not see any 5 MeV excess while the paper says it has.

Observation of 5Mev “bump” or “hole” in area 2-3MeV depends on normalization of compared spectra. We think that bump problem should not be considered separately from neutrino deficiency problem, but then excess in 5MeV area turns into the “hole” in 2-3MeV area. We observe the deviation of measured spectrum from expected one but in from of the “hole” in ~ 2-3MeV. Perhaps, we failed to clearly explain it in the article.

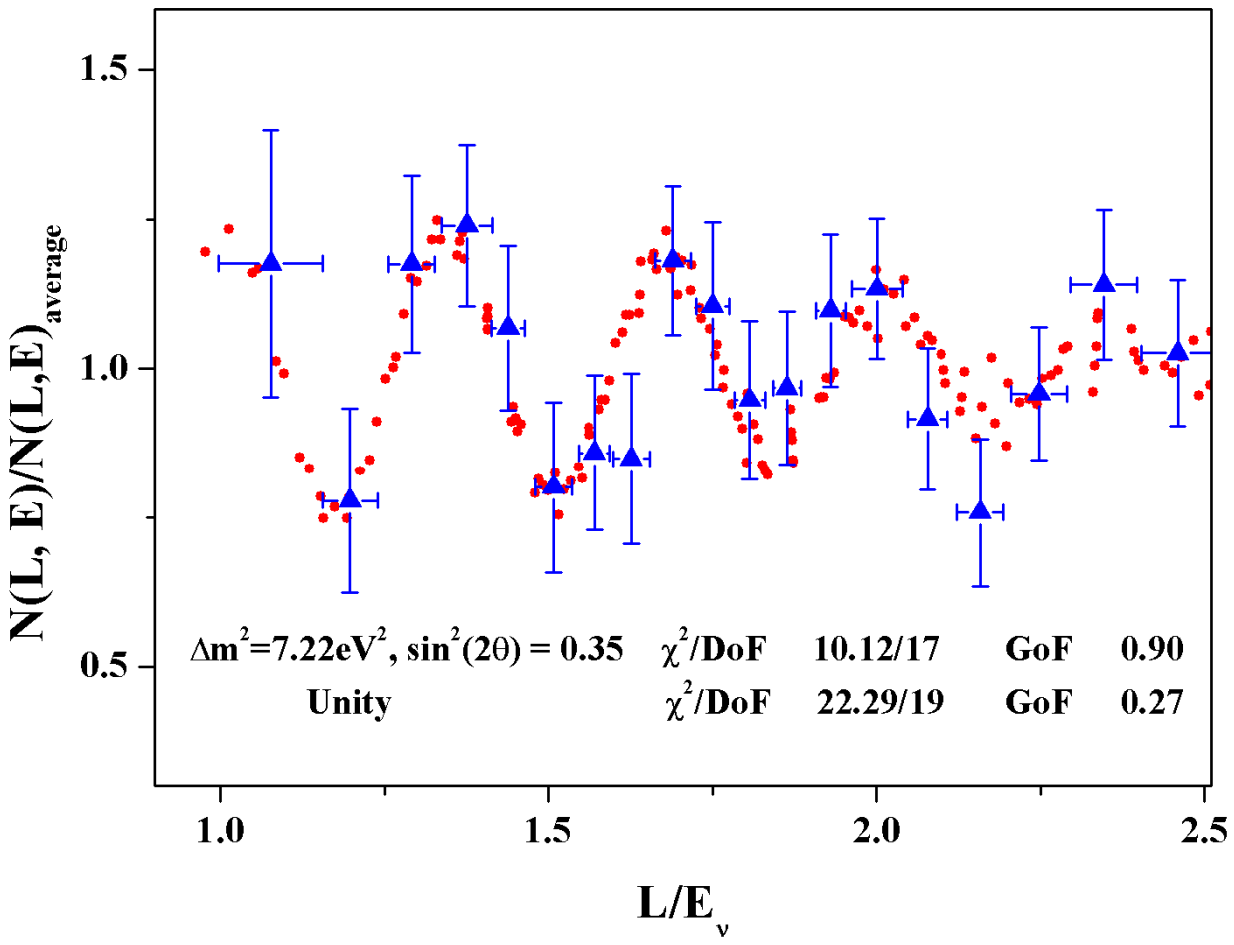
14. Seon-Hee Seo (IBS). Fig. 7: The best fit of sin2(2q14) = 0.35 corresponds to about 17% reduction of the antineutrino flux at average oscillation, and this does not agree with Daya Bay and RENO near detector flux deficit less than 10%.

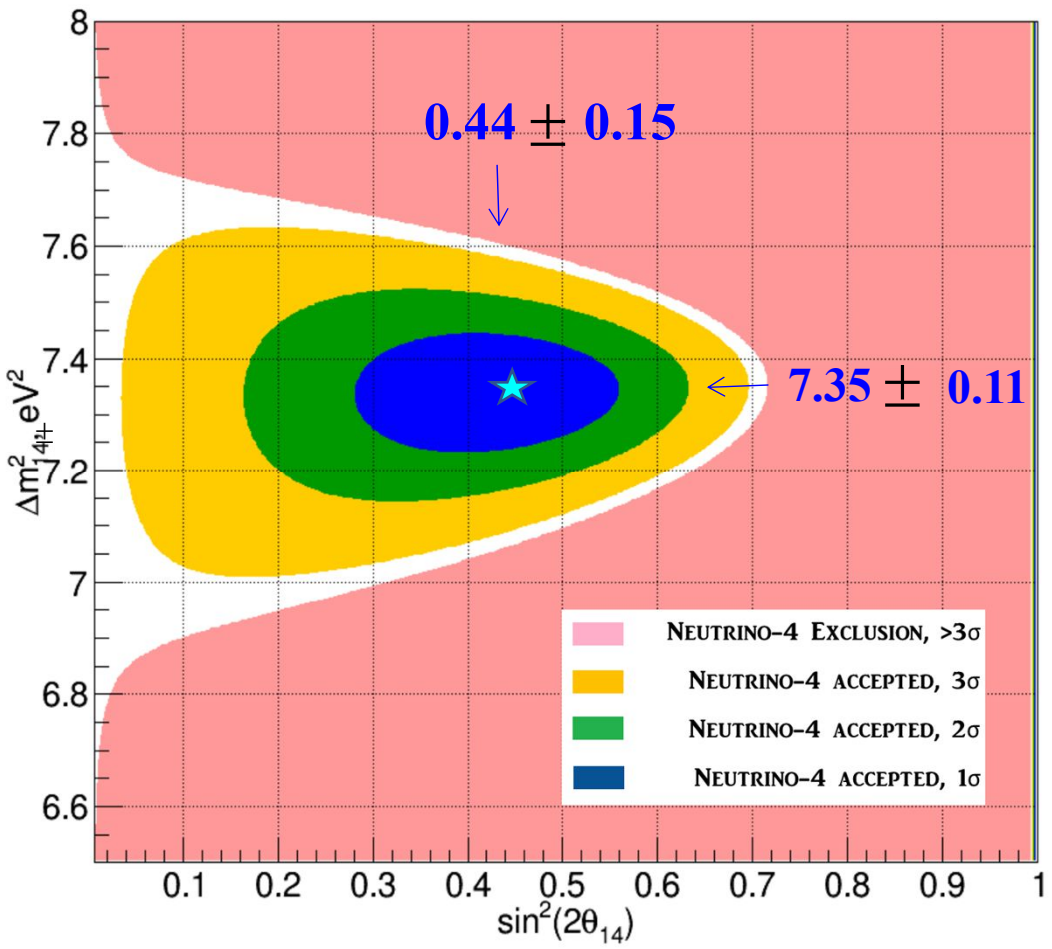
The observation of deficiency at large distances is based on comparison with calculated antineutrino flux. The limit on $\sin^2(2\theta_{14})$ obtained in Daya Bay is $\sin^2(2\theta_{14}) < (0.25 \pm 0.15)$. We obtained $\sin^2(2\theta_{14}) = (0.44 \pm 0.15)$. Therefore, the difference between these values does not exceed $\Delta = (0.19 \pm 0.21)$ one standard deviation.

15. Seon-Hee Seo (IBS). According to Fig.6 b, the best fit of sin2(2q14) looks 0.43 which causes even more flux reduction. Also dm2_41 best fit seems to be 7.35 eV2 in Fig.6 b rather than 7.2 eV2 which is at the 2 sigma region in Fig. 6 b. Why the best fit values of Fig. 6 b and Fig.7 do not match ?

You are certainly right, it was incorrect to declare that values 7.2eV^2 и 0.35 correspond to the best fit in fig.7. Actual best fit values are

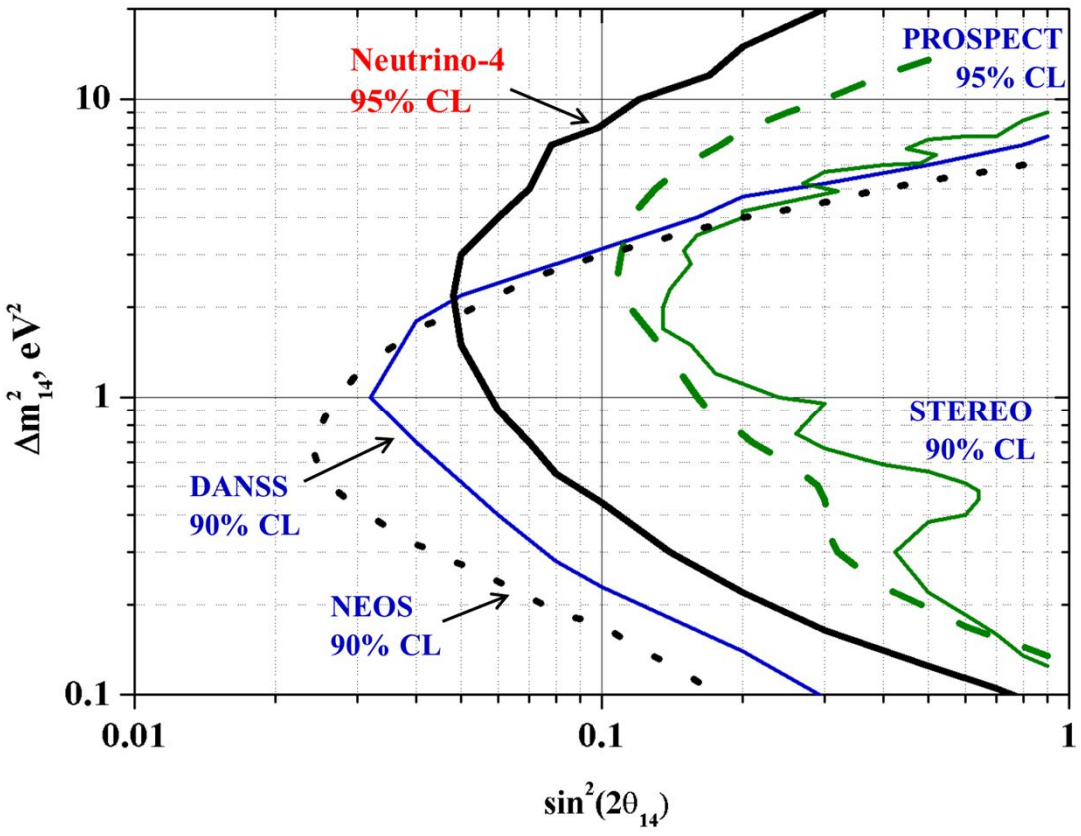
$$\sin^2(2\theta_{14}) = 0.44, \Delta m_{14}^2 = 7.35\mathrm{eV}^2$$


N(L, E)/N(L,E)average
1.5
1.0
0.5
Δm²=7.22eV², sin²(2θ) = 0.35 χ²/DoF 10.12/17 GoF 0.90
Unity χ²/DoF 22.29/19 GoF 0.27
1.0
1.5
2.0
2.5
L/Eν


0.44 ± 0.15
7.35 ± 0.11
Δm²14 eV²
8
7.8
7.6
7.4
7.2
7
6.8
6.6
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
sin²(2θ14)
Neutrino-4 Exclusion, >3σ
Neutrino-4 accepted, 3σ
Neutrino-4 accepted, 2σ
Neutrino-4 accepted, 1σ

16. Seon-Hee Seo (IBS). Fig.8: The red satellite points in 2~2.5 L/E are due to background according to the paper. However, there is almost no background in 2~2.5 L/E in Fig. 9. Could you please explain this ?

Red points in fig.8 correspond to expected values and have no connection with background. The question is unclear.

17. Seon-Hee Seo (IBS). Fig.10: X and Y axis labels are swapped by mistake or do I misunderstand something ?

That is certainly a mistake, thank you for noticing it.