Search for sterile neutrinos at RENO

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On behalf of the RENO collaboration

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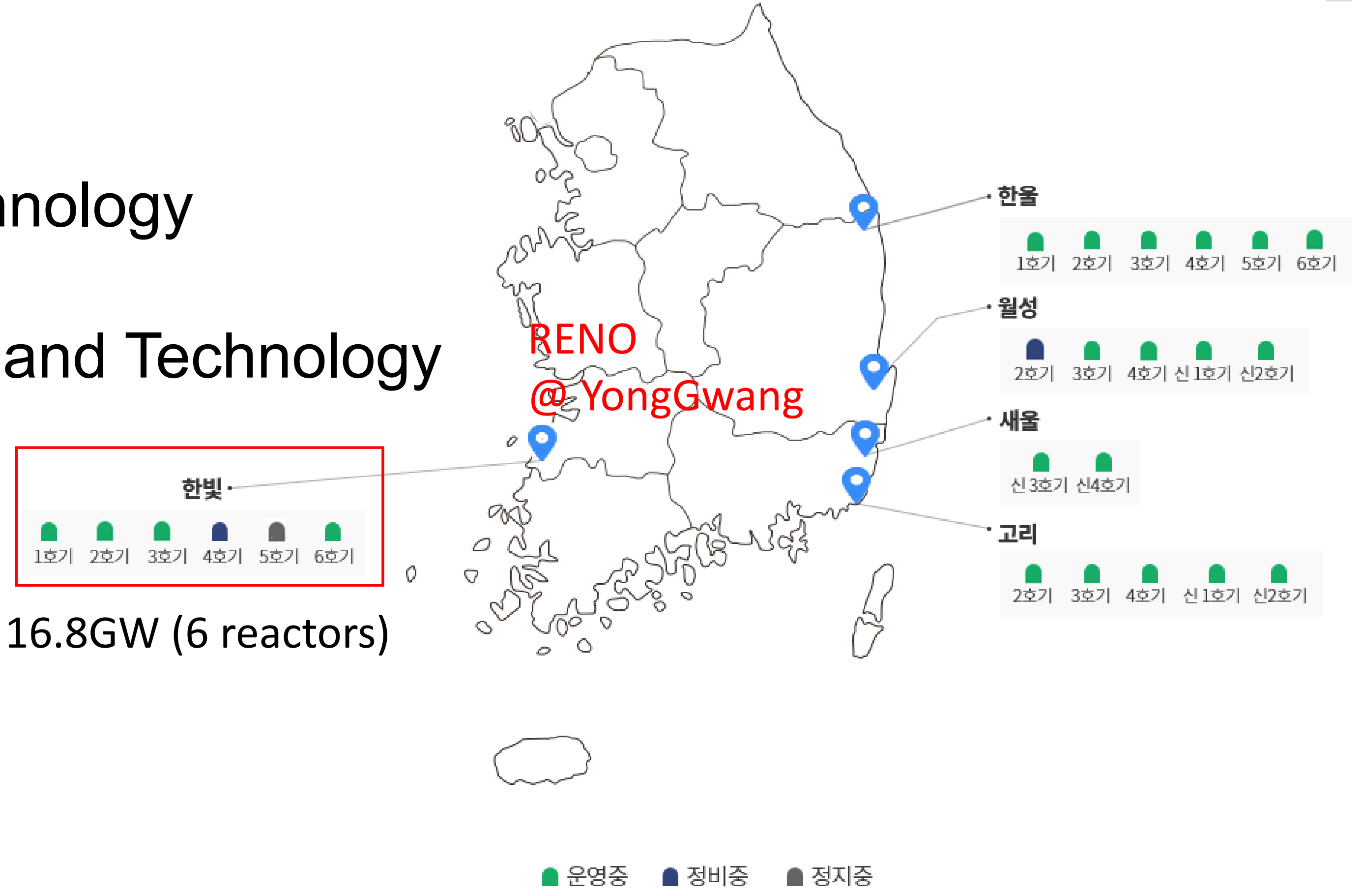
RENO Collaboration

Reactor Experiment for Neutrino Oscillation

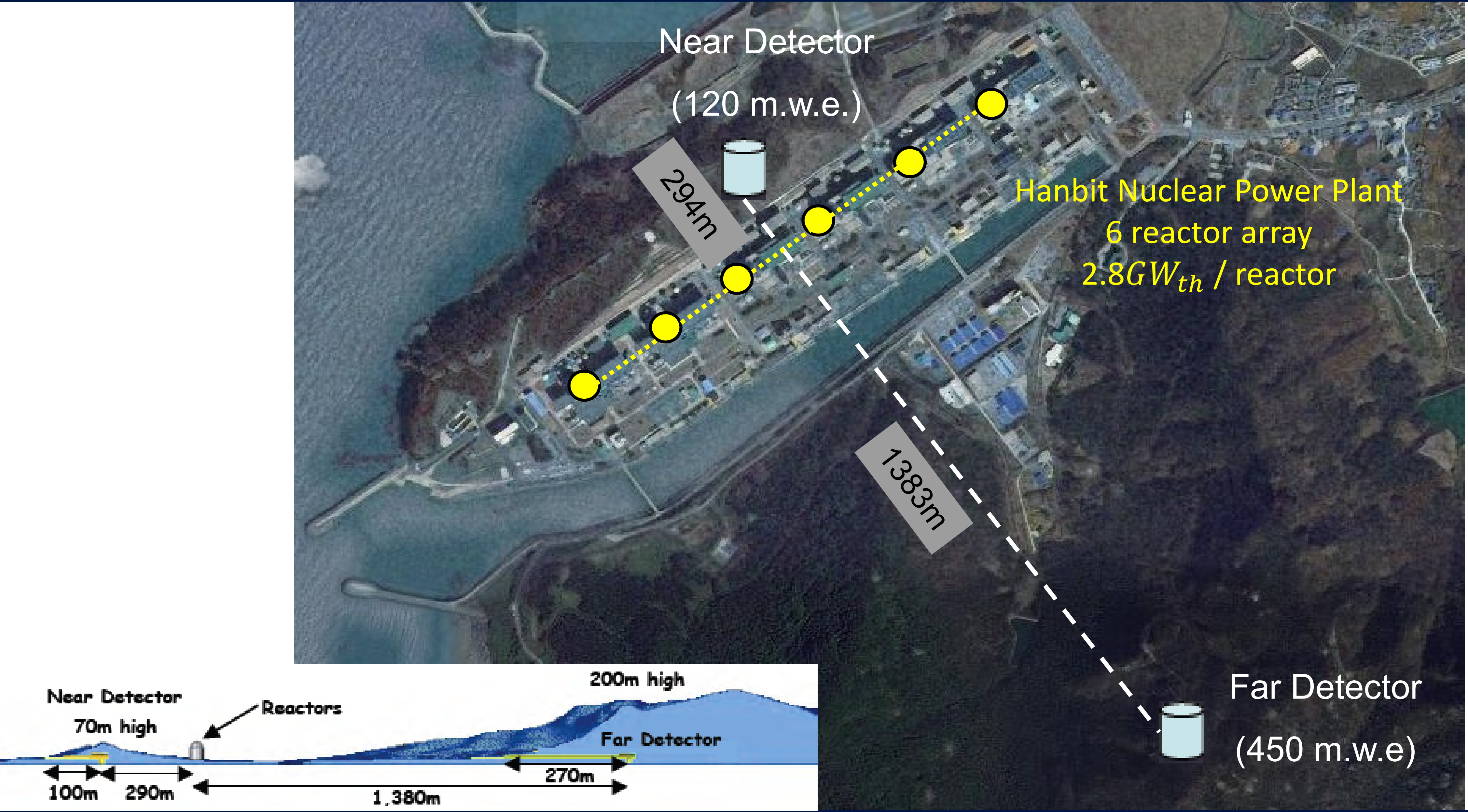
(9 institutions and 30 physicists)

- Start of project : 2006
- The first experiment running with both near & far detectors from Aug. 2011

- Chonnam National University
- Dongshin University
- Gwanju Institute of Science and Technology
- Gyeongsang National University
- Korea Advanced Institute of Science and Technology
- Kyungpook National University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University



RENO experimental site



Search for **light sterile neutrino**

- ✓ **Light sterile neutrino** : A promising solution to explain experimental anomalies (RAA, Gallium, LSND & MiniBooNE)
- ✓ Sterile neutrino gives an explanation for the origin of extremely light neutrino mass. (Albeit we need to extend the standard *see-saw* mechanism a bit to include both light and heavy sterile neutrino)
- ✓ However, sterile neutrino models currently fail to account for all of anomalies simultaneously.

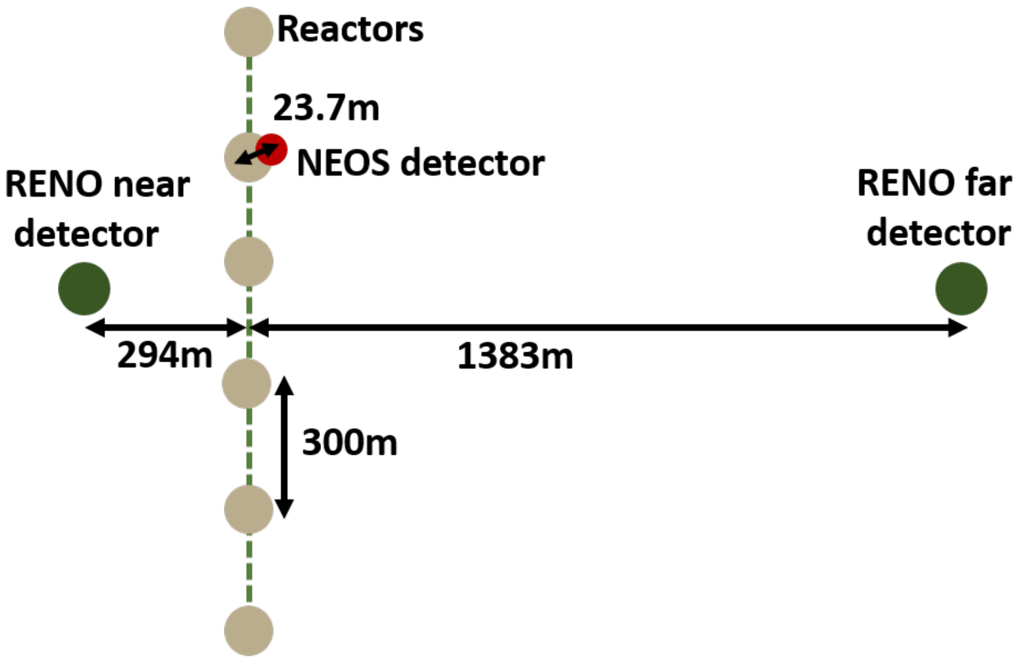
Sensitivity for sterile neutrino search

✓ 3+1 active - sterile neutrino mixing

$$P_{\bar{\nu}_e \to \bar{\nu}_e} \simeq 1 - \sin^2 2\theta_{13} \sin^2\left(1.27\Delta m^2_{31} \frac{\boldsymbol{L}}{\boldsymbol{E}}\right) - \sin^2 \boldsymbol{2\theta_{14}} \sin^2\left(1.27\boldsymbol{\Delta m^2_{41}} \frac{\boldsymbol{L}}{\boldsymbol{E}}\right)$$

✓ L/E determines the sensitivity

Detectors	Baselines (m)					
	R1	R2	R3	R4	R5	R6
Near	660	445	302	339	520	746
Far	1564	1461	1398	1380	1409	1483

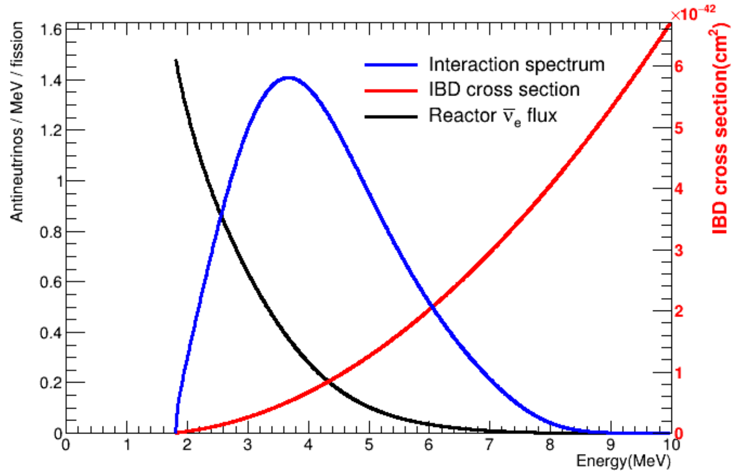


L (m)

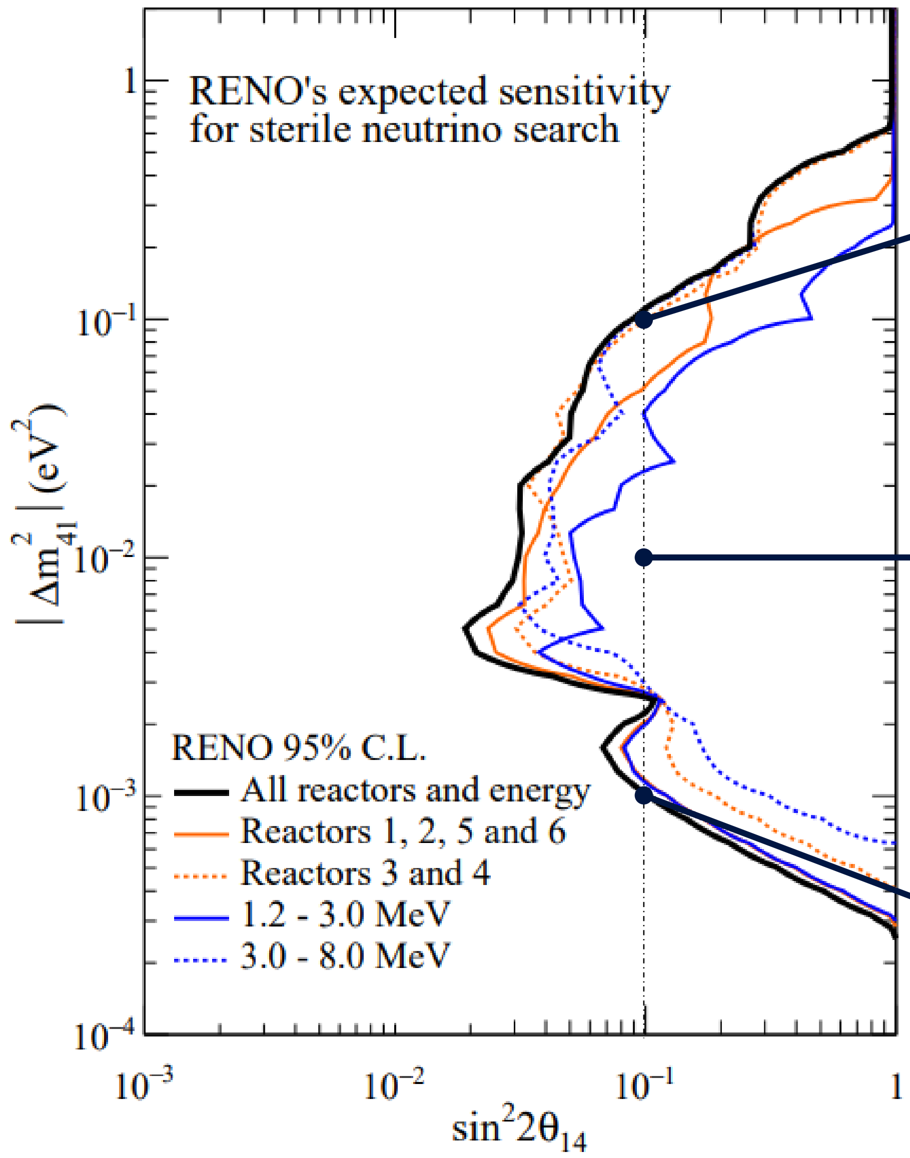
Reactor to NEOS : ~24m
Reactor to RENO (near) : ~400 m
Reactor to RENO (far) : ~1400 m

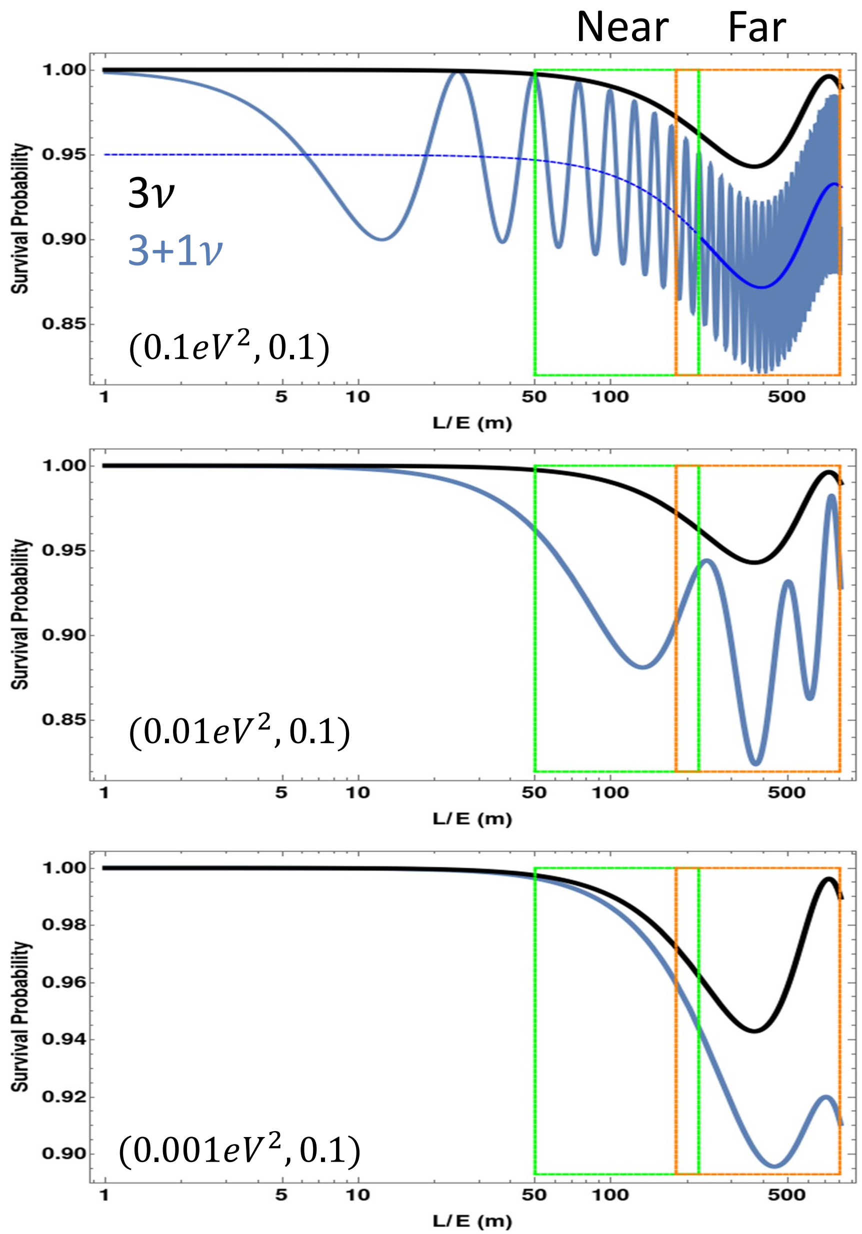
E (MeV)

Neutrino spectrum : 1.8 ~ 10 MeV



Expected sensitivity of RENO's sterile neutrino search



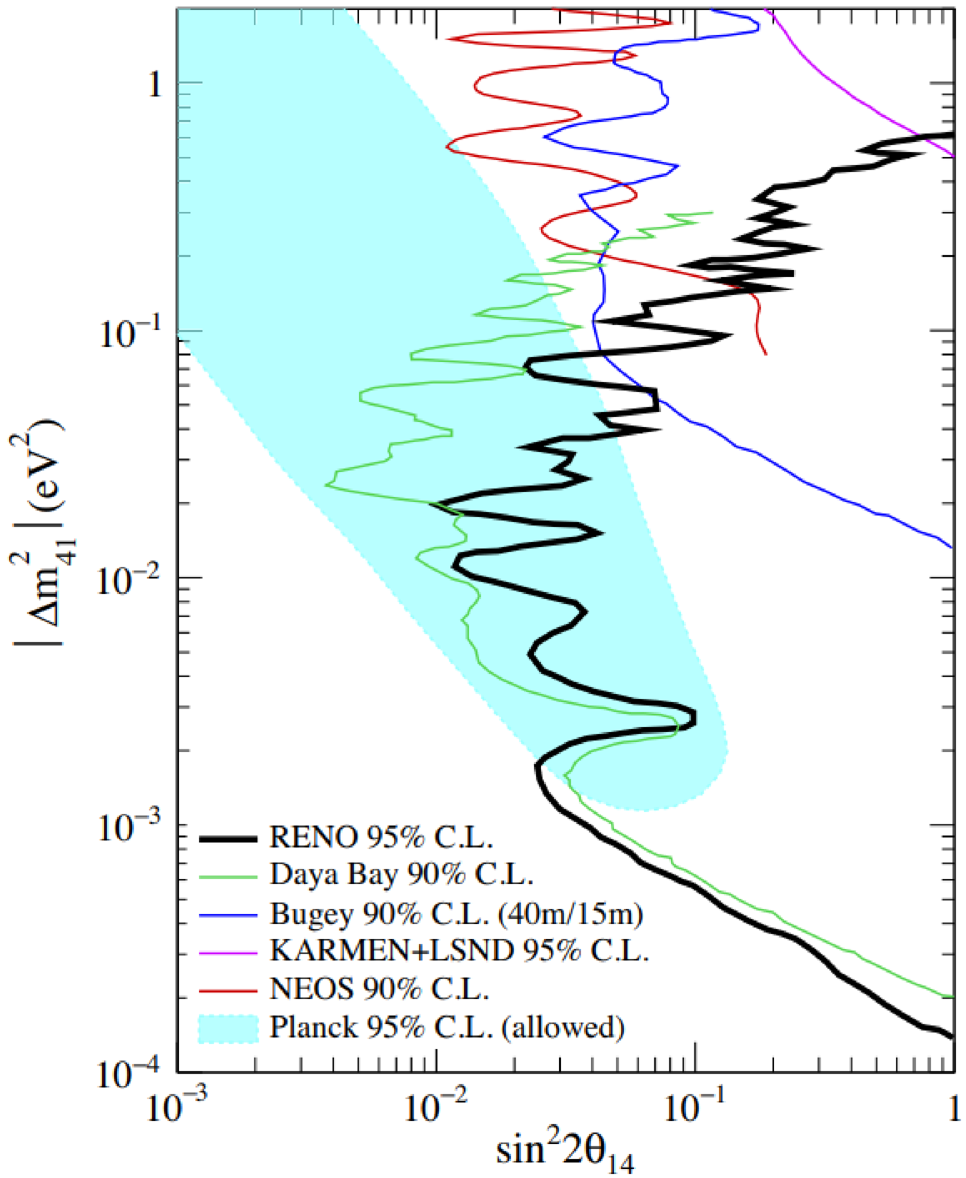


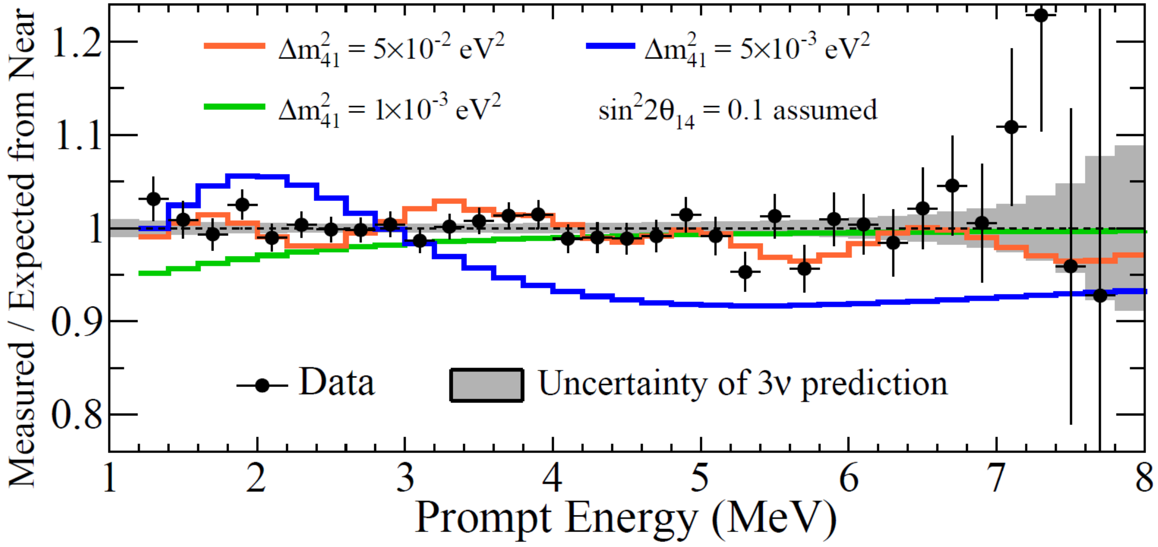
- Long **L**
  (Reactor 1,2,5 and 6)
- Low **E** (1.2~3 MeV)

- Medium **L**
- Medium **E**

- Short **L**
  (Reactor 3 and 4)
- High **E** (3~8 MeV)

Results : **Sub-eV sterile neutrino search** at RENO



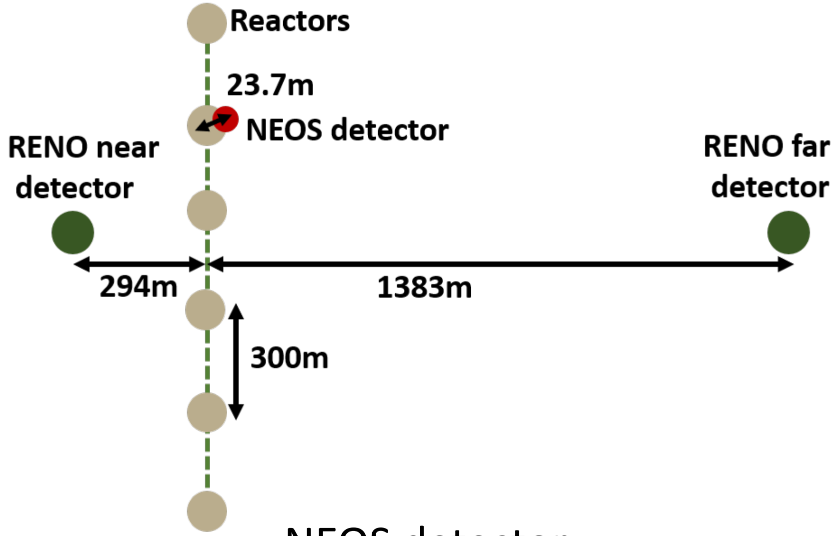


- 2200 days of RENO far / near data
- Excluded $10^{-4} \lesssim |\Delta m^2_{41}| \lesssim 0.5\ eV^2$
- No significant evidence for a sterile neutrino oscillation
  ($\Delta\chi^2 = 1.4$, p-value = 0.87)

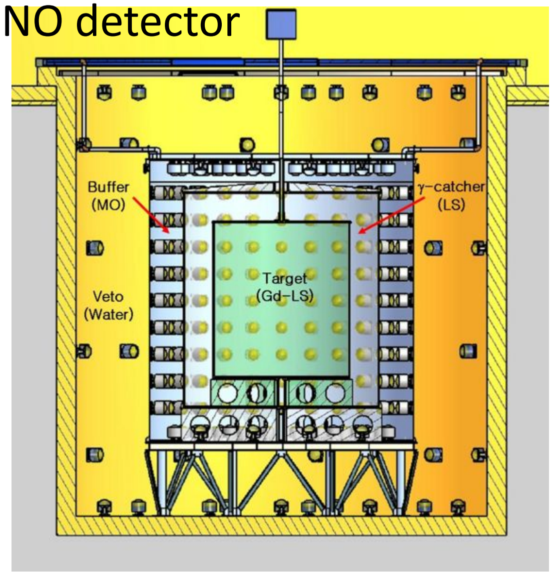
Phys. Rev. Lett. 125 (2020), 191801

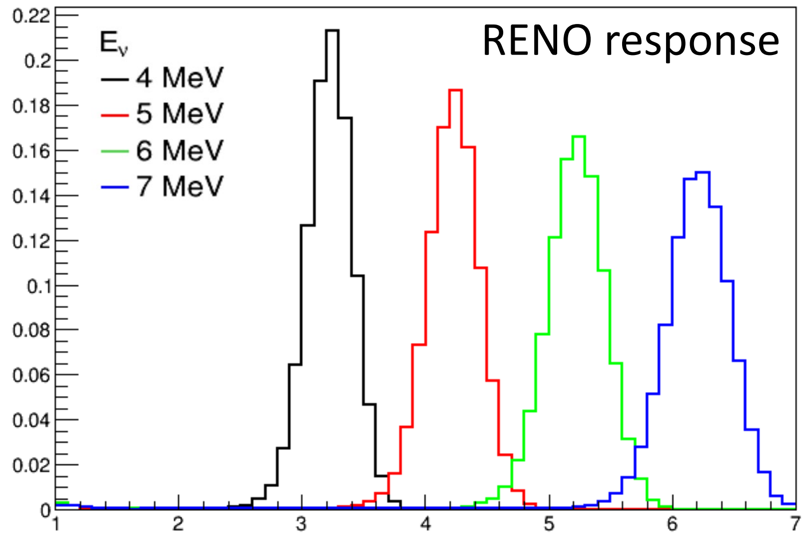
RENO + NEOS joint sterile neutrino search (In progress)

✓ **We share the same reactor source but have different detector response**



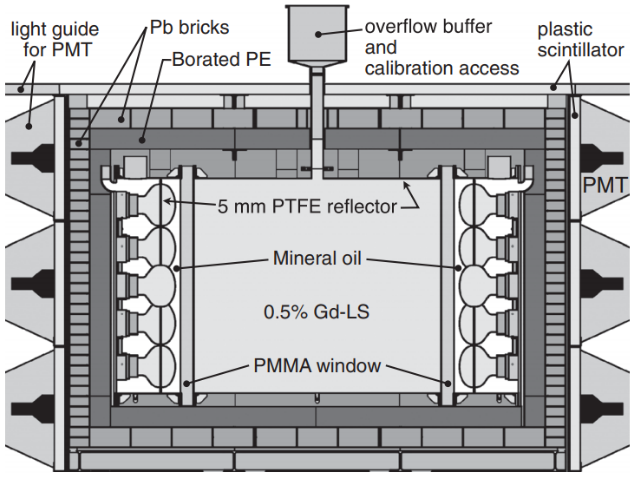
RENO detector

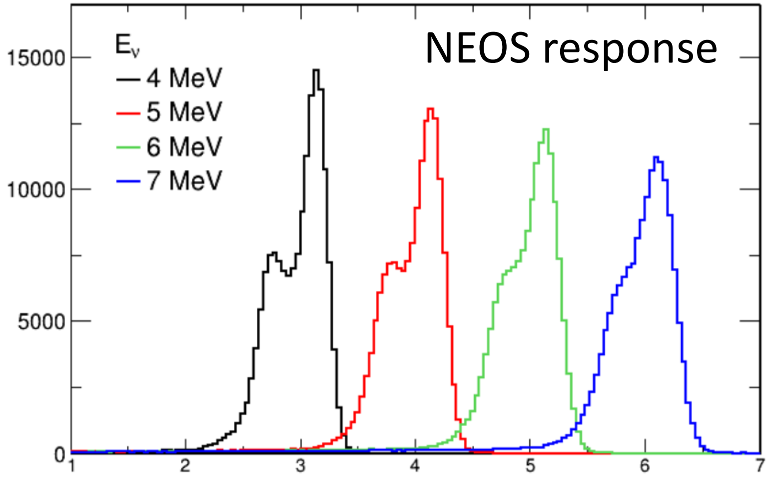




NEOS detector

Yoomin Oh, ERICE 2017





Phys. Rev. Lett. 118, 121802

Search scheme

- ✓ **Spectral shape comparison** to see the possible shape distortion due to active - sterile neutrino oscillation

Convolution with NEOS response

- ✓ **(Ingredient 1)** RENO prompt -> neutrino spectrum -> expected prompt spectrum at NEOS

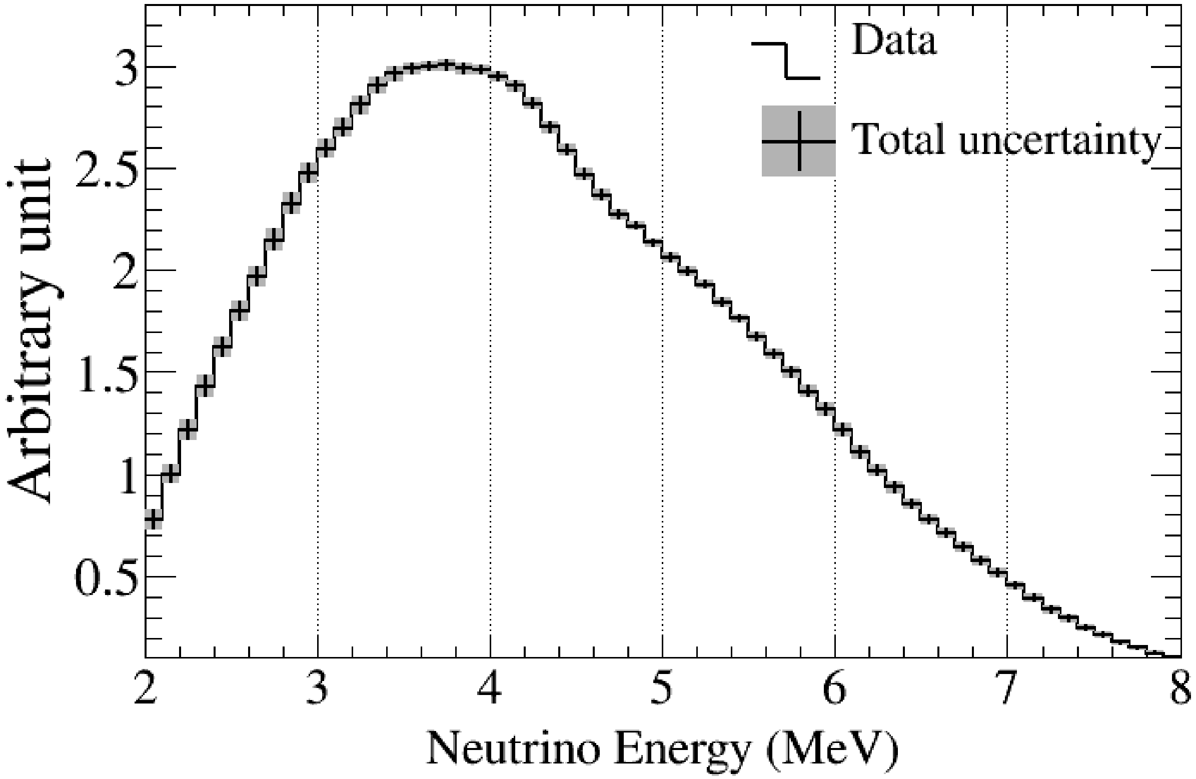
Deconvolution(unfolding)

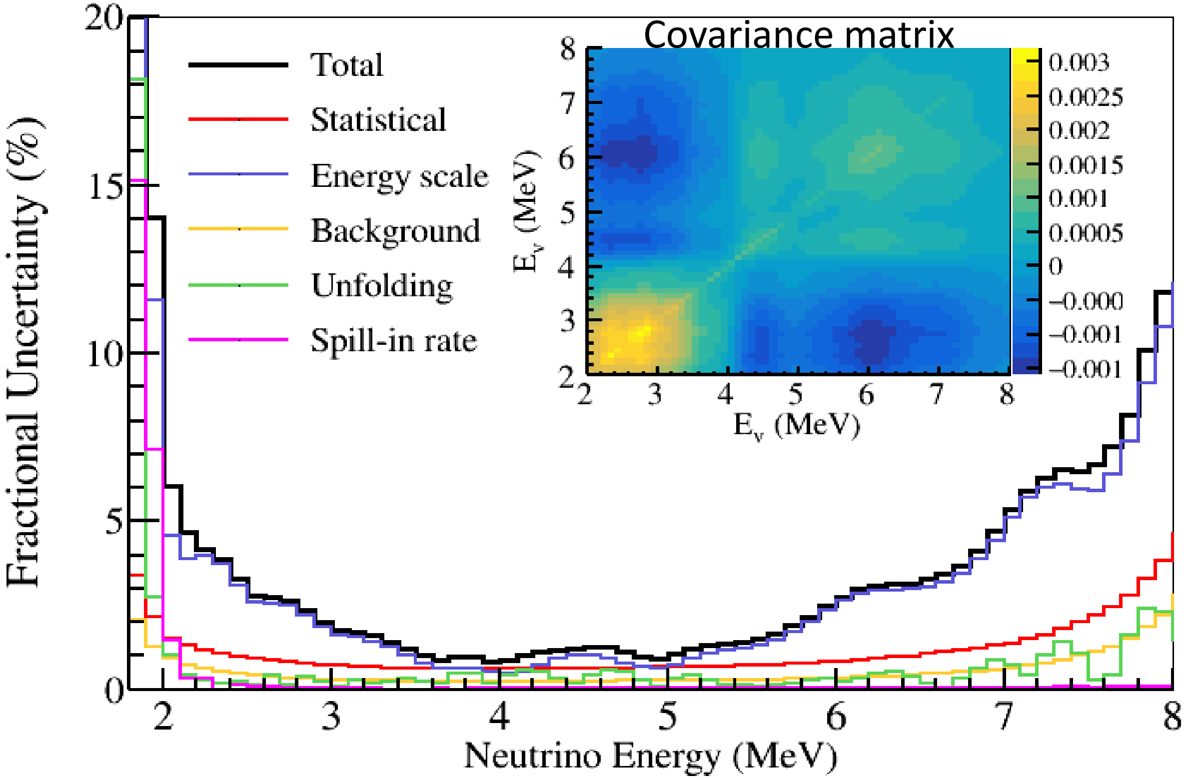
- ✓ **(Ingredient 2)** Measured spectrum of NEOS

- ✓ Vise versa gives equivalent results

Unfolded spectrum (Using Iterative Bayesian Unfolding)

- ✓ Using the Bayesian formula, IBU iteratively updates the prior neutrino spectrum according to the data
- ✓ Systematic uncertainties are considered with the covariance matrix
- ✓ Energy scale is the most dominant error source

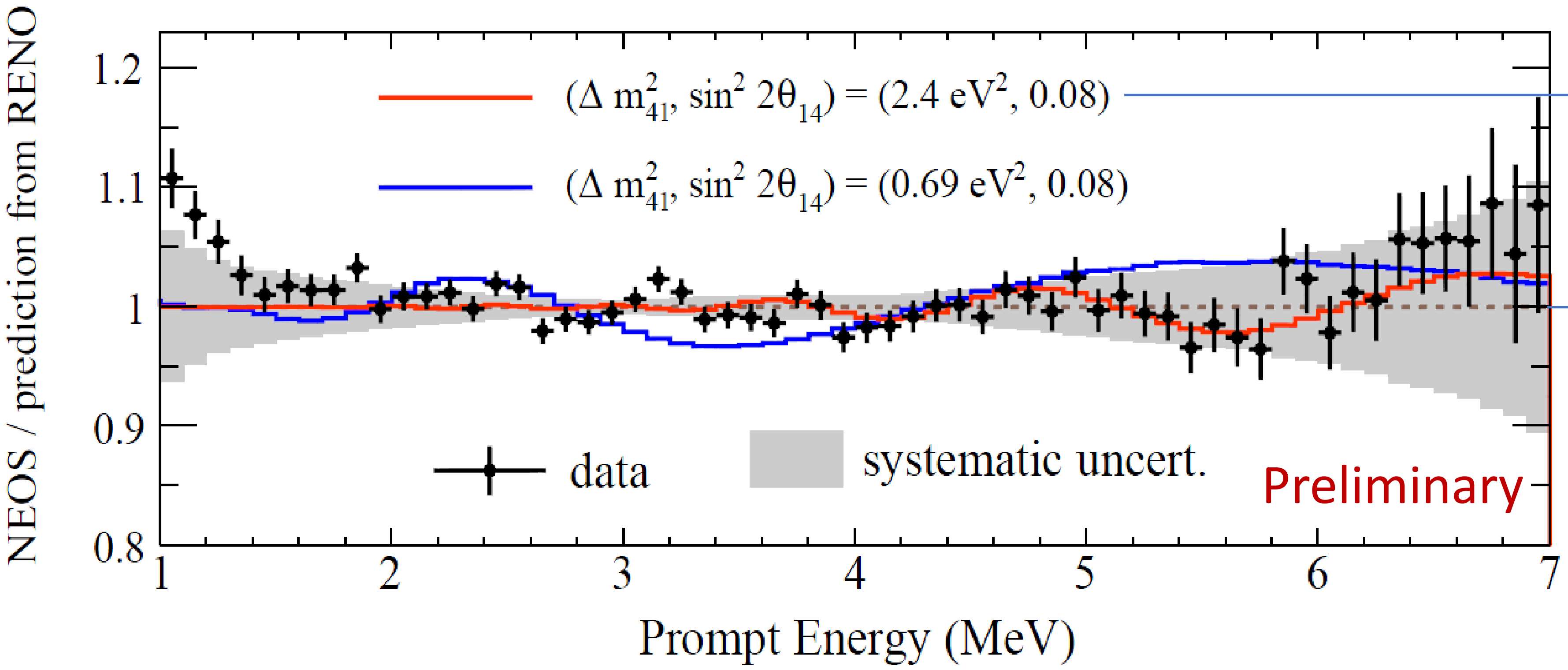




Spectral-only comparison

✓ RENO expected prompt spectrum at NEOS

vs. measured prompt spectrum at NEOS

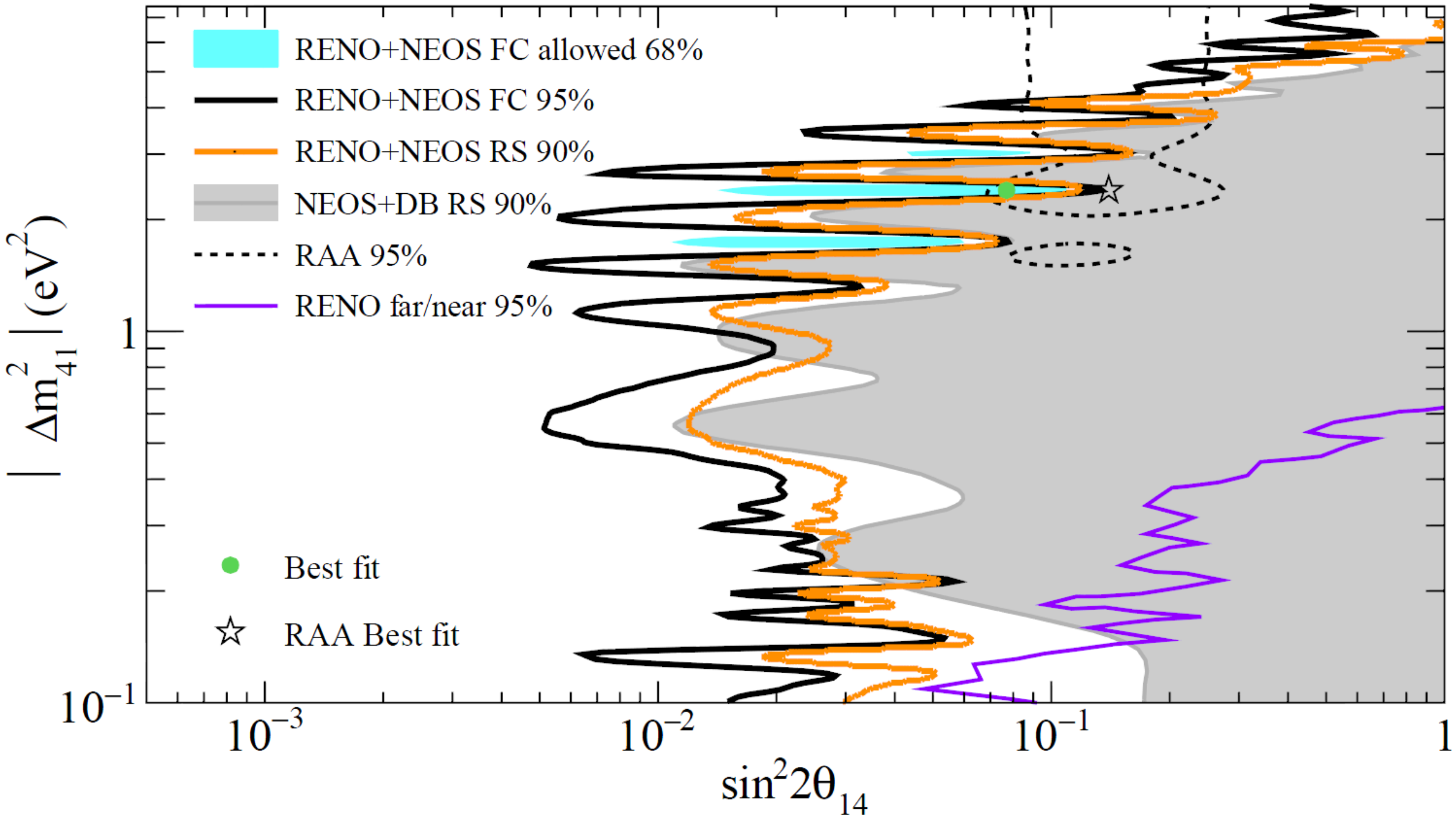


Best fit χ^2 /NDF
= 47.45 / 58

χ^2/NDF
with 3ν (flat ratio)
= 56.24 / 60

RENO+ NEOS **excluded & allowed** region

Preliminary



Best fit at (0.08 , $2.4eV^2$)
4ν Minimum χ^2 : 47.45 / 58
3ν ($\sin^2 2\theta_{14} = 0$) χ^2: 56.24 / 60
$\Delta\chi^2 = 8.8$
P-value : 8.5%

- ✓ Feldman and Cousins method excludes more space than raster scan method except near the best-fit parameter
- ✓ Best-fit parameter is consistent with RAA allowed region

Summary and Conclusion

- **Search for sub-eV sterile neutrino at RENO gives a null result**
  - Excluded $10^{-4} \lesssim \left|\Delta m^2_{41}\right| \lesssim 0.5\ eV^2$

- **Sterile neutrino search using RENO and NEOS data**
  - Best fit ($\Delta m^2_{41} = 2.4eV^2,\ sin^2 2\theta_{14} = 0.08$) is consistent with the RAA allowed region
  - 95% excluded limit : $10^{-3}\mathrm{eV}^2 < \ \Delta m^2_{41} < 7eV^2$ (p-value $\sim 8.5\%$)

RENO & NEOS collaboration list

✓ **RENO and NEOS joint analysis for sterile neutrino search is launched!**

RENO

Reactor Experiment for Neutrino Oscillation

(9 institutions and 30 physicists)

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- Kyungpook National University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

- Start of project : 2006

✚

NEOS Collaboration

- **N**eutrino **E**xperiment for **O**scillation at **S**hort baseline
- 20 Researchers from 8 institutes in Korea
  - Chonnam National University
  - Chung-Ang University
  - Institute for Basic Science (IBS)
  - Korea Research Institute of Standard and Science (KRISS)
  - Korea Atomic Energy Research Institutes (KAERI)
  - Kyungpook National University
  - Sejong University
  - University of Science and Technology

Center for Underground Physics   KRISS 한국표준과학연구원   KAERI   UST

- Project launched in 2012

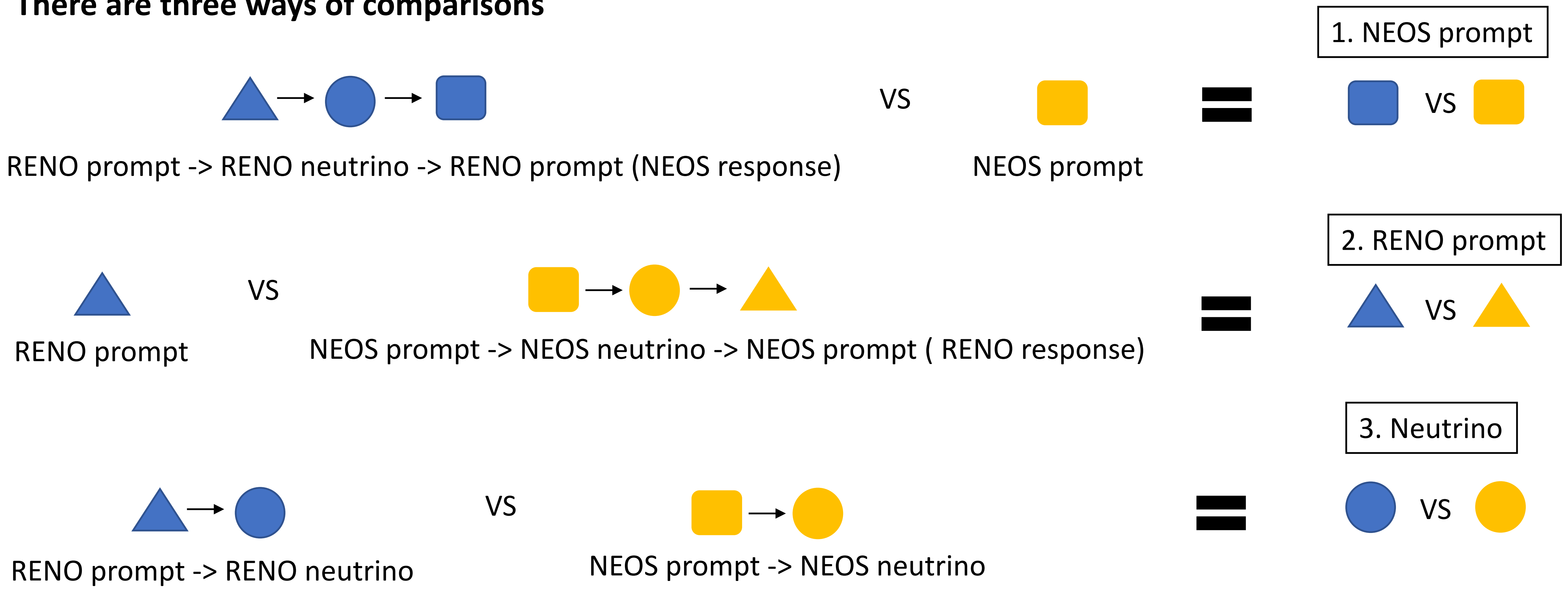
Thank you!

Palazzo bo : https://www.expedia.co.kr/University-Of-Padova-Historic-Centre.d6105070.Place-To-Visit?pwaLob=wizard-package

Back up slides

Search scheme

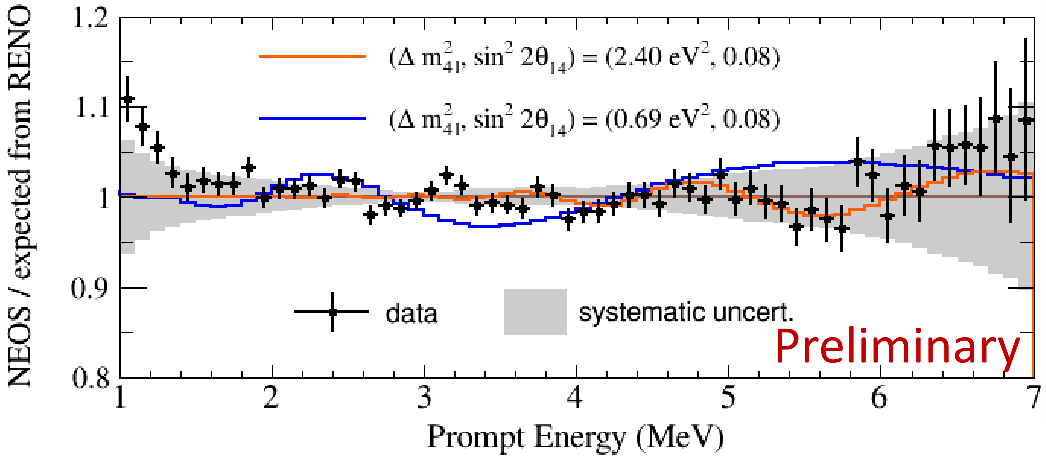
There are three ways of comparisons



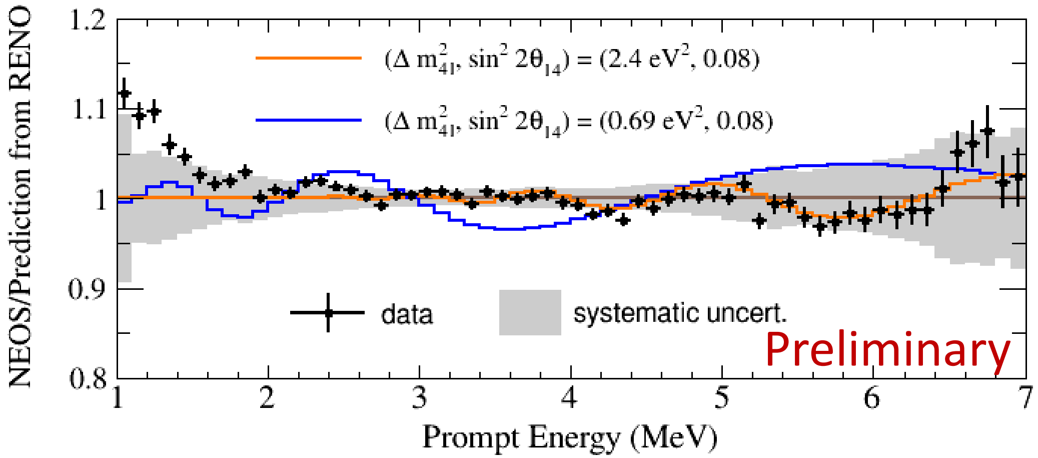
※ Sterile neutrino search using both neutrino spectrum requires caution because we imposed smooth function constraint when unfolding. It is safe to compare in prompt spectrum to test the hypothesis.

Ratio comparisons

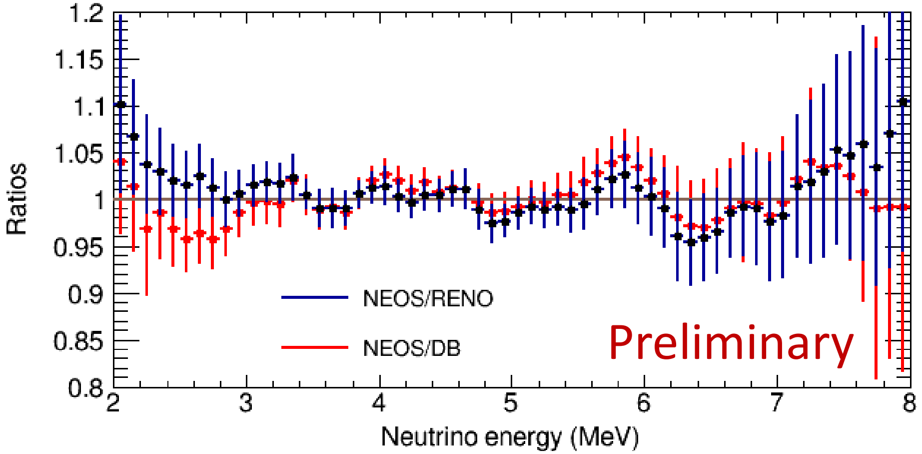
1. NEOS prompt VS



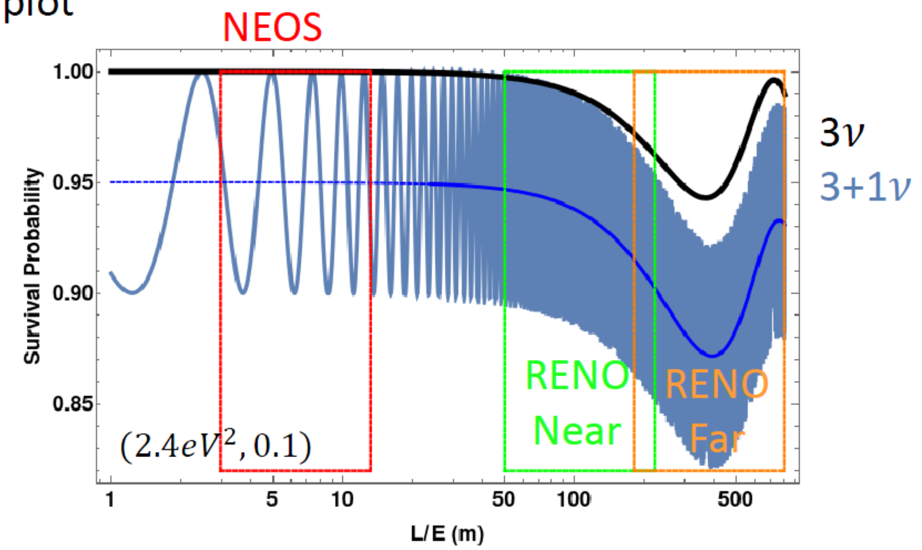
2. RENO prompt VS



3. Neutrino VS

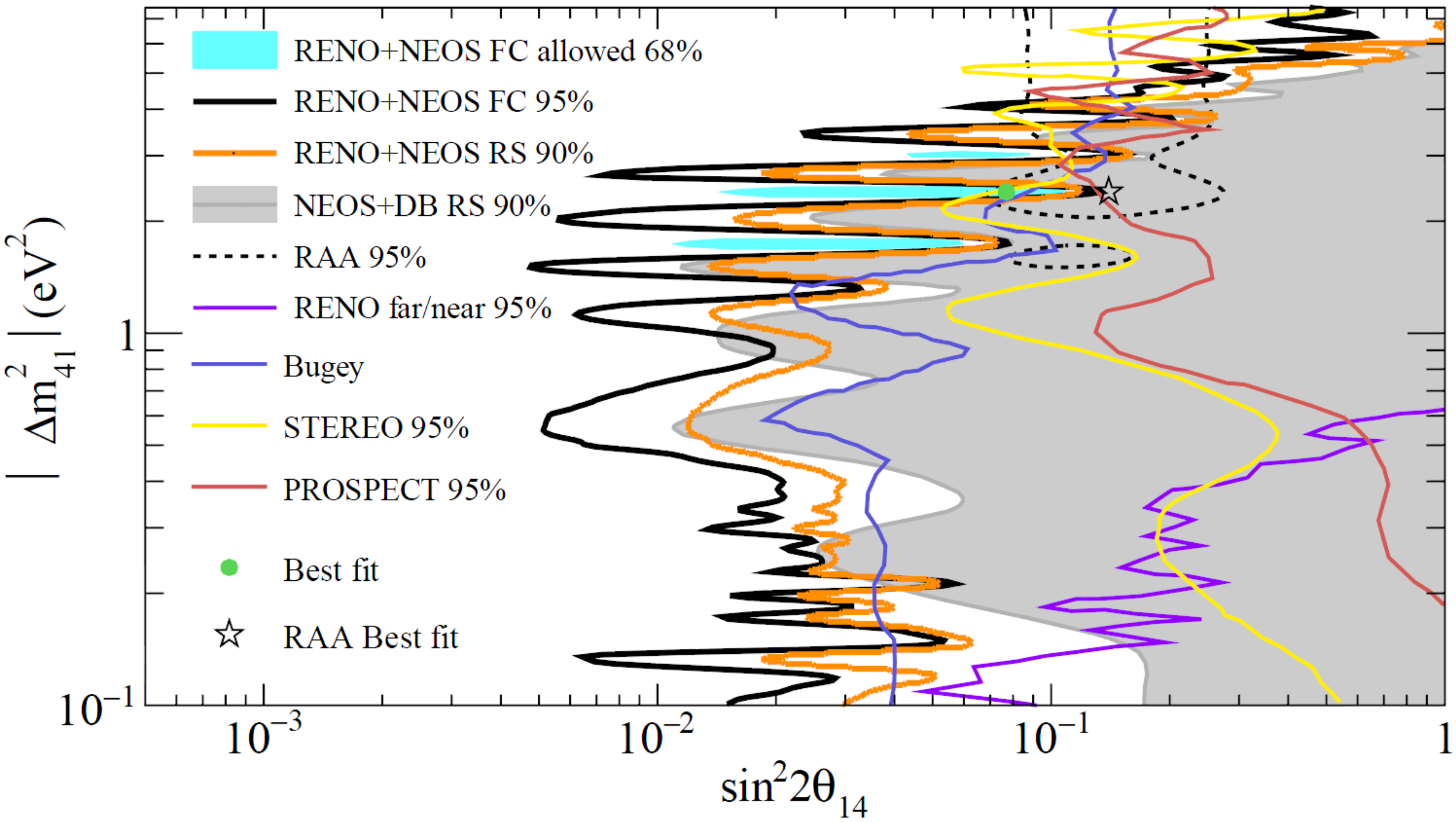


L/E plot



Exclusion contour (with other experiments)

Preliminary



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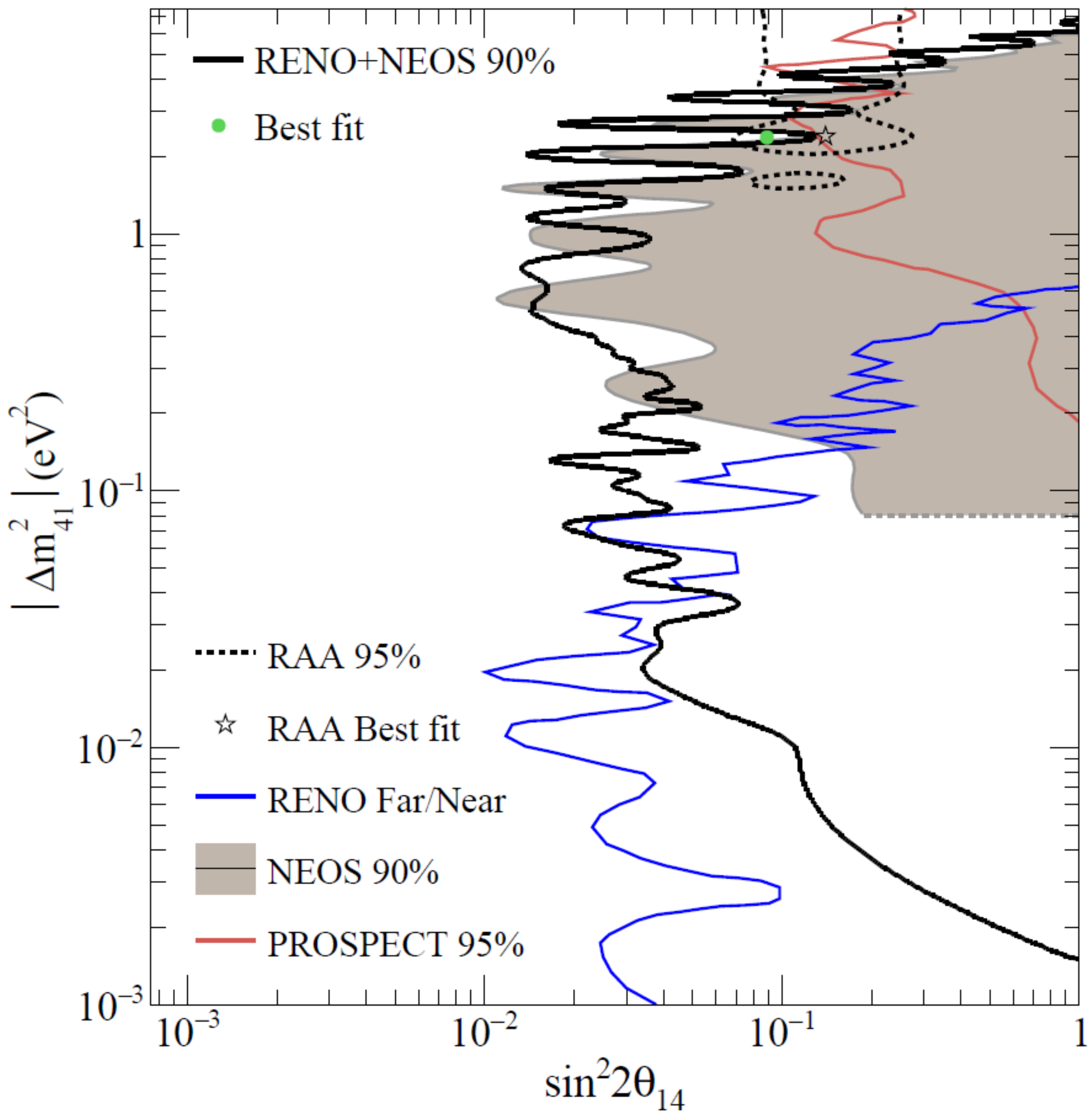
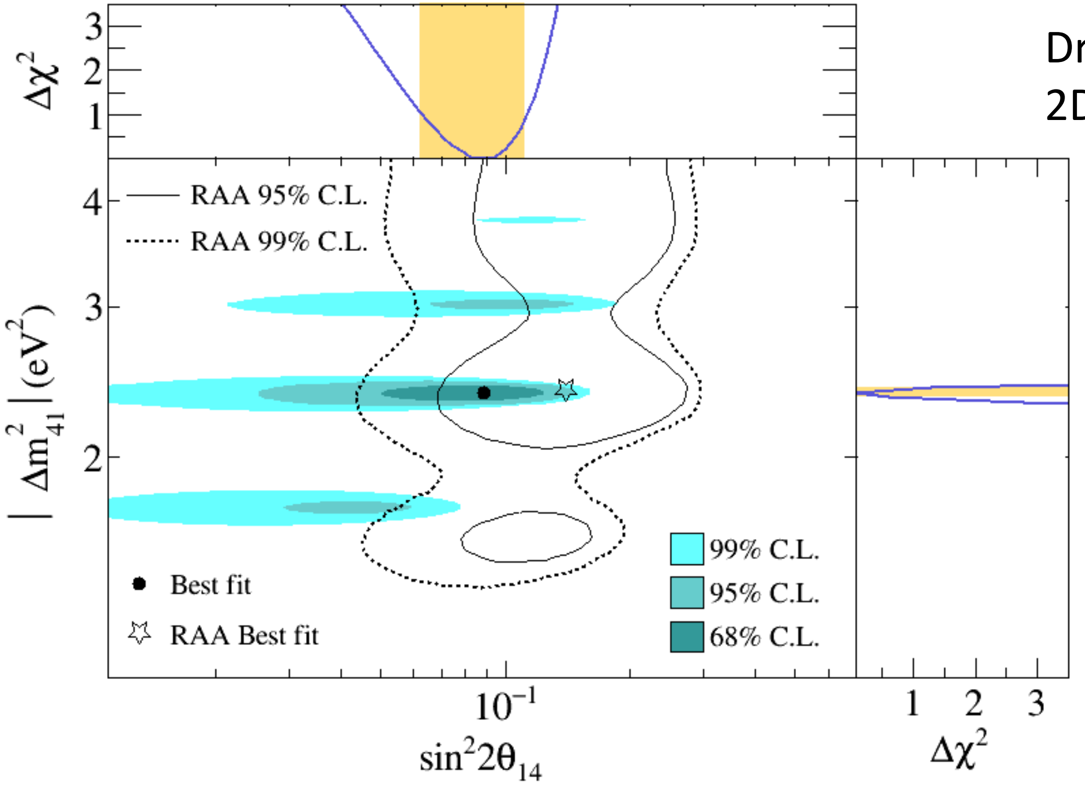
4ν Minimum χ^2 : 47.45 / 58
3ν $(\sin^2 2\theta_{14} = 0)$ χ^2: 56.24 / 60
$\Delta\chi^2 = 8.8$
P-value : 8.5%

- ✓ Best-fit parameter is consistent with RAA allowed, but it has tension with recent STEREO result.
- ✓ Feldman and Cousins method exclude more space than raster scan method except near the best-fit parameter

Previous version of excluded and allowed region



Drawn by Raster scan



Drawn by 2D-scan

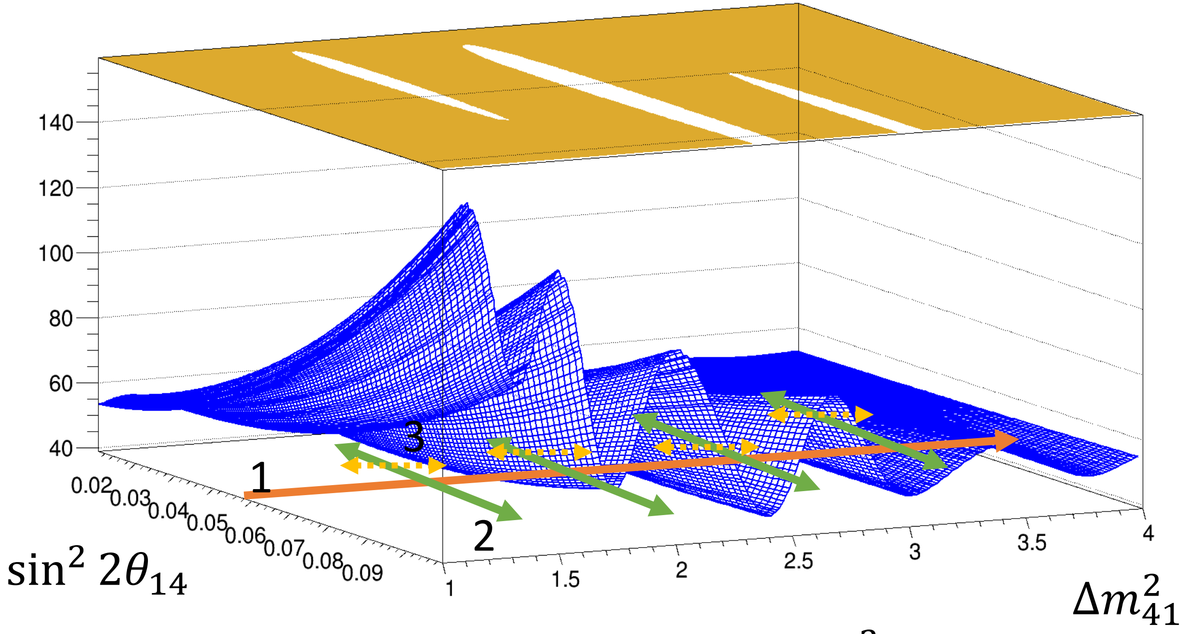
Best fit : $\boldsymbol{\Delta m^2_{41}} = \mathbf{2.37} \pm 0.03\ eV^2$, $\boldsymbol{\sin^2 2\theta_{14}} = \mathbf{0.09} \pm 0.03$

$\chi^2_{4\nu,min}/NDF = 23.2/57 \qquad \chi^2_{3\nu}/NDF = 34.9/59$

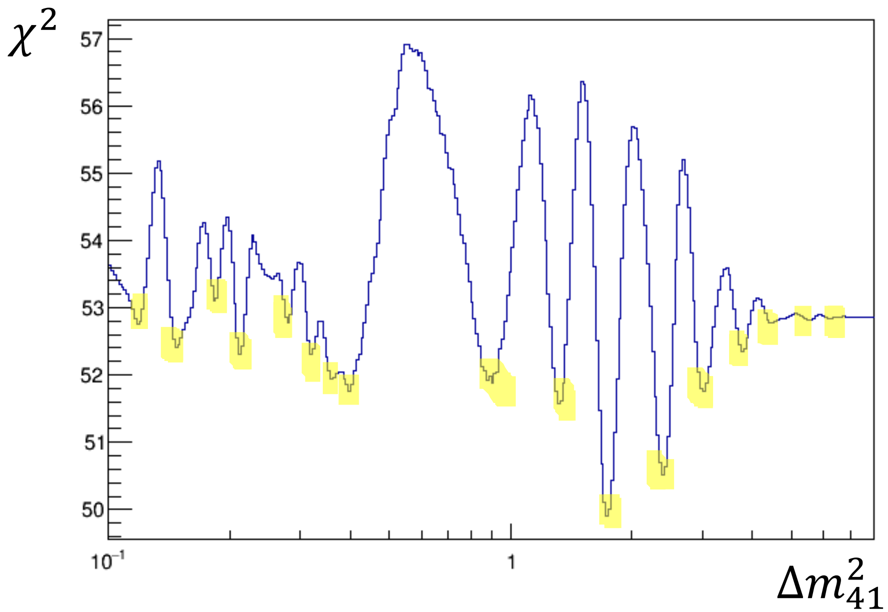
- P-value (assuming 3ν with MC) ~ 13%
- Weak hint for the sterile neutrino oscillation
- The best fit is compatible with the RAA allowed region

(arXiv:2011.00896)

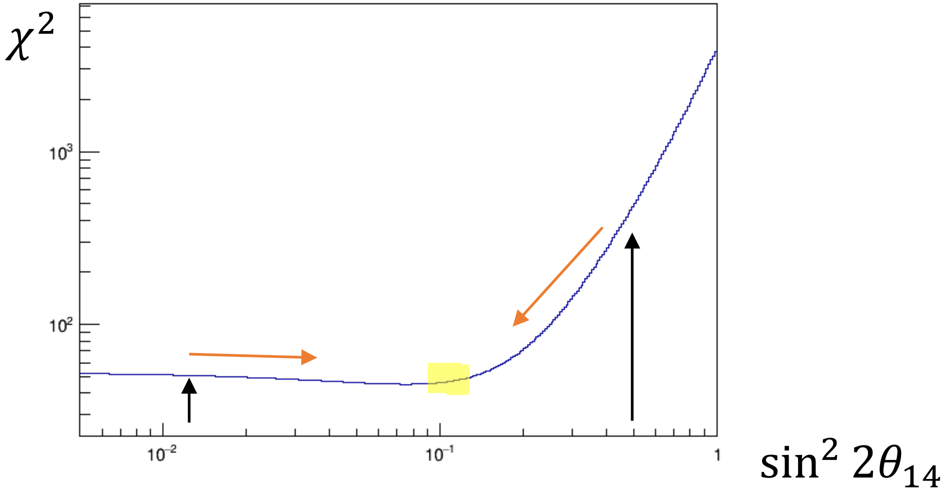
Fast algorithm to find the global minimum for FC simulation



1. Picking up the extreme values with fixed $\sin^2 2\theta_{14}$



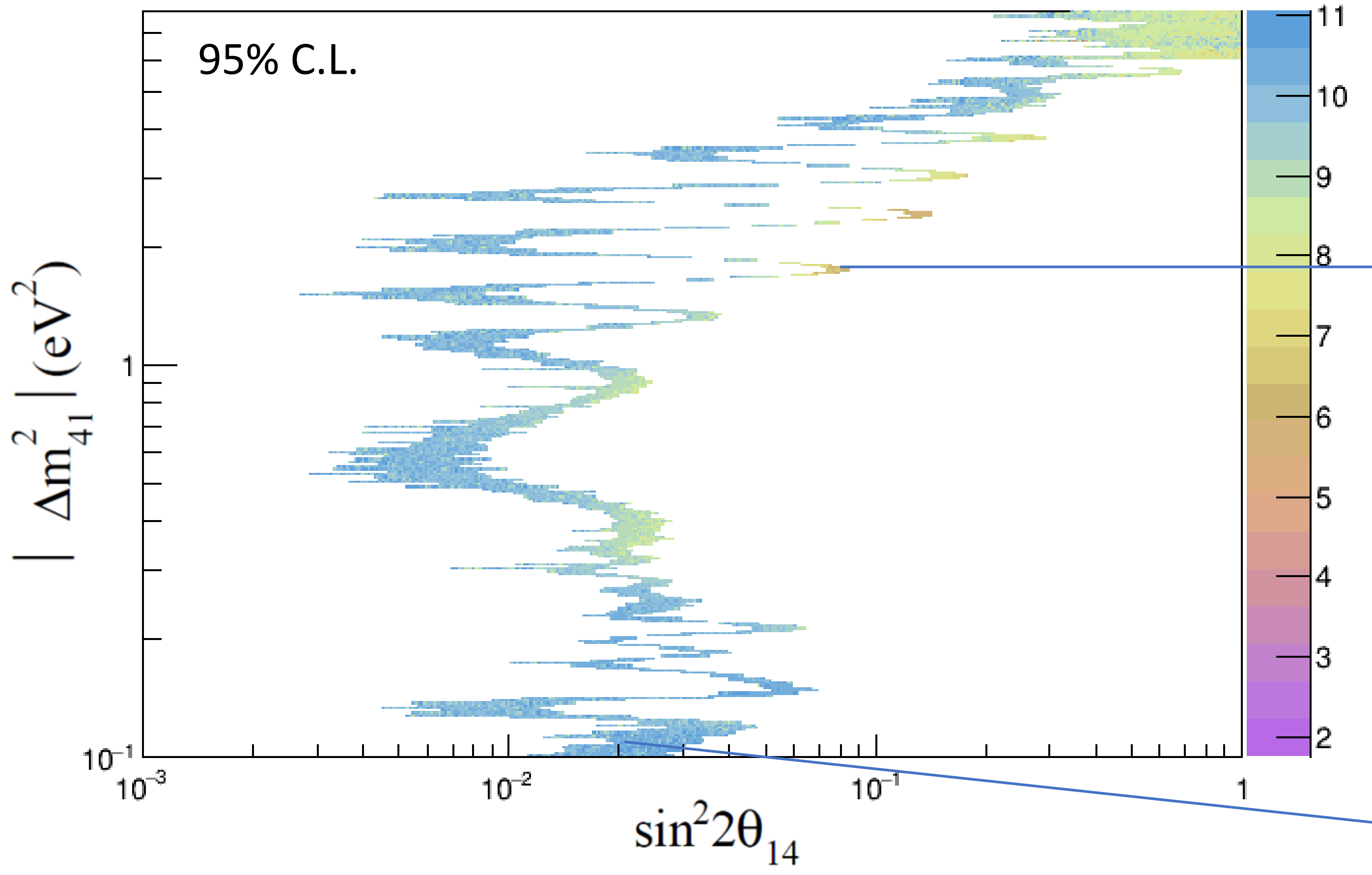
2. Finding the local minimum for fixed Δm^2_{41}

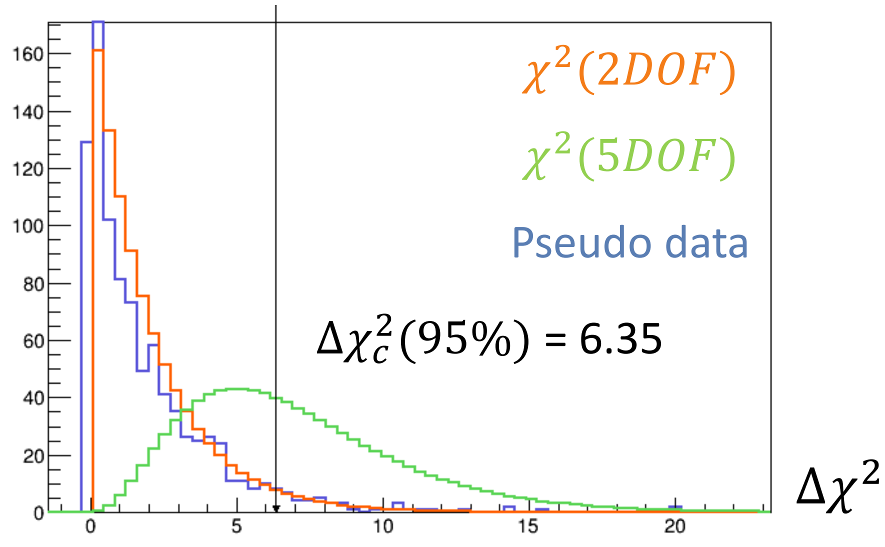


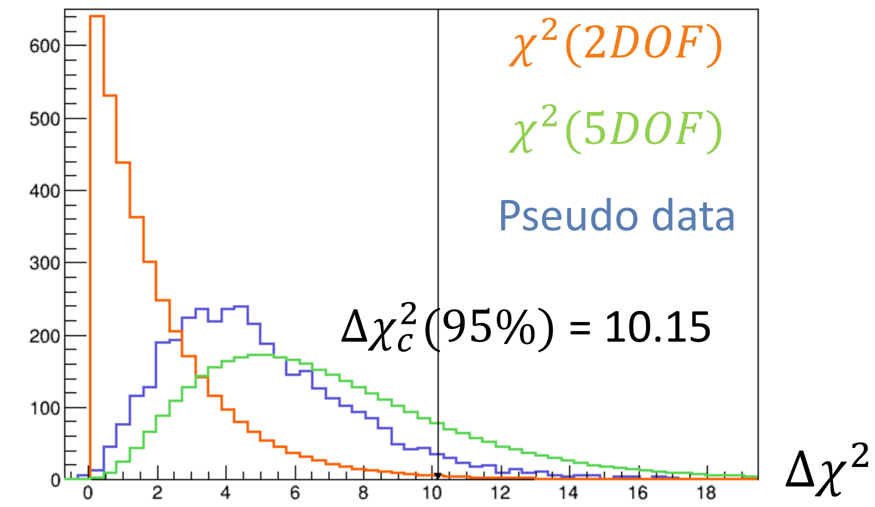
3. Picking up the most smallest local minimum among candidates Δm^2_{41} -> Check one more if that point is local minimum by varying Δm^2_{41}

Calculation speed is boosted ~ **×40**
+ It is still fast even if the grid is dense because it just pick up the extreme value, where the number of extreme value is fixed no matter how dense the grid is.(more accurate)

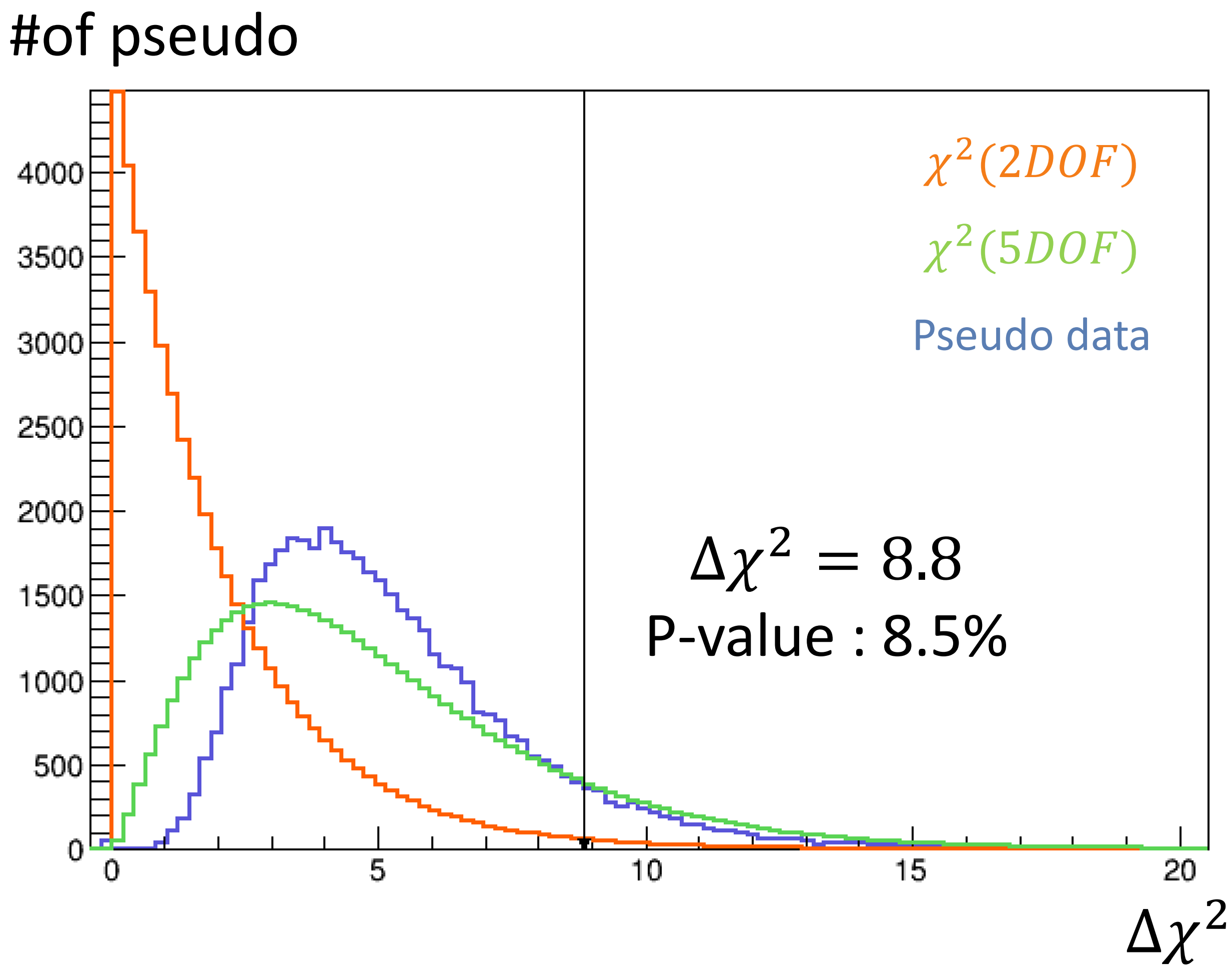
Critical $\Delta\chi^2$ distribution







P-value test



#of pseudo
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
$\chi^2(2DOF)$
$\chi^2(5DOF)$
Pseudo data
$\Delta\chi^2 = 8.8$
P-value : 8.5%
$\Delta\chi^2$