Constraining Super-light Sterile Neutrino Scenario by JUNO and RENO-50

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July. 2014, Paris

Outline

- Super-light Sterile Neutrino Scenario (SSNS)
- JUNO and Reno-50 Experiments
- Simulation
- Oscillation Of Neutrinos within SSNS
- Results
- Conclusion

Reference

- P. Bakhti and Y. Farzan, Constraining Super-light Sterile Neutrino Scenario by JUNO and RENO-50 , JHEP {1310} (2013) 200 ,arXiv:1308.2823 [hep-ph] .

Super-light Sterile Neutrino Scenario (SSNS)

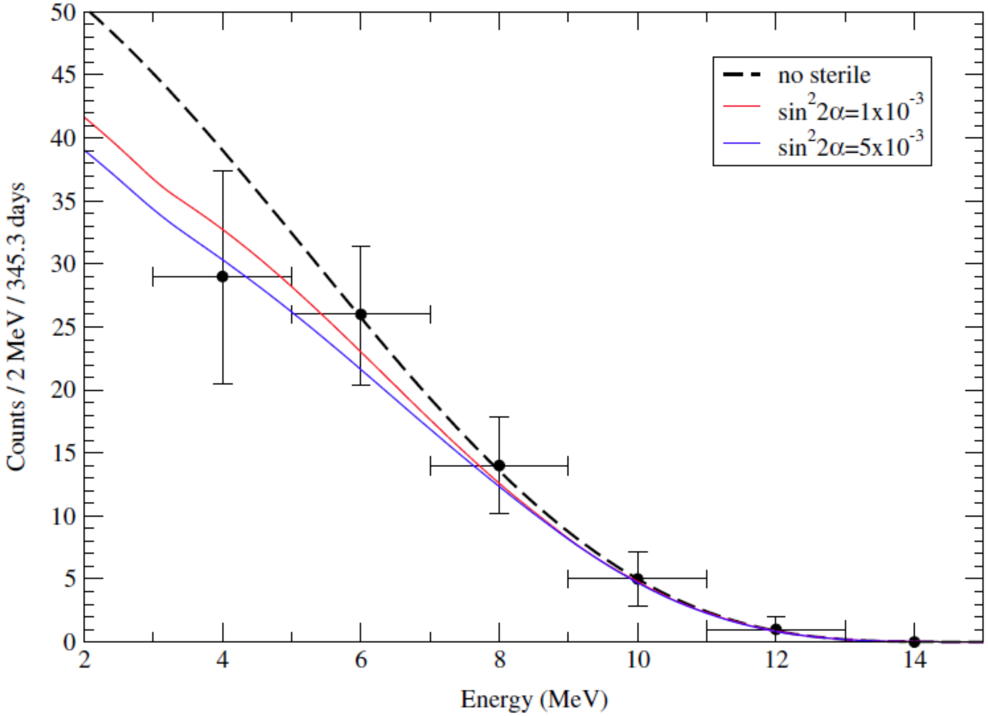
Suppression of upturn in low energy spectrum of solar data

- LMA-MSW solution explain solar data
- Deviation between Low energy solar data and LMA-MSW solution
- Be line measured by Borexino is in complete agreement
- But there is about 1-2 sigma deviation in data found by Homestake, Borexino (Boron spectrum), SNO-LETA, Super-Kamiokande I and III.

Holanda and Smirnov, PRD83 (2011) 113011

SSNS

PHYSICAL REVIEW D **83,** 113011 (2011)



SSNS

- Some proposal to resolve the deviation:
- Superlight Sterile Neutrinos Scenario (SSNS):

De Holanda and Smirnov, PRD 83 (2011) 113611; PRD69 (2004) 113002.

- Non-standard interaction:

Miranda et al, JHEP 0610 (2006) 008; PRD 80 (2009) 105009.

- Can we test SSNS via reactor experiments?

SSNS

$$\begin{pmatrix} \nu_s \\ \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U.\begin{pmatrix} \nu_0 \\ \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix} \qquad U \equiv \begin{pmatrix} 1 & 0 \\ 0 & U_{PMNS} \end{pmatrix}.\mathrm{U_S}$$

$$\mathrm{U_S} = \begin{pmatrix} \cos\alpha & \sin\alpha\, e^{i\delta_1} & 0 & 0 \\ -\sin\alpha\, e^{-i\delta_1} & \cos\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} . \begin{pmatrix} \cos\gamma & 0 & \sin\gamma & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\gamma & 0 & \cos\gamma & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} . \begin{pmatrix} \cos\beta & 0 & 0 & \sin\beta\, e^{i\delta_2} \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\beta\, e^{-i\delta_2} & 0 & 0 & \cos\beta \end{pmatrix}$$

- Solar data

$$\Delta m^2_{01} \sim 0.7 - 2\times 10^{-5}\ \mathrm{eV}^2, \sin^2 2\alpha \sim 10^{-3}$$

De Holanda and Smirnov, PRD 83 (2011) 113611:

SSNS

- Atmospheric data, MINOS: $\sin^2\beta < 0.2 \quad 90\%\,\mathrm{CL}$

  Cirelli et al, Nucl Phys B708 (2005) 215;
  Adomson et al, PRD81 (210) 82004 arXiv:1104.3922

- PLANCK: Extra relativistic degrees of freedom

$$\sin^2\alpha, \sin^2\beta, \sin^2\gamma < few \times 10^{-2}$$

  Mirizzi et al, PLB726 (2013) 8-14

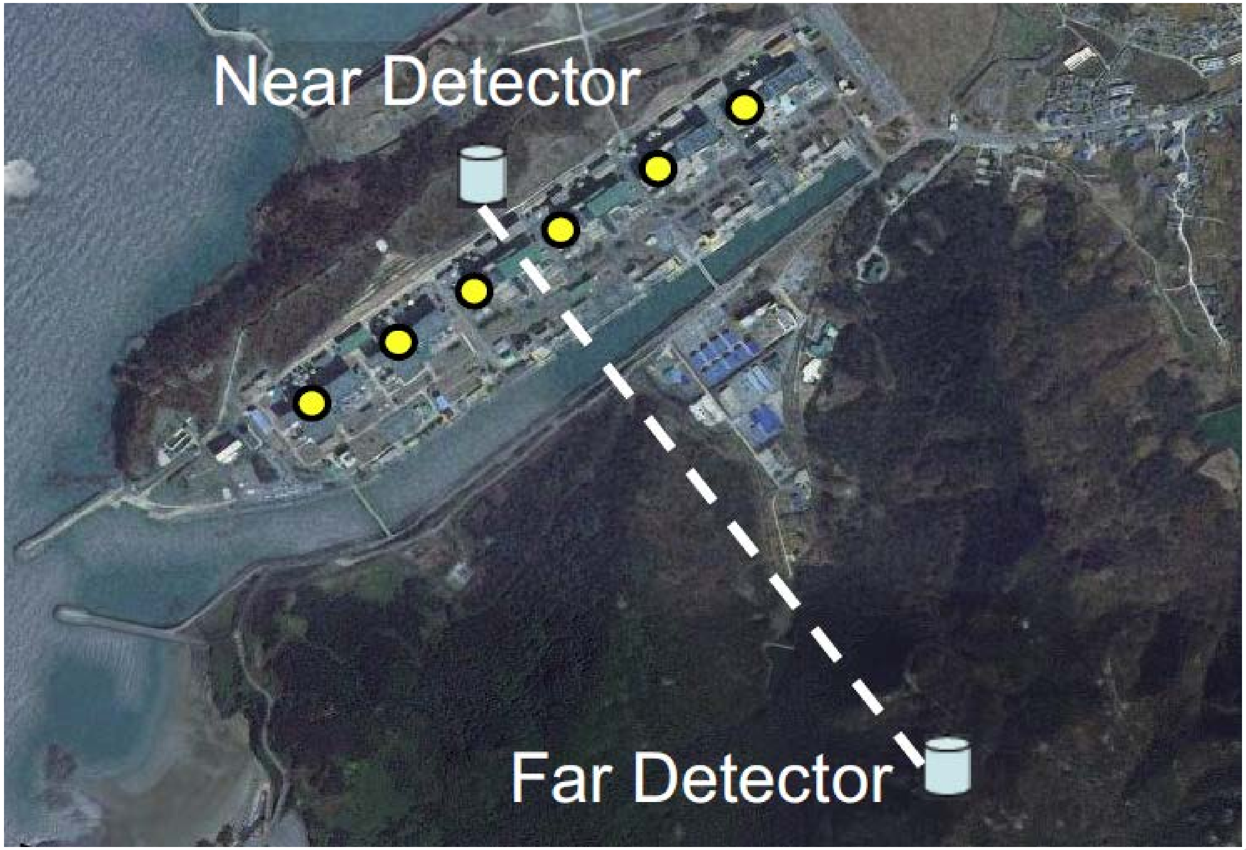
- ...

  Wyman et al, arXiv:1307.7715,
  Archidiacono et al, arXiv:1307.0637

JUNO and Reno-50 Experiments

JUNO in China

Reno-50 in South Korea



JUNO and Reno-50 Experiments

- Baseline ~ 50 km
- Will be ready for data taking in 2020
- Main purpose: Determination of mass hierarchy & constraints on neutrino parameters
- Liquid scintillator detector
- JUNO: 20 kton, 36 GW
- Reno-50: 18 kton, 16.4 GW

Simulation

Simulation

- GLoBES(General Long Baseline Experiment Simulator)

  P. Huber, M. Lindner and W. Winter, Comput. Phys. Commun. 167, 195 (2005) [hep-ph/0407333]; P. Huber, J. Kopp,M. Lindner, M. Rolinec and W. Winter, Comput. Phys. Commun. 177, 432 (2007) [hep-ph/0701187]; http://www.mpi-hd.mpg.de/personalhomes/globes.

- Sterile neutrino

  Joachim Kopp, Manfred Lindner, Toshihiko Ota, and Joe Sato. Non-standard neutrino interactions in reactor and superbeam experiments. Phys.Rev., D77:013007, 2008.

Simulation

- Backgrounds: accidental, geo neutrino & $^{13}C(\alpha,n)^{16}O$

A. Gando et al. [KamLAND Collaboration], arXiv:1303.4667 [hep-ex].

- Cross section: P. Vogel and J. F. Beacom, Phys. Rev. D 60 (1999) 053003 [hep-ph/9903554]
- 5 years
- Energy resolution: $3\% / \sqrt{E_\nu / MeV}$
- 62 bins: $1.8\, MeV$ to $8\, MeV$

Simulation

- Neutrino parameters

NuFIT 1.2 (2013)

	Free Fluxes + RSBL		Huber Fluxes, no RSBL	
	bfp $\pm1\sigma$	3σ range	bfp $\pm1\sigma$	3σ range
$\sin^2\theta_{12}$	$0.306^{+0.012}_{-0.012}$	$0.271 \to 0.346$	$0.313^{+0.013}_{-0.012}$	$0.277 \to 0.355$
$\theta_{12}/^\circ$	$33.57^{+0.77}_{-0.75}$	$31.37 \to 36.01$	$34.02^{+0.79}_{-0.76}$	$31.78 \to 36.55$
$\sin^2\theta_{23}$	$0.446^{+0.008}_{-0.008} \oplus 0.593^{+0.027}_{-0.043}$	$0.366 \to 0.663$	$0.444^{+0.037}_{-0.031} \oplus 0.592^{+0.028}_{-0.042}$	$0.361 \to 0.665$
$\theta_{23}/^\circ$	$41.9^{+0.5}_{-0.4} \oplus 50.3^{+1.6}_{-2.5}$	$37.2 \to 54.5$	$41.8^{+2.1}_{-1.8} \oplus 50.3^{+1.6}_{-2.5}$	$36.9 \to 54.6$
$\sin^2\theta_{13}$	$0.0231^{+0.0019}_{-0.0019}$	$0.0173 \to 0.0288$	$0.0244^{+0.0019}_{-0.0019}$	$0.0187 \to 0.0303$
$\theta_{13}/^\circ$	$8.73^{+0.35}_{-0.36}$	$7.56 \to 9.77$	$9.00^{+0.35}_{-0.36}$	$7.85 \to 10.02$
$\delta_{CP}/^\circ$	266^{+55}_{-63}	$0 \to 360$	270^{+77}_{-67}	$0 \to 360$
$\frac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	$7.45^{+0.19}_{-0.16}$	$6.98 \to 8.05$	$7.50^{+0.18}_{-0.17}$	$7.03 \to 8.08$
$\frac{\Delta m^2_{31}}{10^{-3}\ \mathrm{eV}^2}$ (N)	$+2.417^{+0.014}_{-0.014}$	$+2.247 \to +2.623$	$+2.429^{+0.055}_{-0.054}$	$+2.249 \to +2.639$
$\frac{\Delta m^2_{32}}{10^{-3}\ \mathrm{eV}^2}$ (I)	$-2.411^{+0.062}_{-0.062}$	$-2.602 \to -2.226$	$-2.422^{+0.063}_{-0.061}$	$-2.614 \to -2.235$

M. C. Gonzalez-Garcia, M. Maltoni, J. Salvado and T. Schwetz, JHEP 1212 (2012) 123 [arXiv:1209.3023 [hep-ph]].

Oscillation of neutrinos

Oscillation of neutrinos

- In the case of nonzero mixing:

$$1\text{-}\sin\beta = \sin\gamma = 0 \;\;\&\;\; \alpha \neq 0$$

$$2\text{-}\sin\alpha = \sin\beta = 0 \;\;\&\;\; \gamma \neq 0$$

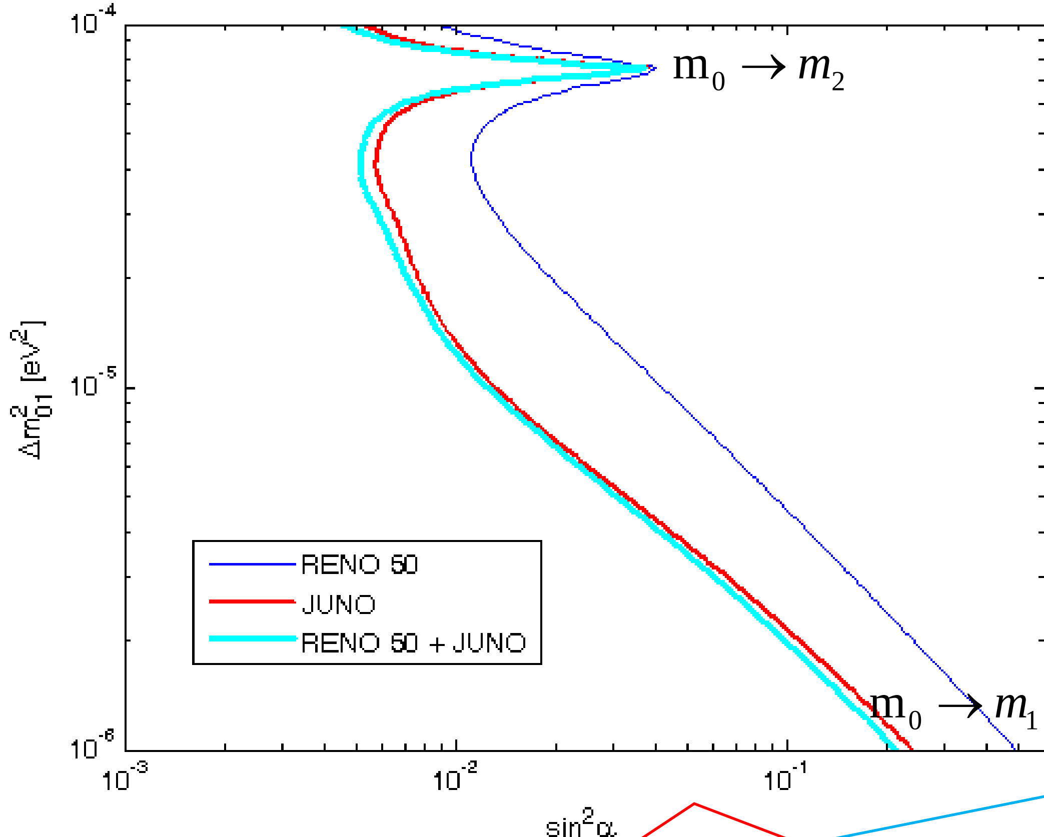
$$3\text{-}\sin\alpha = \sin\gamma = 0 \;\;\&\;\; \beta \neq 0$$

Results

Results

$$\text{case 1: } \sin\beta = \sin\gamma = 0 \ \ \& \ \ \alpha \neq 0$$

The 95% C.L. upper bound on $\sin^2\alpha$ versus Δm^2_{01}

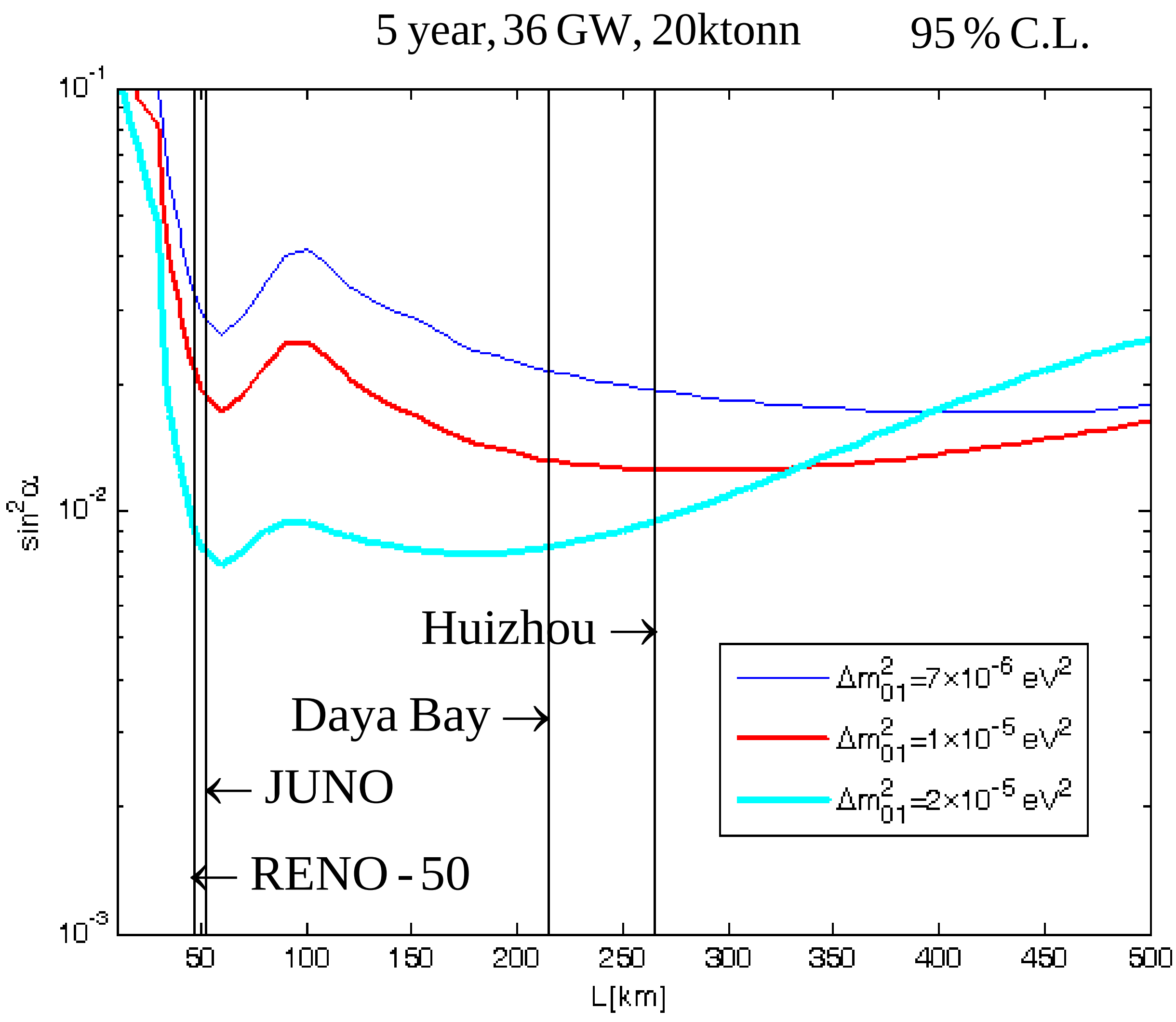


$$\alpha = \gamma = \beta = 0$$

Five years of data taking

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = \left|\cos^2\theta_{13}\cos^2\theta_{12}\sin^2\alpha e^{i\Delta_0} + \cos^2\alpha\cos^2\theta_{13}\cos^2\theta_{12}e^{i\Delta_1} + \cos^2\theta_{13}\sin^2\theta_{12}e^{i\Delta_2} + \sin^2\theta_{13}e^{i\Delta_3}\right|^2$$

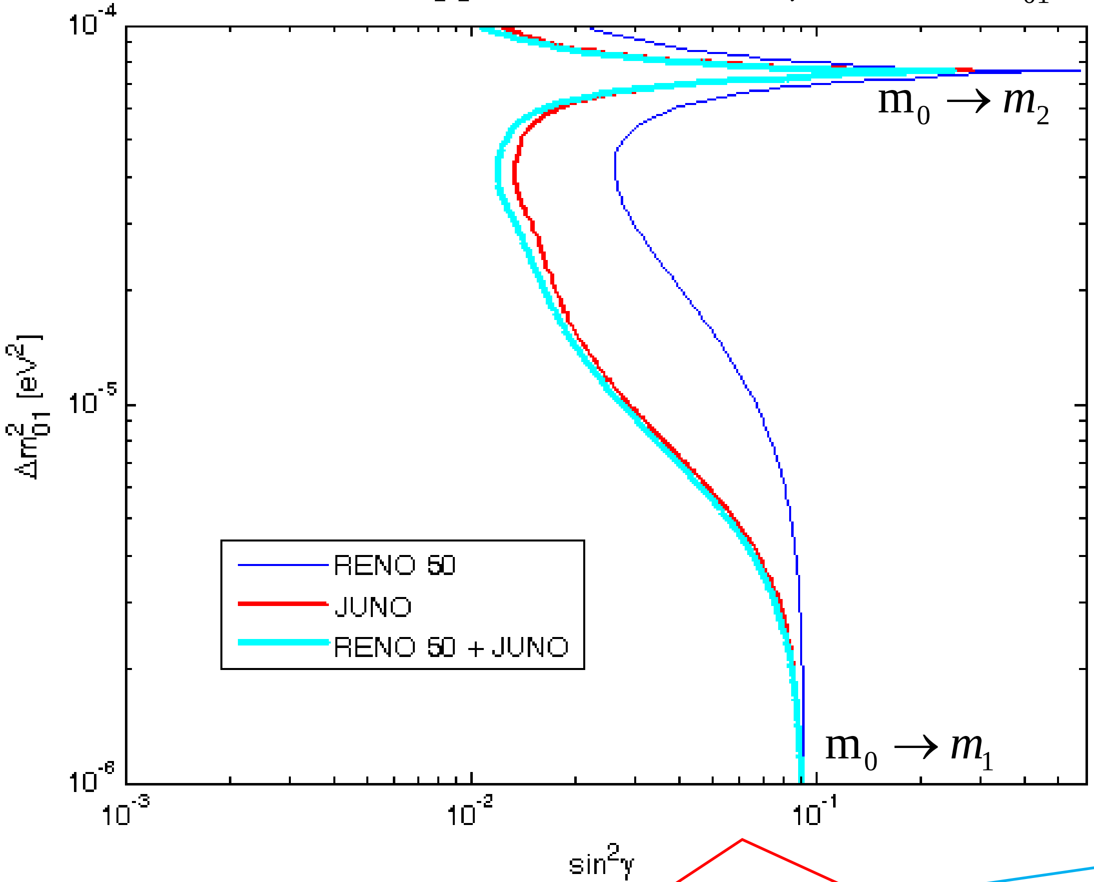
Results


5 year, 36 GW, 20ktonn
95 % C.L.
10^{-1}
10^{-2}
10^{-3}
$\sin^2\alpha$
50
100
150
200
250
300
350
400
450
500
L[km]
Huizhou →
Daya Bay →
← JUNO
← RENO - 50
$\Delta m^2_{01}=7\times10^{-6}$ eV^2
$\Delta m^2_{01}=1\times10^{-5}$ eV^2
$\Delta m^2_{01}=2\times10^{-5}$ eV^2

Results

$$\text{case 2}: \sin\alpha = \sin\beta = 0 \;\; \& \;\; \gamma \neq 0$$

The 95% C.L. upper bound on $\sin^2\gamma$ versus Δm^2_{01}

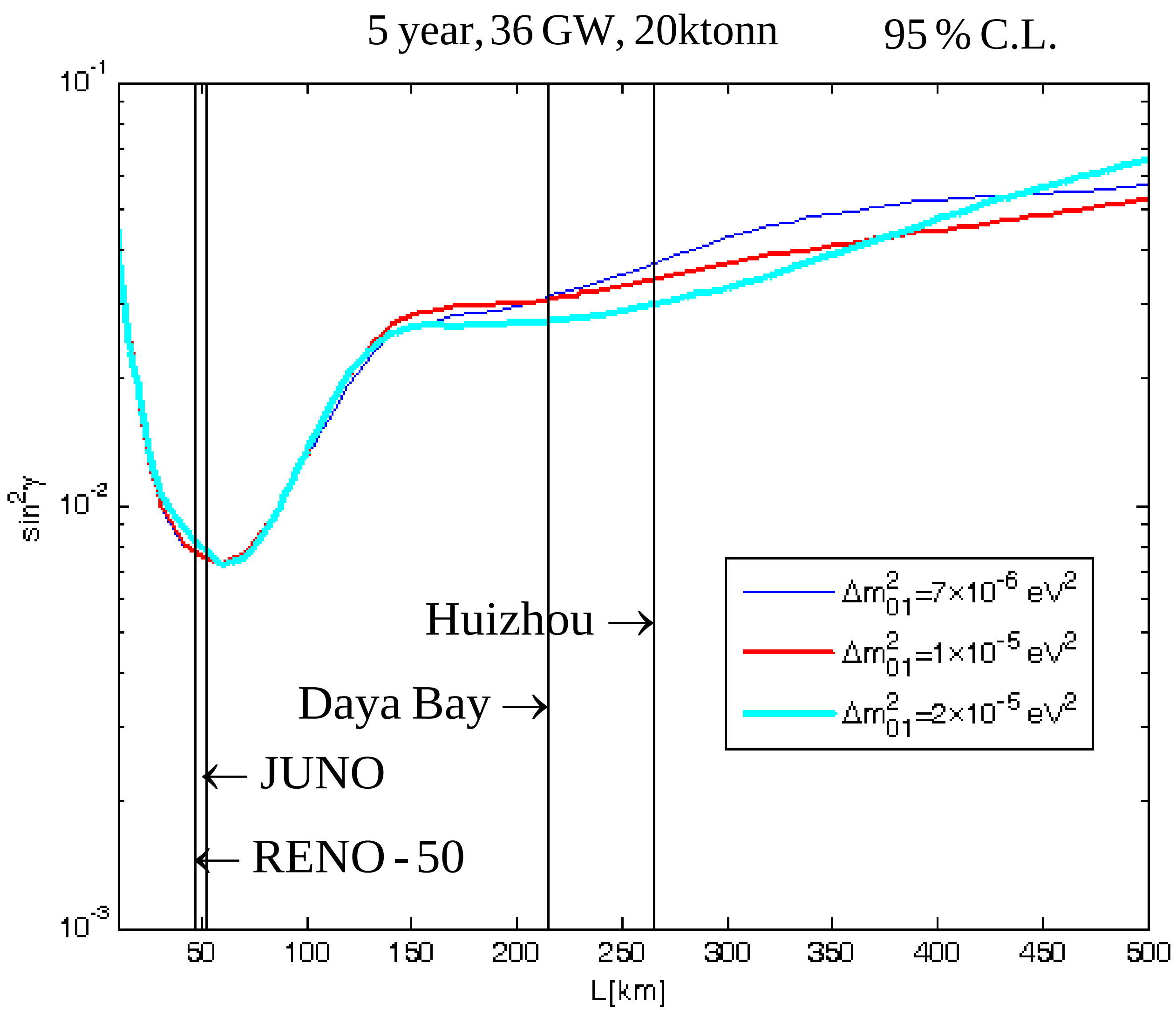


$$\alpha = \gamma = \beta = 0$$

Five years of data taking

$$P(\bar{\nu}_e \to \bar{\nu}_e) = \left|\cos^2\theta_{13}\sin^2\theta_{12}\sin^2\gamma e^{i\Delta_0} + \cos^2\theta_{13}\cos^2\theta_{12}e^{i\Delta_1} + \cos^2\theta_{13}\sin^2\theta_{12}\cos^2\gamma e^{i\Delta_2} + \sin^2\theta_{13}e^{i\Delta_3}\right|^2$$

Results



5 year, 36 GW, 20ktonn
95 % C.L.
10^{-1}
10^{-2}
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50
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250
300
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400
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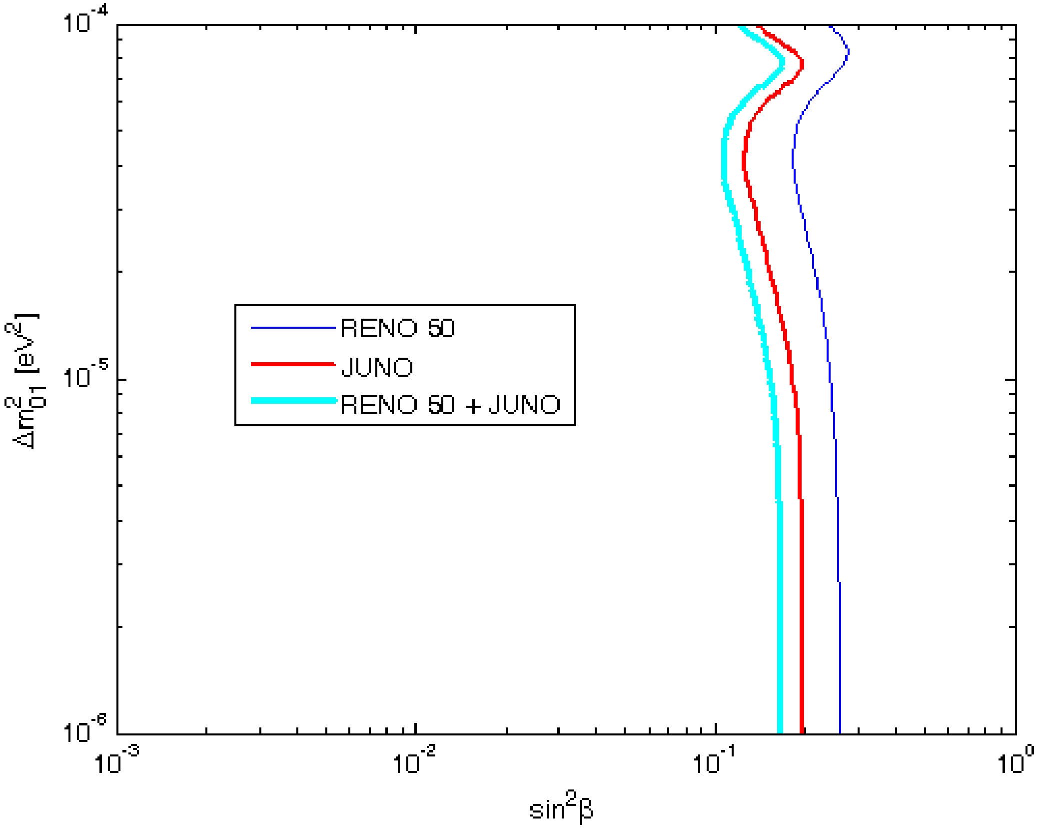
500
L[km]
Huizhou →
Daya Bay →
← JUNO
← RENO - 50
$\Delta m^2_{01}=7\times10^{-6}$ eV^2
$\Delta m^2_{01}=1\times10^{-5}$ eV^2
$\Delta m^2_{01}=2\times10^{-5}$ eV^2

Results

$$\text{case } 3: \sin\alpha = \sin\gamma = 0 \ \ \& \ \ \beta \neq 0$$

The 95% C.L. upper bound on $\sin^2\beta$ versus Δm^2_{01}



$$\alpha = \gamma = \beta = 0$$

Five years of data taking

$$\sin^2\theta_{13} \ll 1$$

$$P(\bar{\nu}_e \to \bar{\nu}_e) = \left|\sin^2\theta_{13}\sin^2\beta e^{i\Delta_0} + \cos^2\theta_{13}\cos^2\theta_{12}e^{i\Delta_1} + \cos^2\theta_{13}\sin^2\theta_{12}e^{i\Delta_2} + \sin^2\theta_{13}\cos^2\beta e^{i\Delta_3}\right|^2$$

Results

- Performance of JUNO is better than RENO-50: because the source of JUNO is more powerful
- The effect of background is negligible
- With four times larger data could constrain SSNS

$$\sin^2\alpha < 2.8\times10^{-3}$$

Probing the range of parameters that explains the suppression of low energy upturn of the spectrum

Conclusion

Conclusion

- The medium baseline reactor experiments can (in principle) probe SSNS

Thanks for your attention