Resolving JHF degeneracy

Tokyo Metropolitan Univ.

Hiroaki Sugiyama

collaborator :

H. Minakata

O. Yasuda

Motivation

Our paper hep-ph/0211111

(yesterday Yasuda-san's talk)

... { · mono energetic beam (E_ν = 0.6 GeV)

· no errors in JHF (statistics, systematics, correlation)

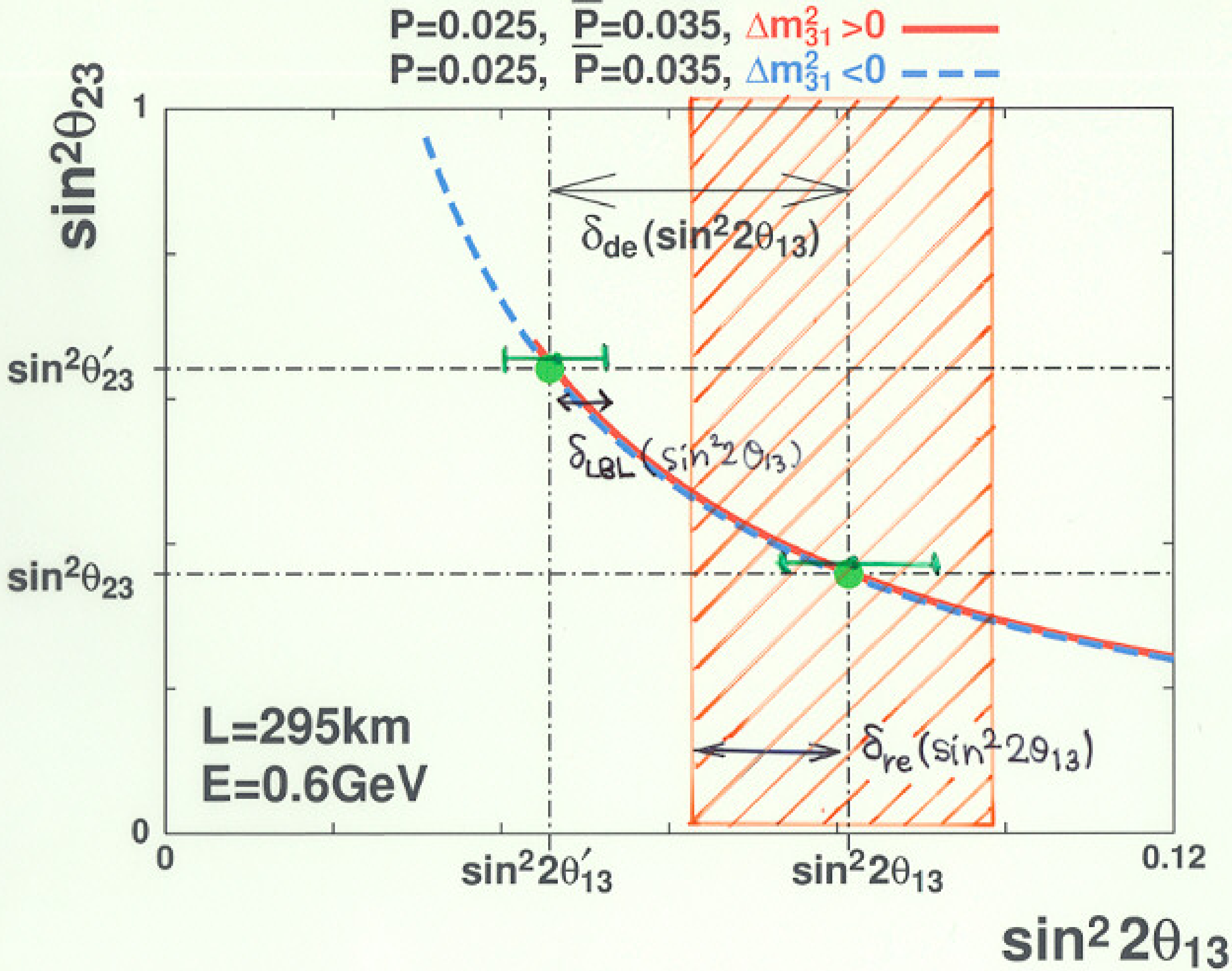
$\Downarrow$

Quantitative analysis of JHF

Considering degeneracy

(· beam spectrum

· χ^2



$\delta_{re}(\sin^2 2\theta_{13}) < \delta_{de}(\sin^2 2\theta_{13}) - \delta_{LBL}(\sin^2 2\theta_{13})$

$\Rightarrow$ degeneracy solved

Preparation

- setting of LBL

$$\left\{\begin{array}{llll} \text{JHF}-\text{SK} : & 0.75\,\text{MW} & \xrightarrow{295\text{km}} & 22.5\,\text{kt} \\ \text{JHF}-\text{HK} : & 4\,\text{MW} & \longrightarrow & 540\,\text{kt} \end{array}\right.$$

· OAB 2° (peak energy = 0.7 GeV)

- a check of our calculation

··· # of events in F.V. (JHF-SK 5yr)

	$\nu_\mu \to \nu_\mu$ C.C. (w/o osci.)	$\nu_\mu \to \nu_e, \nu_\mu, \nu_\tau$ N.C.	beam ν_e C.C.+N.C.	$\nu_\mu \to \nu_e$ ($\sin^2 2\theta_{\mu e}$
LOI	10713.6	4080.3	292.1	301.
ours	10751.5	4072.4	293.1	309

Statistical analysis

- correlations of errors

$\longrightarrow$ minimization of multi-dim. $\Delta\chi^2$
(fitting procedure)

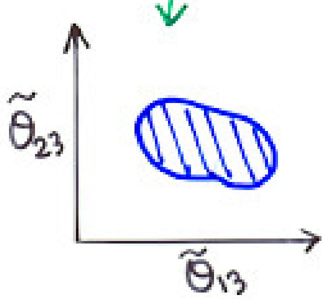
by varying parameters at once

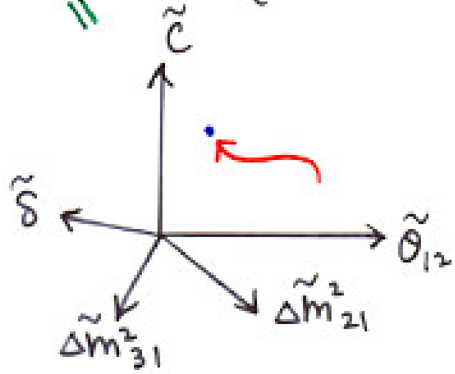
ex.

$C \times \sqrt{2}\, G_F N_e$

$$\begin{cases} S \equiv \{\theta_{12},\ \Delta m^2_{21},\ \Delta m^2_{31},\ \delta,\ C\} \\ N(\theta_{13}, \theta_{23}, S) \ : \ \text{an artificial result of an experiment} \\ N(\tilde{\theta}_{13}, \tilde{\theta}_{23}, \tilde{S}) \ : \ \text{a hypothesis to be tested} \end{cases}$$

$$\Delta\chi^2(\tilde{\theta}_{13}, \tilde{\theta}_{23}; \theta_{13}, \theta_{23}, S) \equiv \min_{\tilde{S}} \frac{\{N(\tilde{\theta}_{13}, \tilde{\theta}_{23}, \tilde{S}) - N(\theta_{13}, \theta_{23}, S)\}^2}{(\delta N(\theta_{13}, \theta_{23}, S))^2}$$





- fixed parameters

$$t_{12}^2 \equiv \tan^2\theta_{12} = 0.36$$
$$\Delta m_{21}^2 = 7.3 \times 10^{-5}\ \mathrm{eV}^2$$

lower LMA best fit

$C = 1$ coefficient of matter effect

$$|\Delta m_{31}^2| = 2.5 \times 10^{-3}\ \mathrm{eV}^2$$

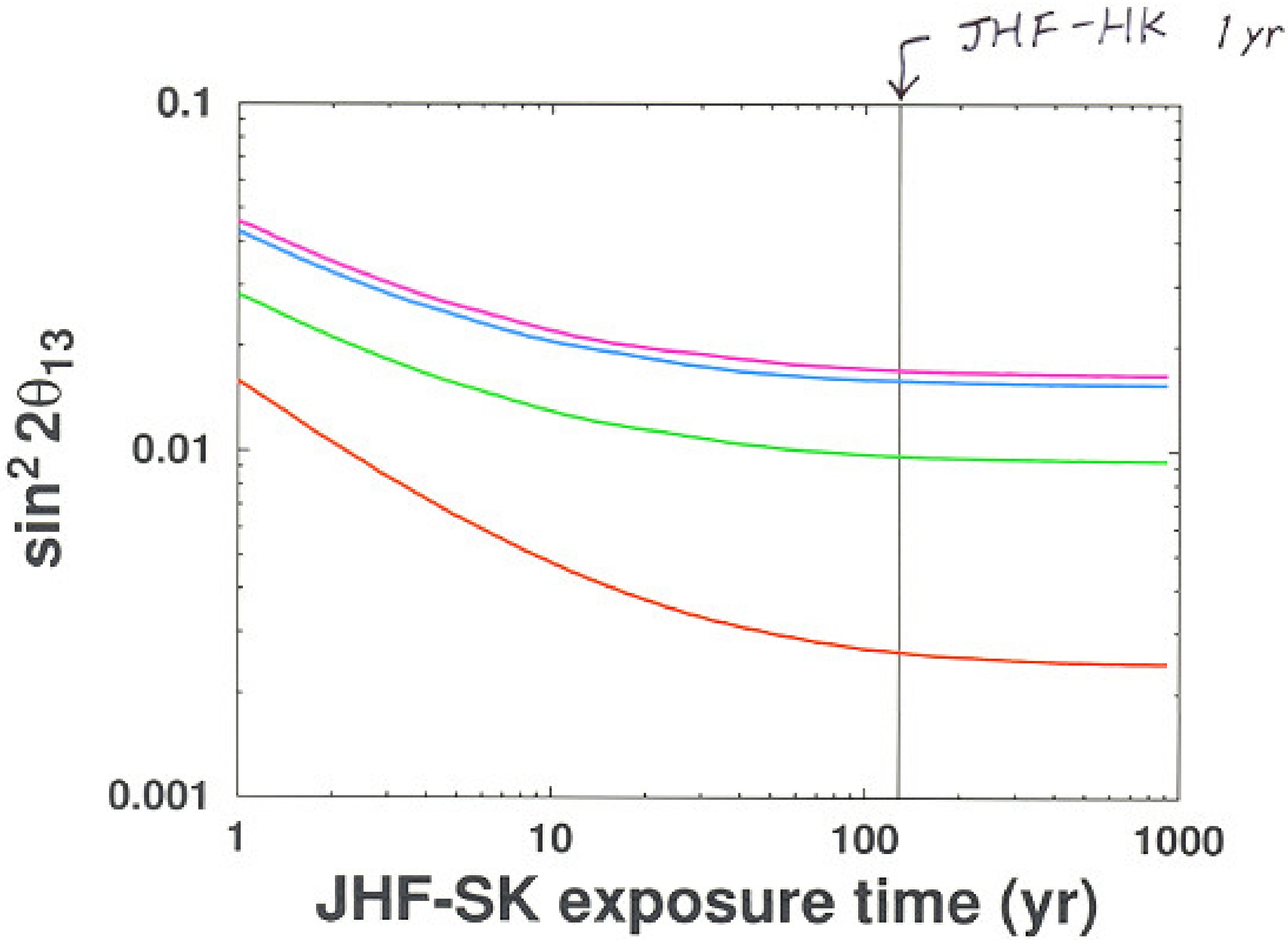
- constraints

... effective 90% CL regions

※ no constraints → too much minimized $\Delta\chi^2$

$$\tilde{t}_{12}^2 = 0.36 \pm 0.17$$
$$\Delta\tilde{m}_{21}^2 = (7.3 \pm 2.25) \times 10^{-5}\ \mathrm{eV}^2$$
$$\tilde{C} = 1 \pm 0.05$$
$$|\Delta\tilde{m}_{31}^2| = (2.5 \pm 0.1) \times 10^{-3}\ \mathrm{eV}^2$$
$$\sin^2 2\tilde{\theta}_{23} : 1\% \text{ error}$$

expected in JHF-SK ν_μ disappearance



red line ($\Delta m^2_{21} = 0$, $\sin^2 2\theta_{23} = 1$, $A = 0$)

unknown δ

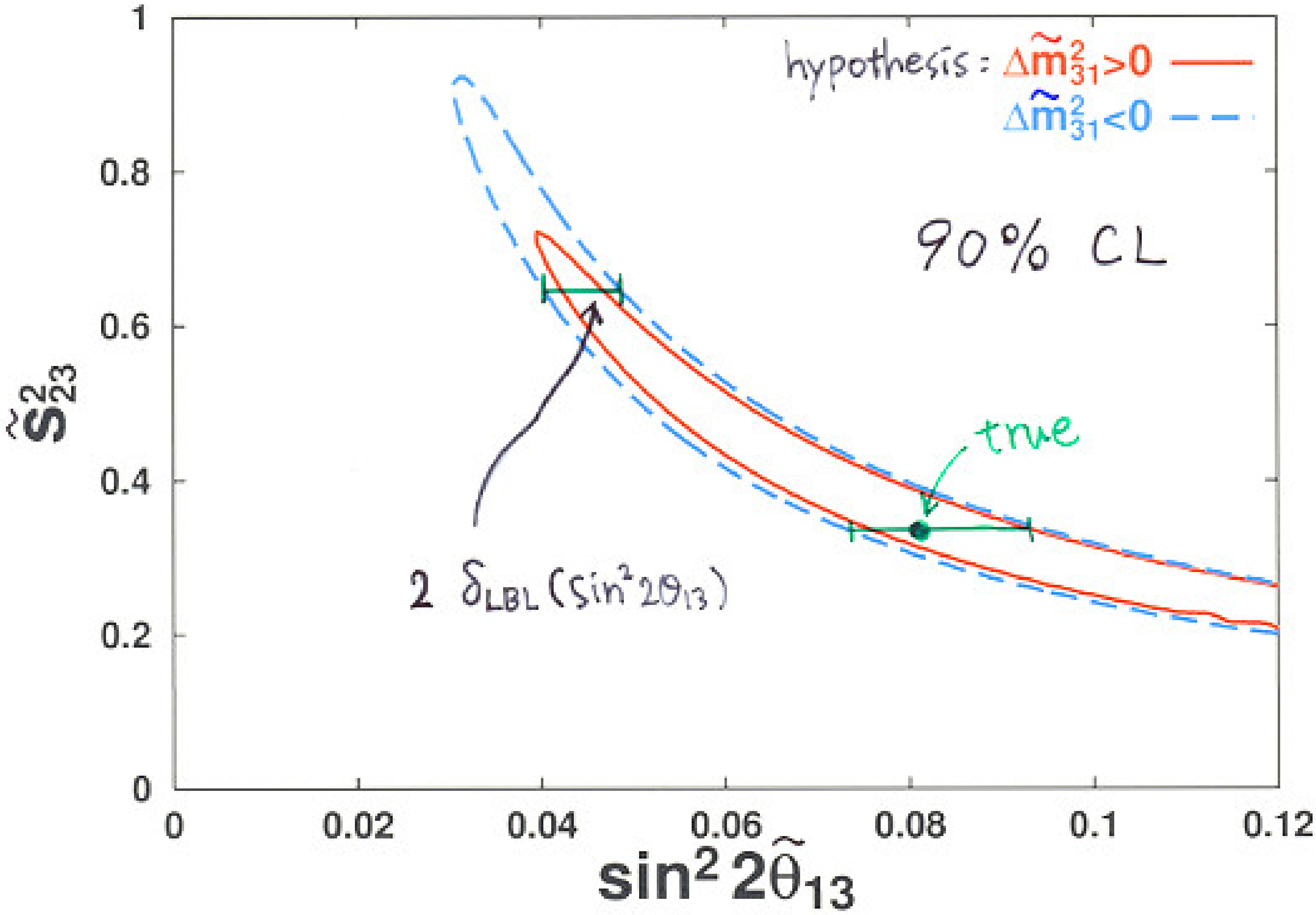
green line ($\underline{\Delta m^2_{21} \neq 0}$, $\sin^2 2\theta_{23} = 1$, $A = 0$)

unknown $\mathrm{sgn}(\pi/2 - \theta_{23})$

brue line ($\Delta m^2_{21} \neq 0$, $\underline{\sin^2 2\theta_{23} = 0.92}$, $A = 0$)

unknown $\mathrm{sgn}(\Delta m^2_{31})$

magenta line ($\Delta m^2_{21} \neq 0$, $\sin^2 2\theta_{23} = 0.92$, $A \neq 0$)



true values : $\sin^2 2\theta_{13} = 0.08$, $s_{23}^2 = 0.36$

$\Delta m^2_{31} > 0$, $\delta = \pi/2$

inside of solid (dashed) line is

allowed region with $\Delta m^2_{31} > 0$ hypothesis

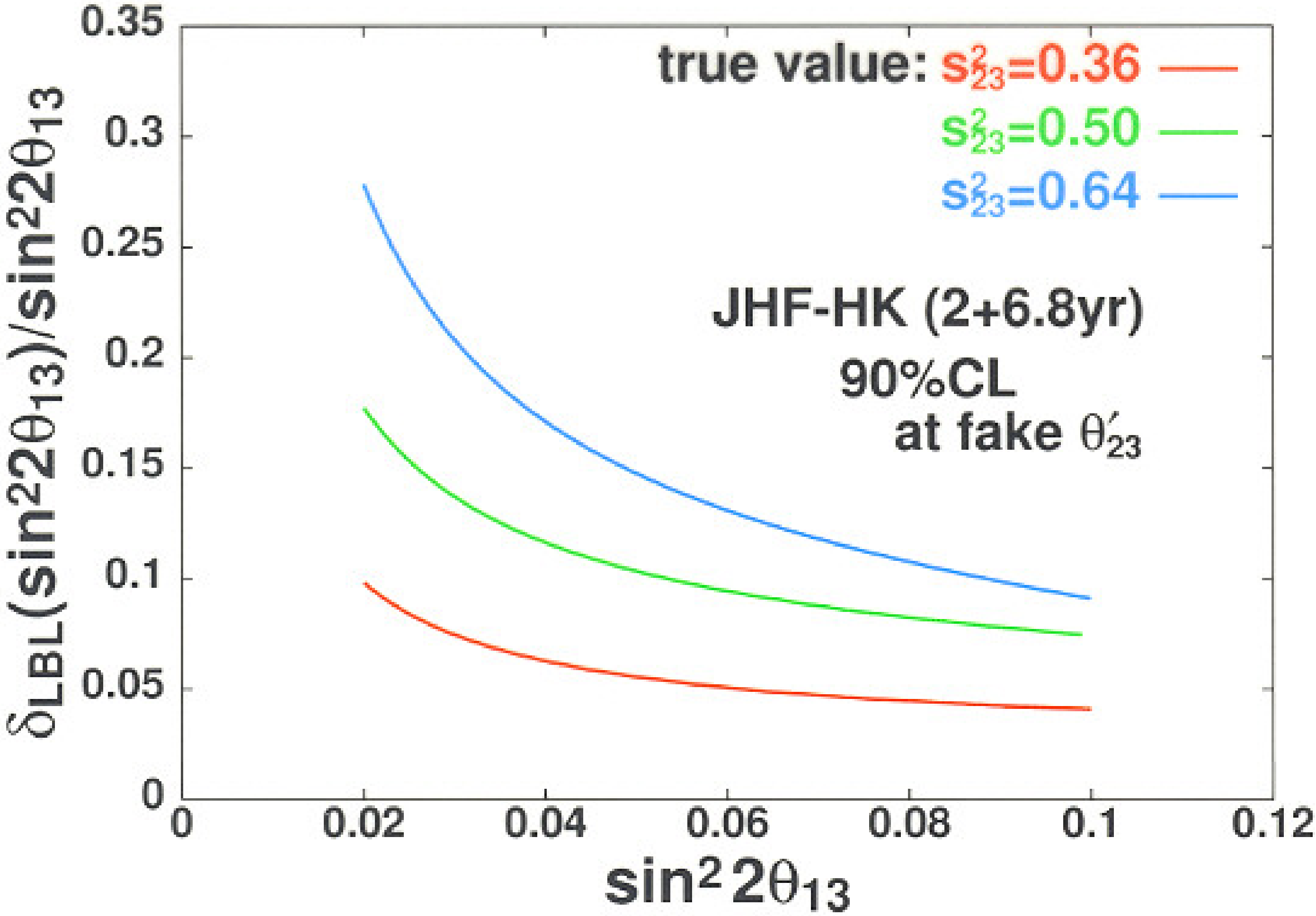
($\Delta m^2_{31} < 0$)

※ $\delta = \pi/2 \ (-\pi/2) \Rightarrow$

$\nu_\mu \to \nu_e$ is suppressed

$\Delta m^2_{31} < 0 \ (>0) \Rightarrow (\bar{\nu}_\mu \to \bar{\nu}_e)$

$\longrightarrow \ \delta = \pi/2 \ (-\pi/2) \Rightarrow \Delta\tilde{m}^2_{31} < 0 \ (>0)$ gives good fit



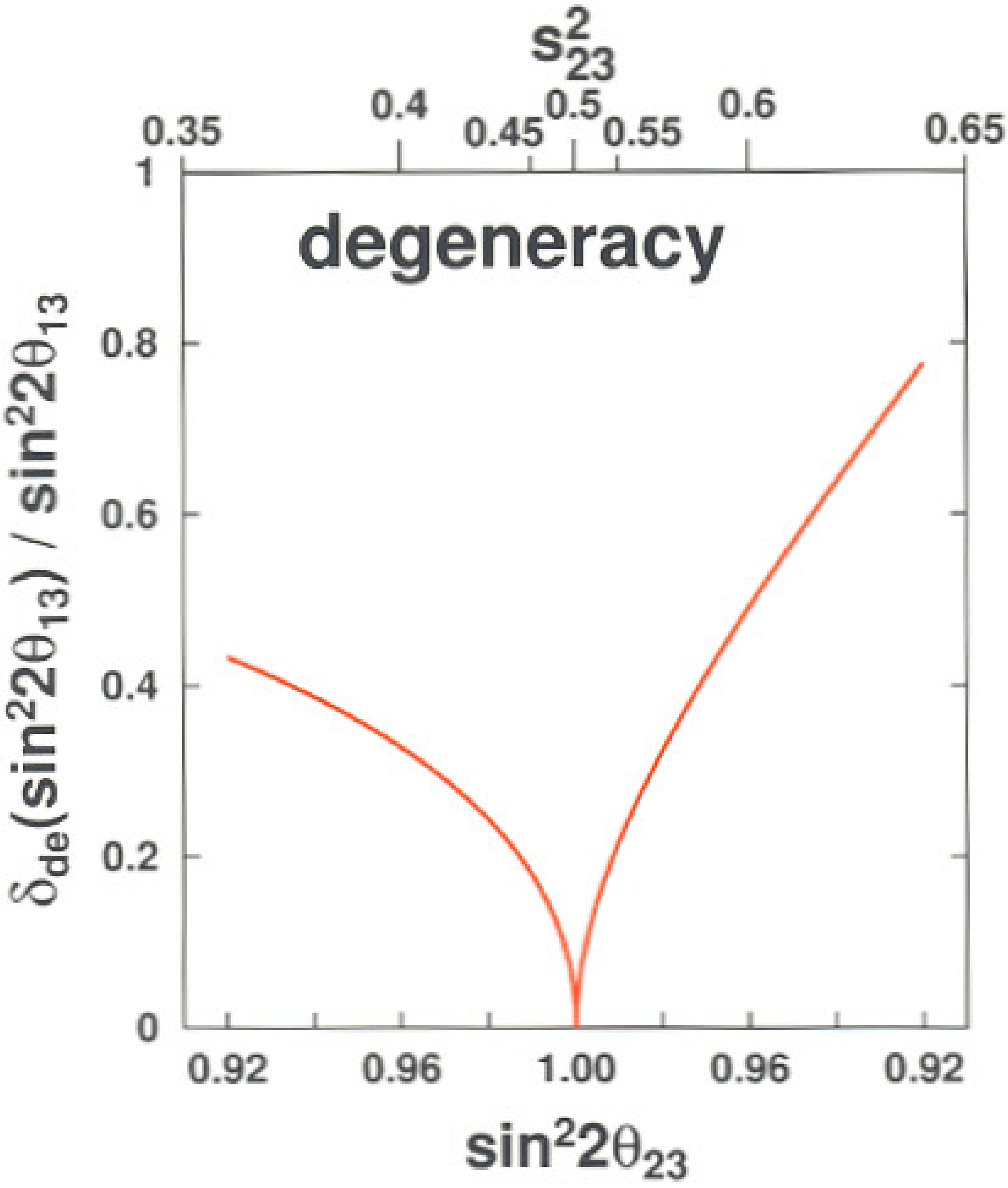
roughly, $N \propto S_{23}^2 \sin^2 2\theta_{13}$

$$\longrightarrow \delta_{LBL}(\sin^2 2\theta_{13}) \propto \frac{\delta N}{S_{23}^2}$$

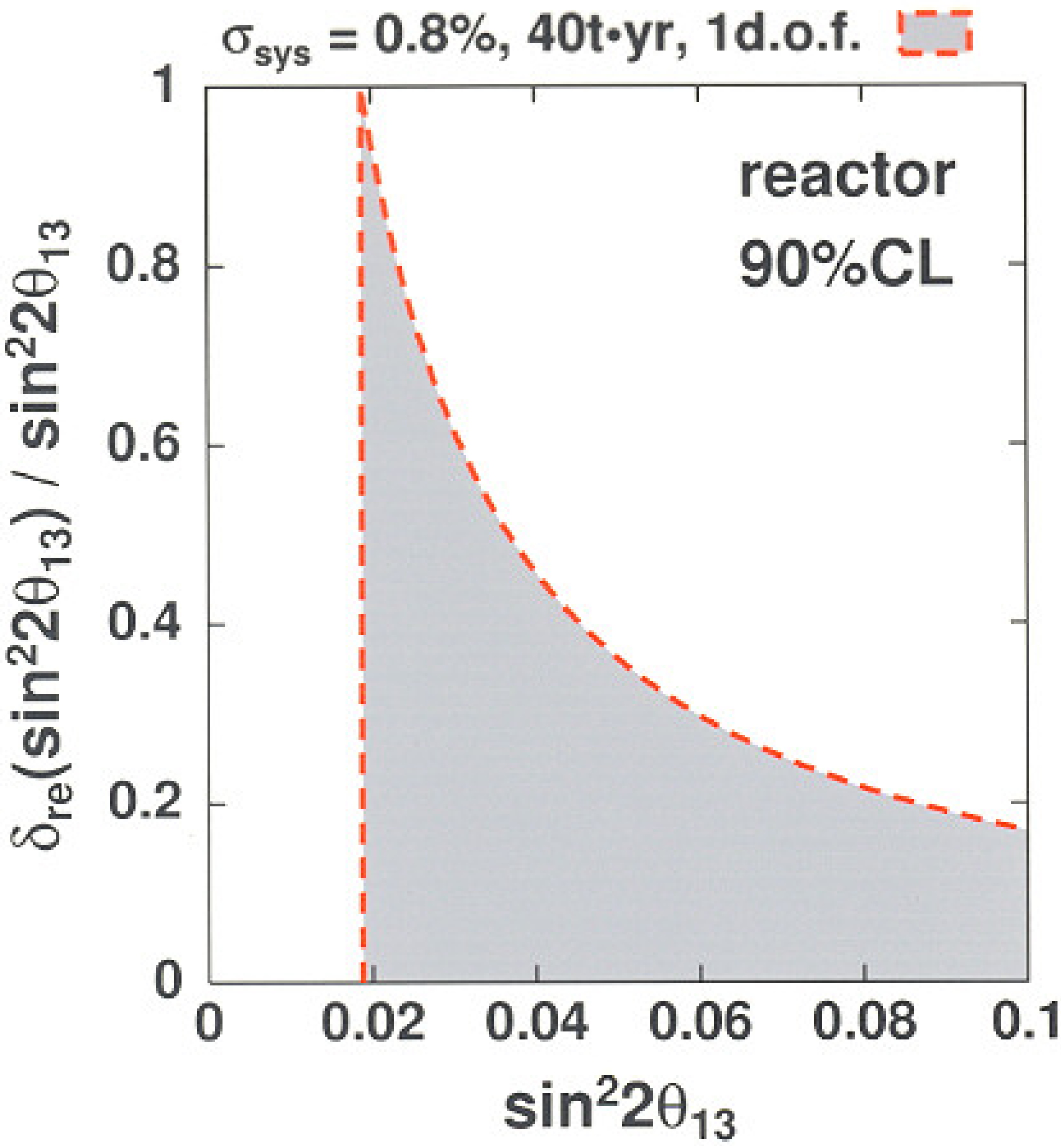
large value of true S_{23}^2 $\Rightarrow$ small $(S'_{23})^2$

$\nwarrow (S'_{23})^2 = 1 - S_{23}^2$

$\Rightarrow$ large $\delta_{LBL}(\sin^2 2\theta_{13})$



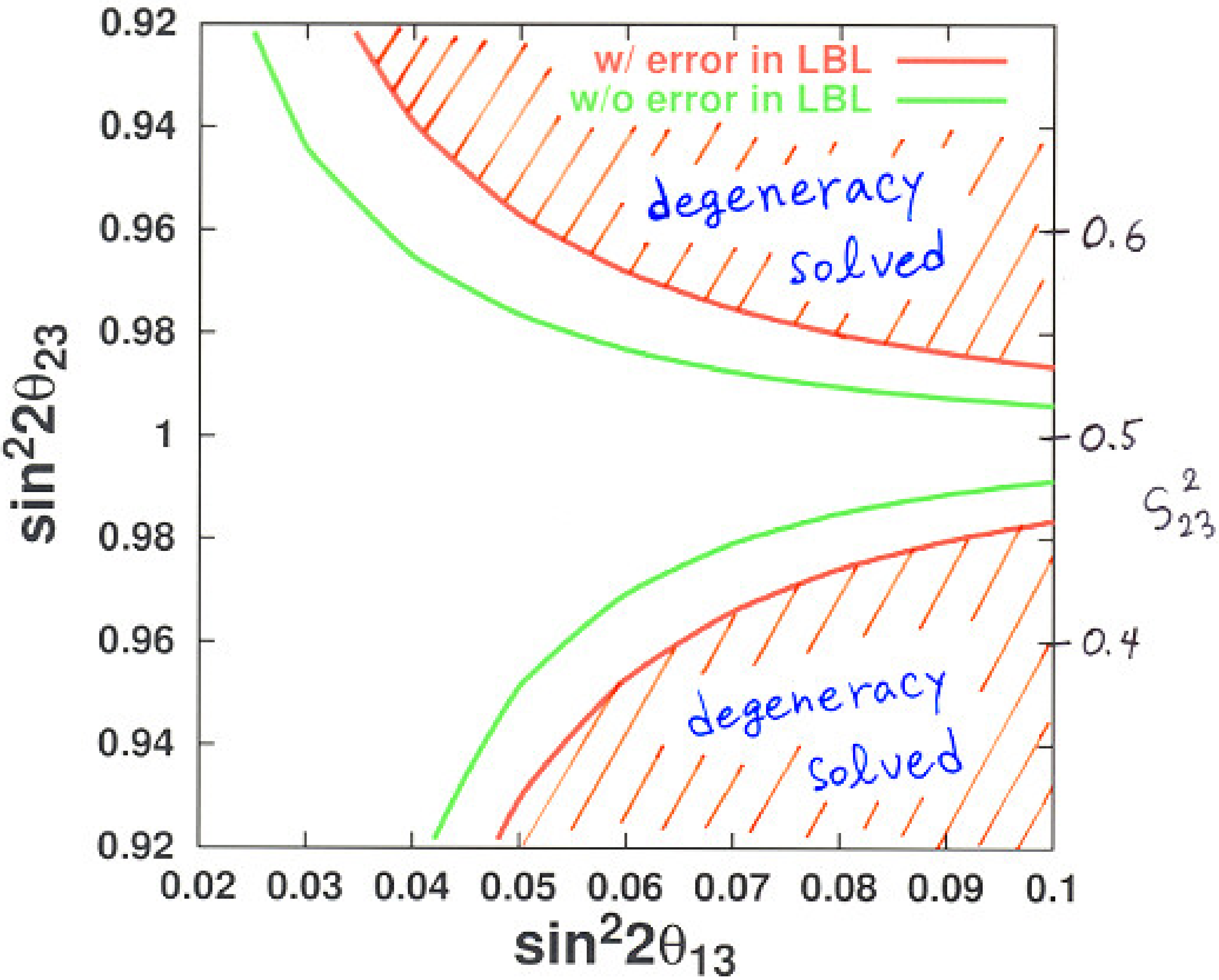
$$\delta_{de}(\sin^2 2\theta_{13}) \equiv \left| \underset{\text{fake}}{\sin^2 2\theta'_{13}} - \underset{\text{true}}{\sin^2 2\theta_{13}} \right|$$



$\delta_{re}(\sin^2 2\theta_{13}) = 0.018$

$\delta_{re}(\sin^2 2\theta_{13}) < \delta_{de}(\sin^2 2\theta_{13}) - \delta_{LBL}(\sin^2 2\theta_{13})$

$\Rightarrow$ degeneracy solved



Solving θ_{23} degeneracy is possible enough even if error in LBL is considered

$\cancel{CP}$ sensitivity

... can we reject $\tilde{\delta} = 0$ hypothesis?

large s_{23}^2 $\Rightarrow$ δ tends to be far from zero

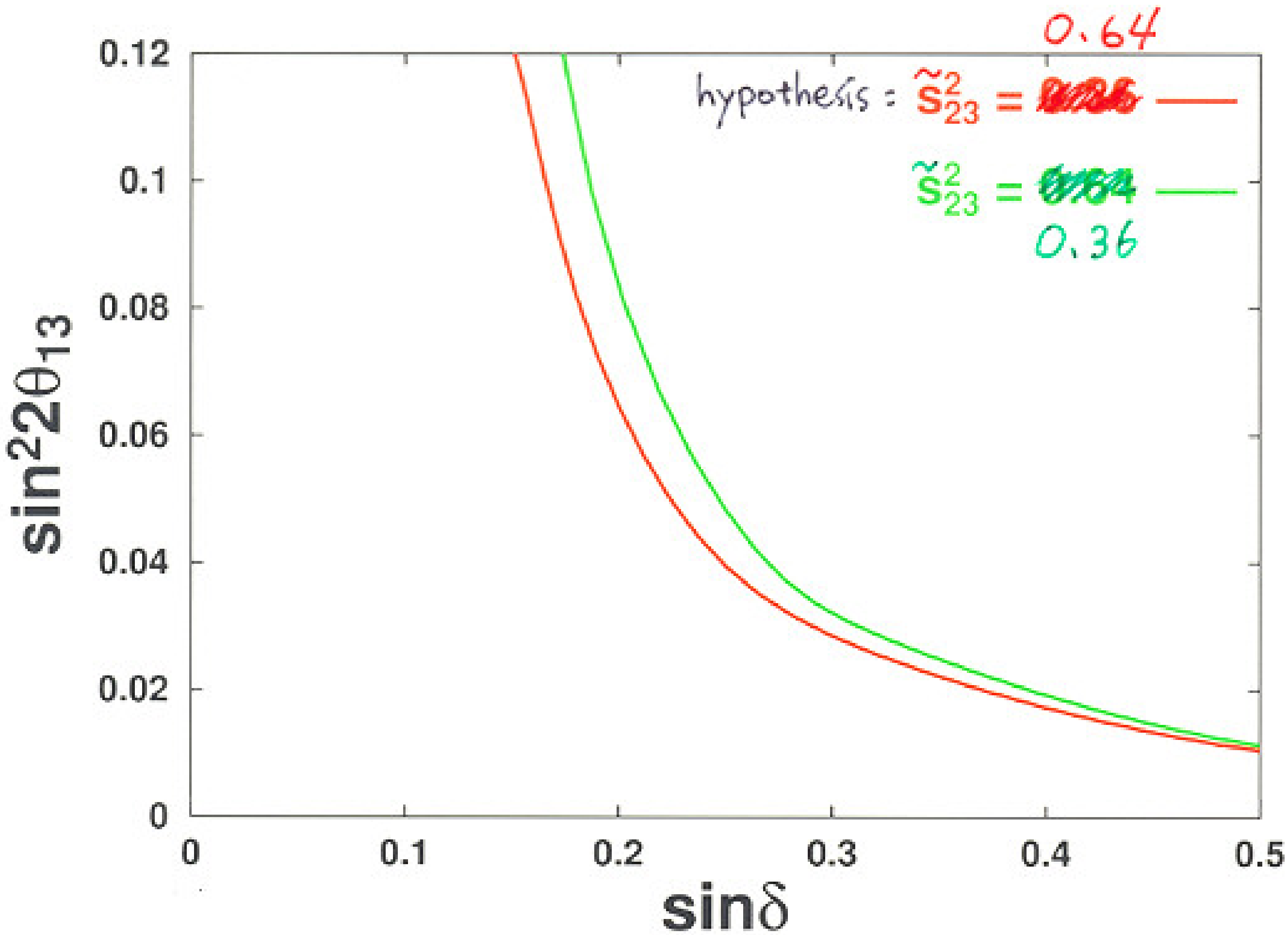
small s_{23}^2 $\Rightarrow$ " near to zero

true

even if δ is far from zero at $s_{23}^2 = 0.64$

δ' can be near to zero at $(s_{23}')^2 = 0.36$

fake



true values : $\sin^2 2\theta_{13}$, $s_{23}^2 = 0.64$

$\Delta m^2_{31} > 0$, δ

hypothesis : $\tilde{\delta} = 0$, $\tilde{s}^2_{23} = 0.64$, $\Delta \tilde{m}^2_{31} > 0$

($\tilde{s}^2_{23} = 0.36$)

if degeneracy of θ_{23} is solved

CP sensitivity can be improved

Summary

- θ_{23} degeneracy can be solved by reactor θ_{13} measurments even if errors in LBL are taken into account

- CP sensitivity can be improved by solving θ_{23} degeneracy