Dec. 11, 2001
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Sensitivity on CPV in 2nd phase

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All numbers are preliminary

$\nu_\mu \rightarrow \nu_e$ oscillation probability(1)

Control size **Control matter effect**

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \frac{\Delta m_{31}^2 L}{4E} \times \left(1 + \frac{2a}{\Delta m_{31}^2} \left(1 - 2S_{13}^2\right)\right)$$

$$+8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \sin \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \sin \frac{\Delta m_{21}^2 L}{4E}$$

CPV

$$+4S_{12}^2 C_{13}^2 \left\{C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos\delta\right\} \sin^2 \frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 S_{13}^2 S_{23}^2 \cos \frac{\Delta m_{32}^2 L}{4E} \sin \frac{\Delta m_{31}^2 L}{4E} \frac{aL}{4E} \left(1 - 2S_{13}^2\right)$$

$\delta \rightarrow -\delta$, $a \rightarrow -a$ for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

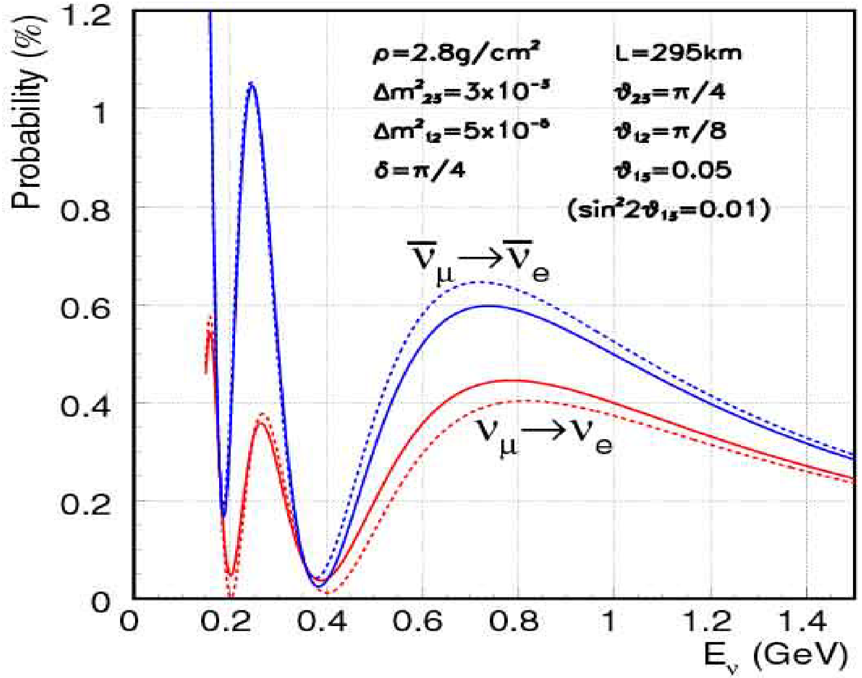
Matter eff.:

$$a = 7.56 \times 10^{-5} [\mathrm{eV}^2] \cdot \left(\frac{\rho}{[\mathrm{g/cm}^3]}\right) \cdot \left(\frac{E}{[\mathrm{GeV}]}\right)$$

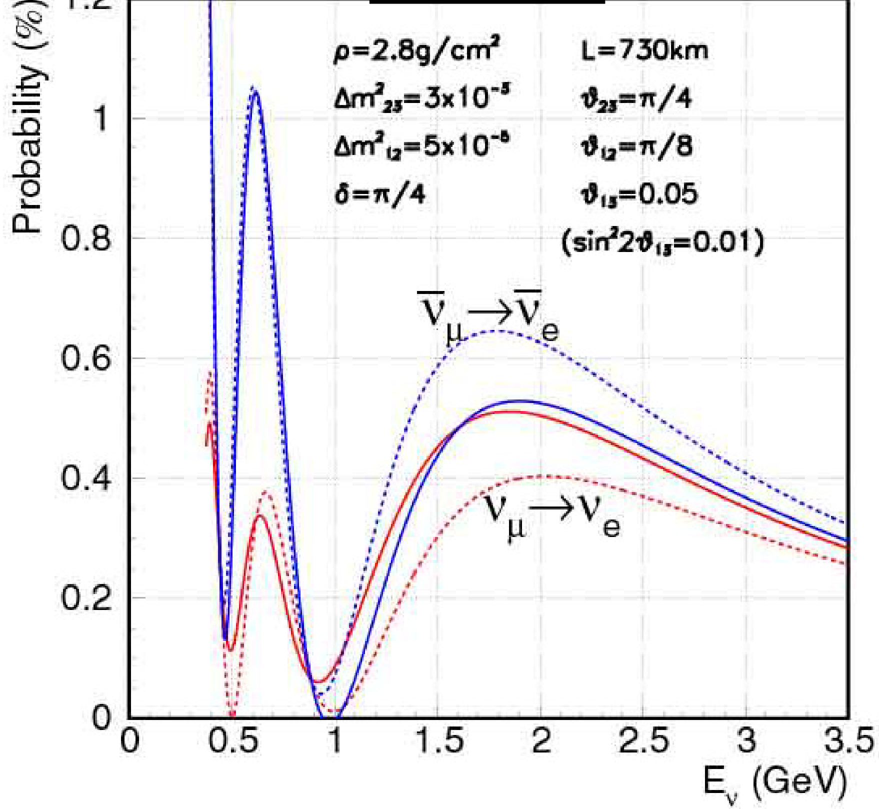
$$A_{CP} \equiv \frac{P - \bar{P}}{P + \bar{P}} \approx \frac{\Delta m_{12}^2 L}{E} \cdot \frac{\sin 2\theta_{12}}{\sin \theta_{13}} \cdot \sin\delta$$

$\nu_\mu \rightarrow \nu_e$ oscillation probability(2)

295km



730km



Solid line: w/ matter
Dashed line: w/o matter

Small Matter Effect at 295km.

CP measurement

Observables

$$N_e(E_{rec}) = N_{obs}(E_{rec}) - N_{BG}(E_{true})$$

$$= \int dE_{true} \Phi_\mu(E_{true}) \cdot P_{\mu\to e}(E_{true}) \cdot \sigma_e(E_{true}) \cdot \varepsilon_e(E_{true}) \cdot r_e(E_{true}, E_{rec})$$

μ flux **cross sec.** **det.eff** **det.responce**

unfold det. responce

$$N_e(E_{true}) = \Phi_\mu(E_{true}) \cdot \underline{P_{\mu\to e}(E_{true})} \cdot \sigma_e(E_{true}) \cdot \varepsilon_e(E_{true})$$

Divide by exp'ed # of ν_μ events w/o oscillation

$$P'_{\mu\to e}(E_{true}) \equiv \frac{N_e(E_{true})}{N_\mu^{\exp}(E_{true})} = \frac{N_e(E_{true})}{\Phi_\mu^{\exp} \cdot \sigma_\mu \cdot \varepsilon_\mu} = \frac{N_e(E_{true})}{\Phi_\mu^{\exp} \cdot \sigma_e \cdot \varepsilon_e} \times \underbrace{\frac{\sigma_e}{\sigma_\mu}}_{r_\sigma} \cdot \underbrace{\frac{\varepsilon_e}{\varepsilon_\mu}}_{r_\varepsilon}$$

$$= P_{\mu\to e}(E_{true}) \cdot r_\sigma(E_{true}) \cdot r_\varepsilon(E_{true})$$

CP Asymmetry

$$A_{CP} \equiv \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} = \frac{P' / r_\sigma r_\varepsilon - \bar{P}' / \bar{r}_\sigma \bar{r}_\varepsilon}{P' / r_\sigma r_\varepsilon + \bar{P}' / \bar{r}_\sigma \bar{r}_\varepsilon}$$

$$= A' + \frac{2\bar{P}'^2}{(P' + \bar{P}')^2}(\delta_r + \delta_\varepsilon)$$

where

$$A' \equiv \frac{P' - \bar{P}'}{P' + \bar{P}'}, \quad \delta_\sigma \equiv \frac{\bar{r}_\sigma - r_\sigma}{r_\sigma}, \quad \delta_\varepsilon \equiv \frac{\bar{r}_\varepsilon - r_\varepsilon}{r_\varepsilon} \qquad \left(r_\sigma = \sigma_e / \sigma_\mu, \ r_\varepsilon = \varepsilon_e / \varepsilon_\mu\right)$$

Only fractional differences of e/μ cross section and efficiency ratio enter.
➔ Small correction

Procedure

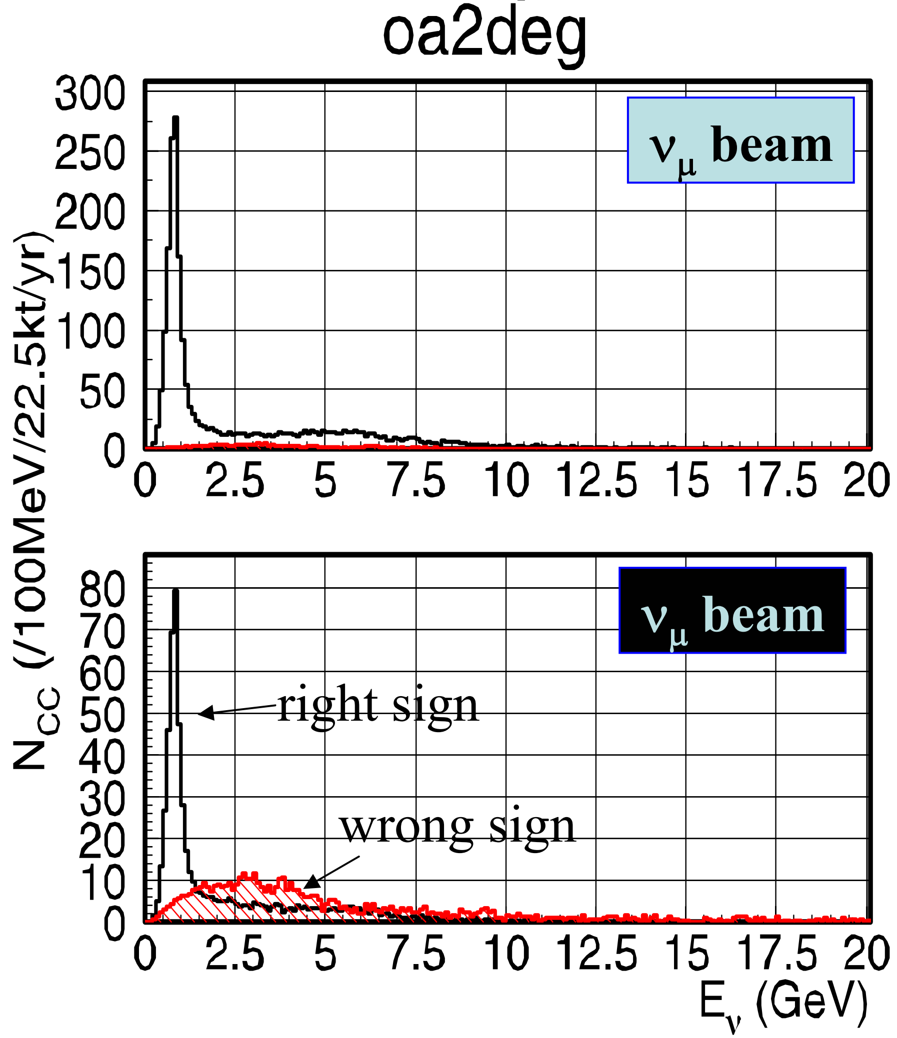
- Detect electron like events
- Energy reconstruction
- BG subtraction
  - Beam ν_e
  - ν_μ NC π^0 production (incl. BG from wrong sign ν_μ)
- Fake asymmetry correction
  - spectrum
  - cross section
  - efficiency
  - matter effect
- Asymmetry

Parameters

- OAB2°
- 4MW, 1Mt F.V. ➔ 231x(JHF1)
  - □ ν_μ: 1(2)year, ν_μ: 3.4(6.8)year
  - □ $\Delta m_{21}=5\text{x}10^{-5}\text{eV}^2$, $\theta_{12}=\pi/8$
  - □ $\Delta m_{32}=\Delta m_{31}=3\text{x}10^{-3}\text{eV}^2$, $\theta_{23}=\pi/4$
  - □ $\delta=\pi/4$

unless otherwise stated

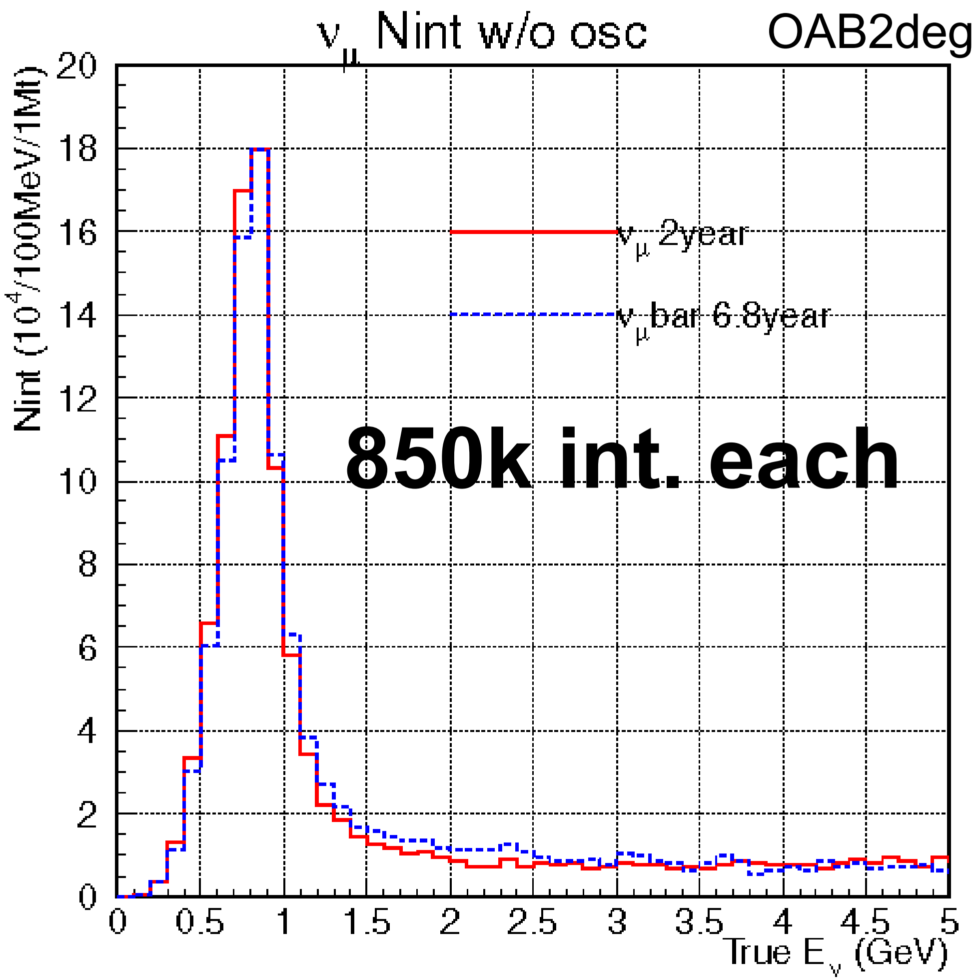
$\nu_\mu / \bar{\nu}_\mu$ # of CC int. (w/o osc.)



10^{21}pot/yr (1st phase)

- # of int. for $\bar{\nu}_\mu$ is factor ~3 smaller than ν_μ due to cross section.
- Wrong sign contamination is worse for OAB.

$\nu_\mu/\overline{\nu}_\mu$ normalization by beam

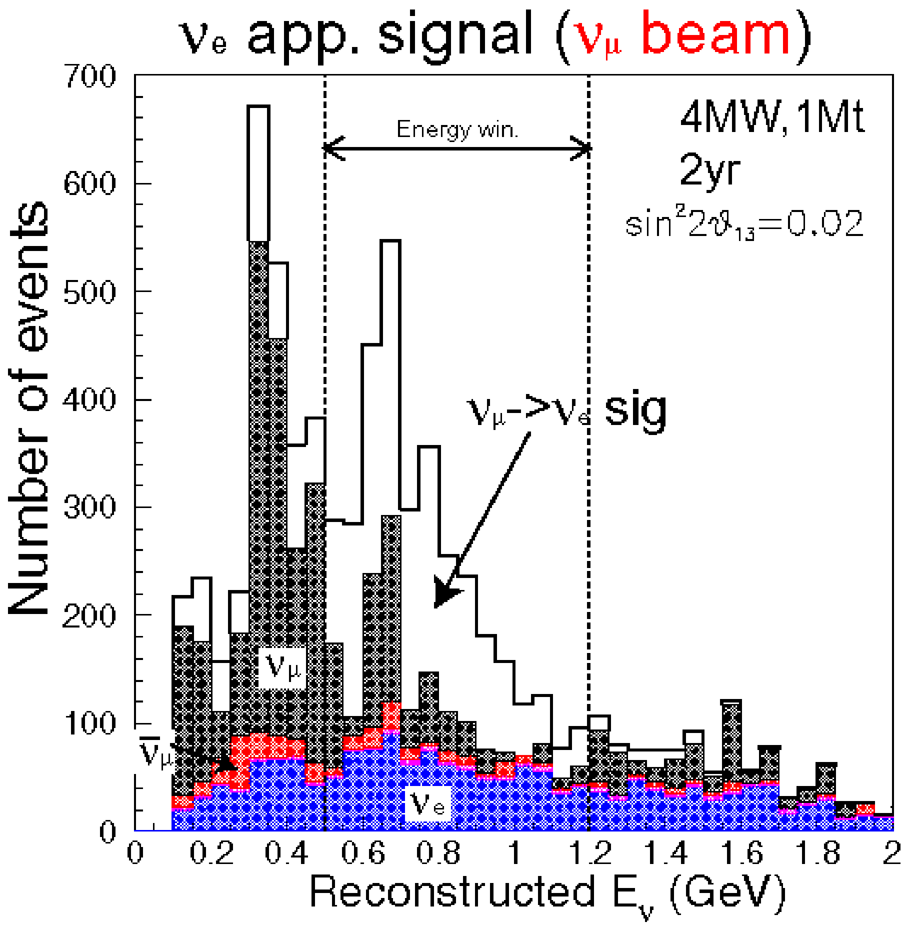


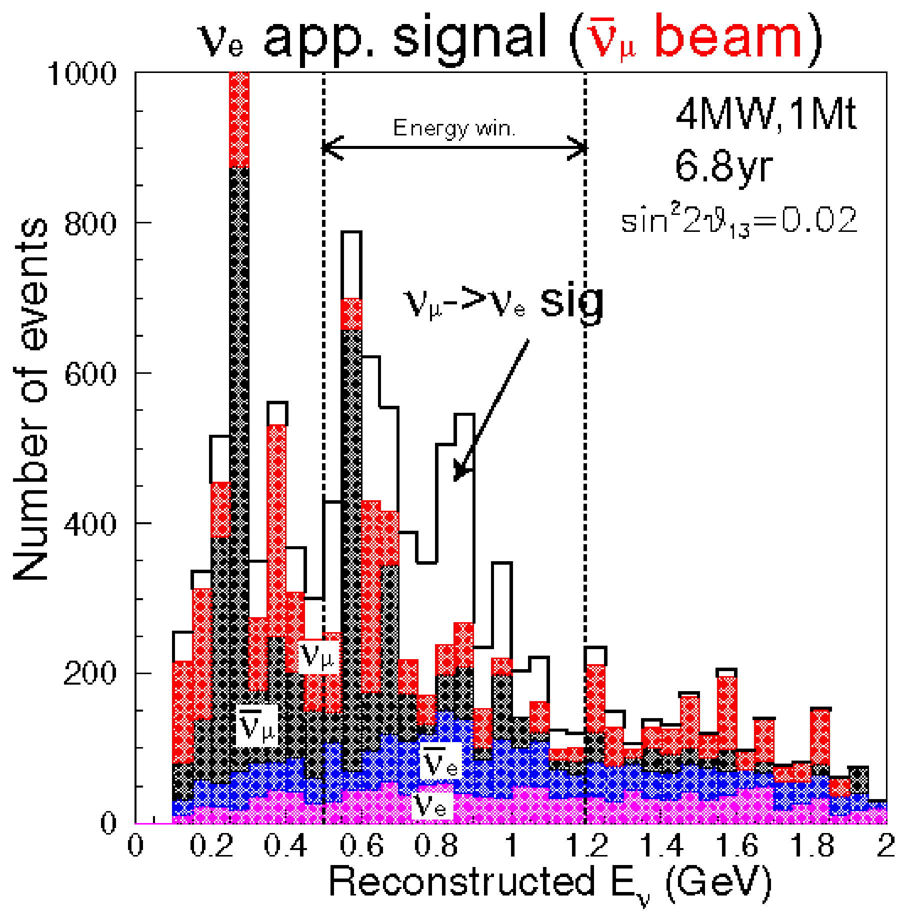
3.4times running time for $\nu_\mu$bar due to small σ.

Slight diff. in spectra causes fake assym→need to correct.

Electron Candidates

(e/π^0 sep. algorism developed for JHF-SK)





Expected Signal & BG

4MW, 1Mt, ν_μ2yr, ν_μ6.8yr, $\sin^2 2\theta_{13}$=0.1(Chooz)

ν_μ beam	Signal	BG				
		Total	νμ	νμbar	νe	νebar
Gen'ed in FV	40k		878k	99k	28k	4.7k
Selected	8893	1691	686	122	834	49
			41%	7%	49%	3%
Efficiency	22%		0.08%	0.12%	3.00%	1.04%
QE	8404	w/π0	613	96	33	3.4
from En>1.2GeV			355	115	196	20

νμ BG: 88%π^0, 58%HE

wrong sign cont. small

$\bar{\nu}_\mu$ beam	Signal	BG				
		Total	νμ	νμbar	νe	νebar
Gen'ed in FV	40k		1079k	830k	44k	30k
Selected	9272	3572	799	1316	594	862
			22%	37%	17%	24%
Efficiency	23%		0.07%	0.16%	1.35%	2.89%
QE	8228	w/π0	714	1112	50	28

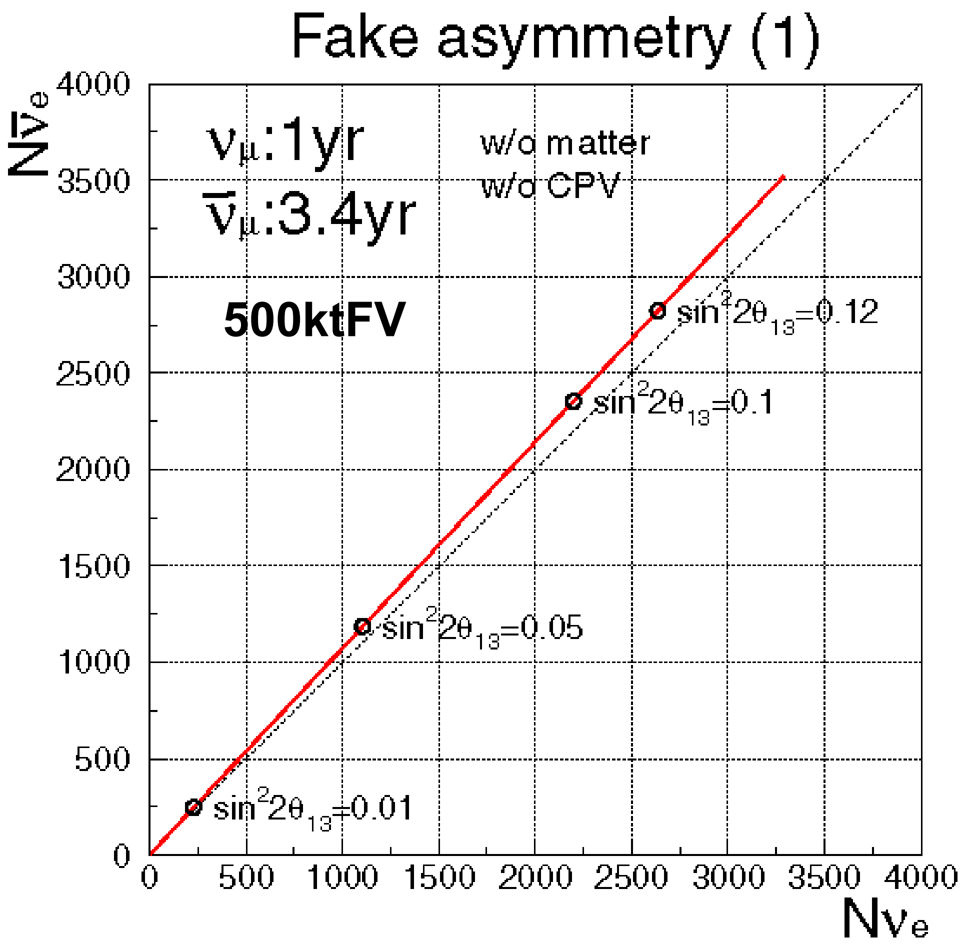
All src. compara.

νμ BG: 86%π^0, 67%HE

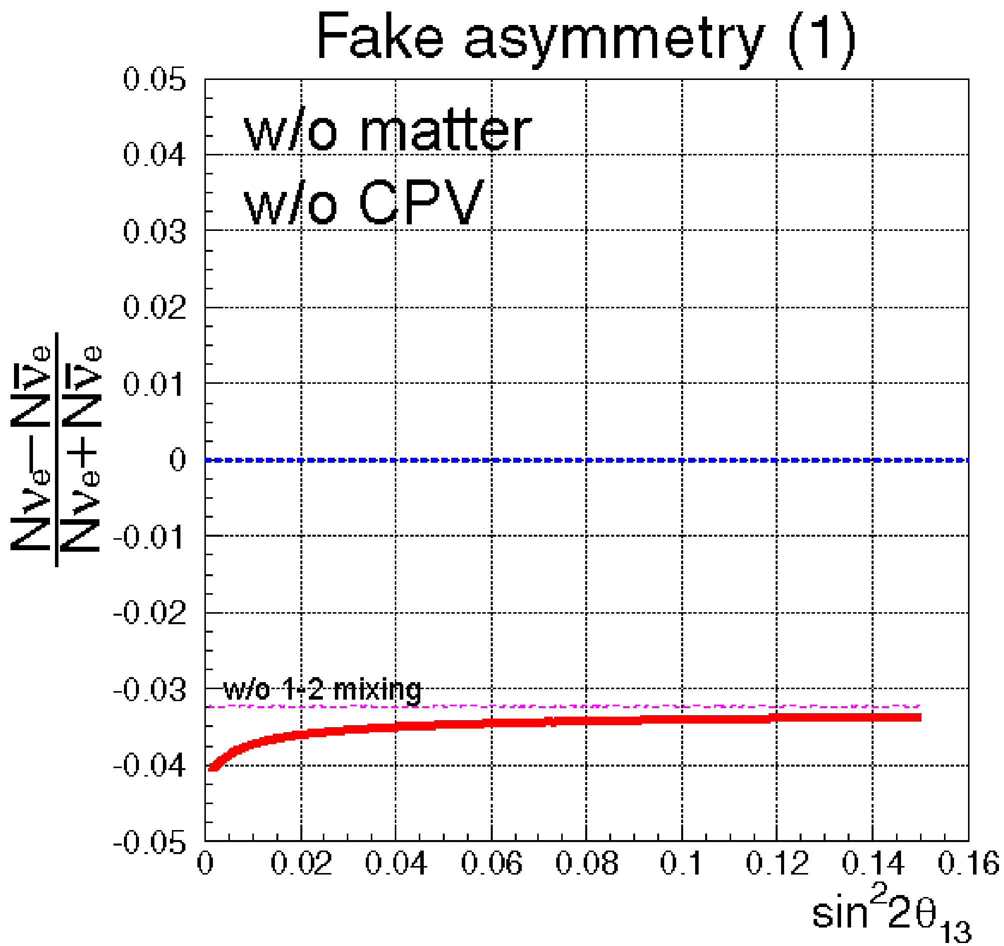
Signal: ~90% CCQE

Fake asymmetry (FA) (1)

- spectrum $\Phi(E)$
- cross section
  - □ $\sigma_e/\sigma_\mu - \sigma_{\bar{e}}/\sigma_{\bar{\mu}}$
- detection efficiency
  - □ $\varepsilon_e/\varepsilon_\mu - \varepsilon_{\bar{e}}/\varepsilon_{\bar{\mu}}$

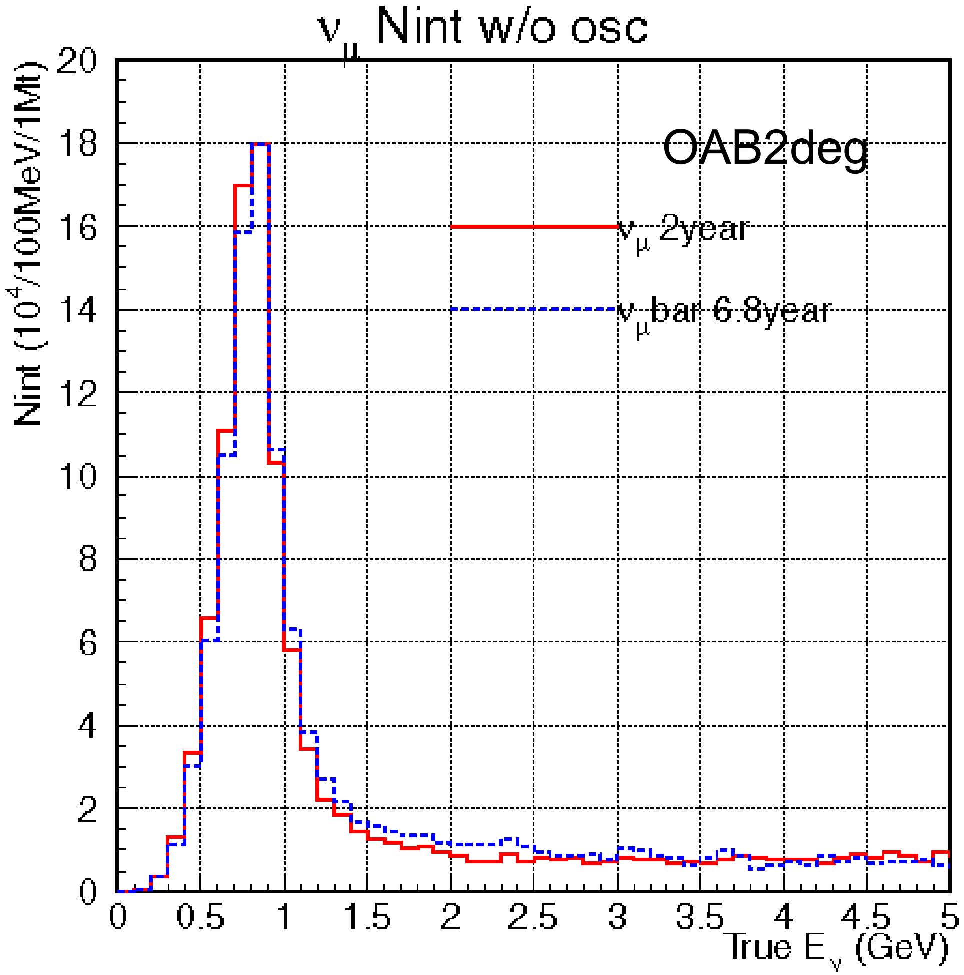


Fake asymmetry (1)



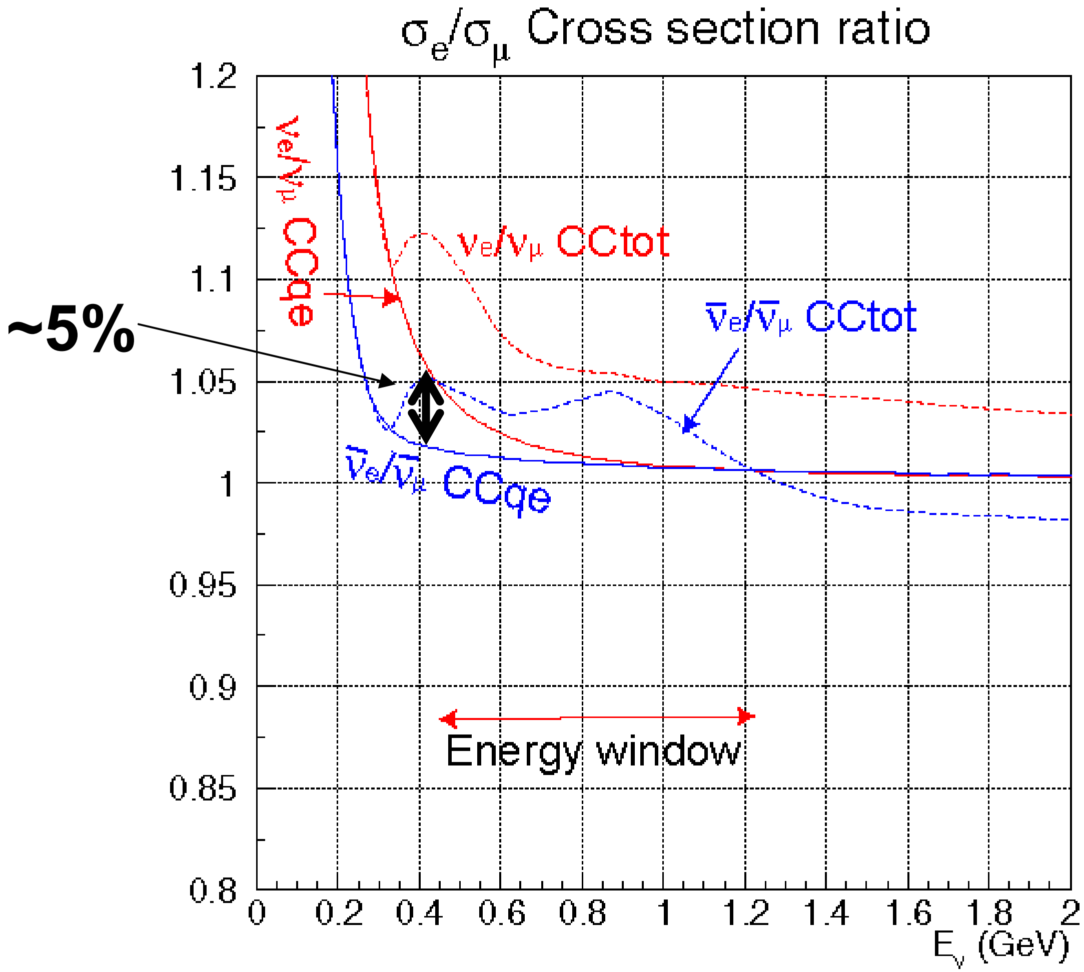
A_{fake1}~-0.04

Spectrum Difference



In real experiment,
FD measures spectrum
and make correction.

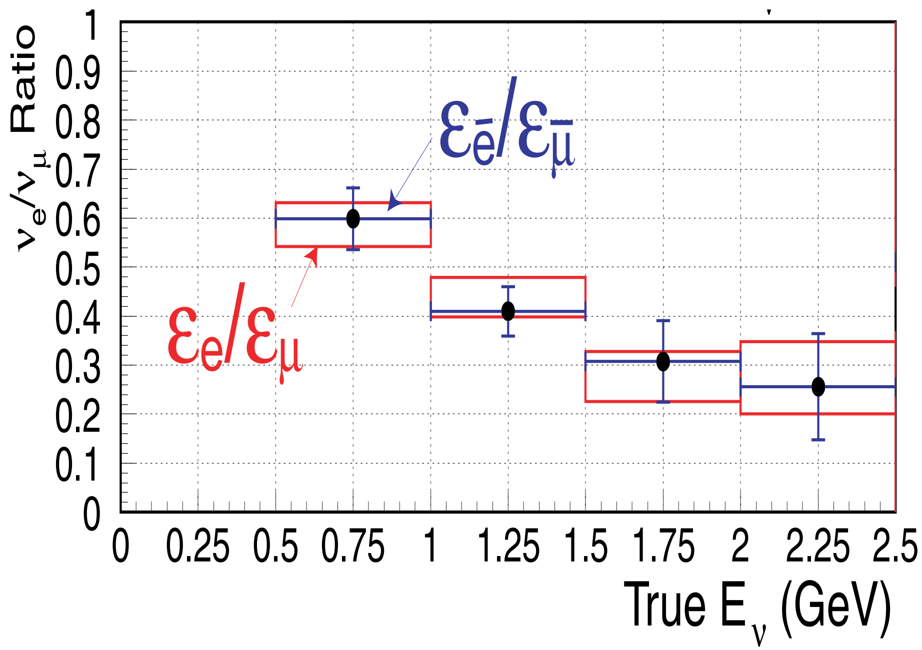
Cross section difference



CCqe ratio diff
1~5% @ energy window

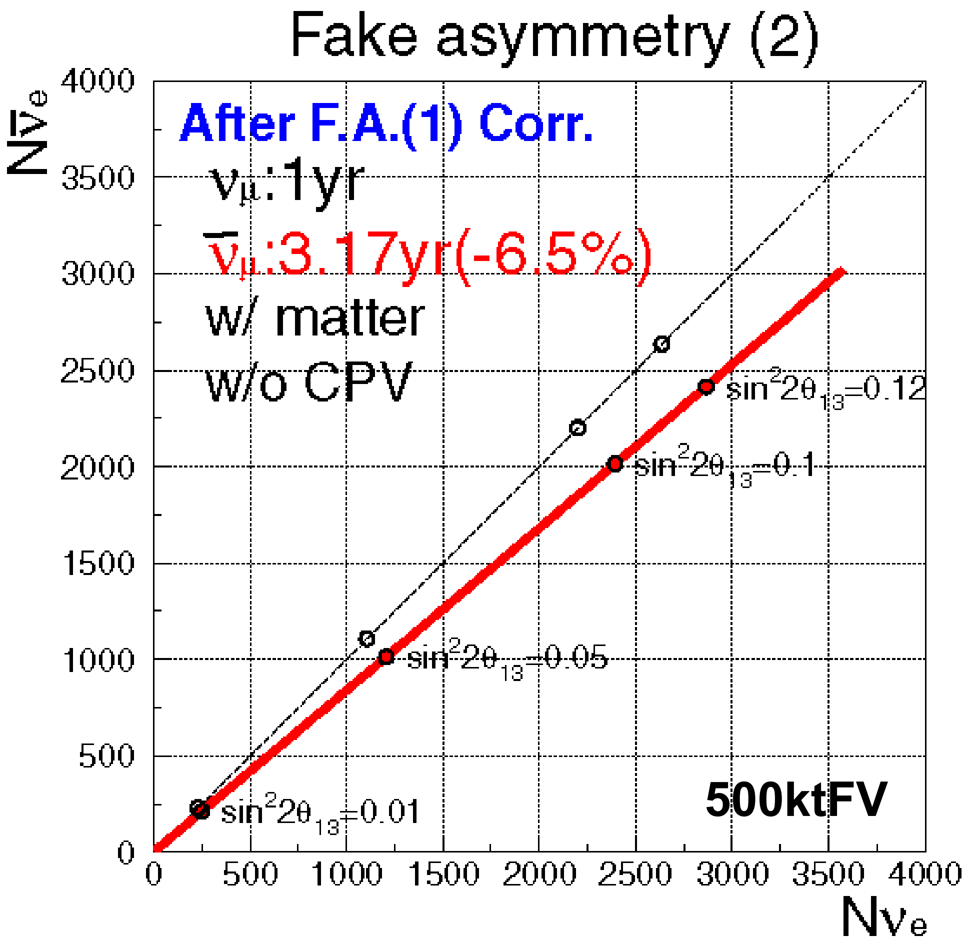
Quick rise in low energy side → need detailed info.
➔ cross section measurement? (νfact?)

Efficiency difference



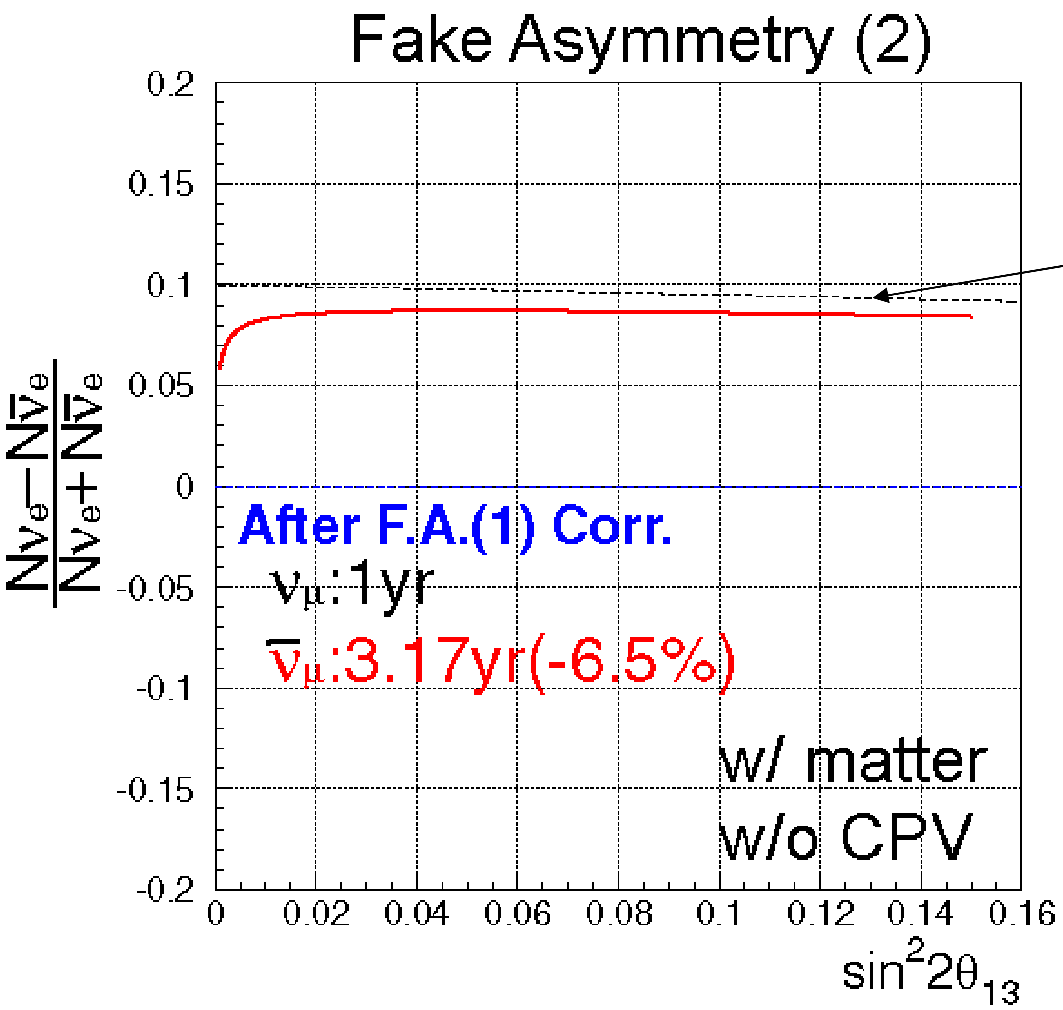
"MC" says
No significant diff.
in efficiency ratio
within MC stat.

Fake asymmetry (2): FA(1)corr.



Correct FA(1) by adjusting only normalization (running time) by -6.5%

Fake Asymmetry (2): matter



$$\theta_{12} = 0, \quad \Delta m_{32} = \Delta m_{31}$$

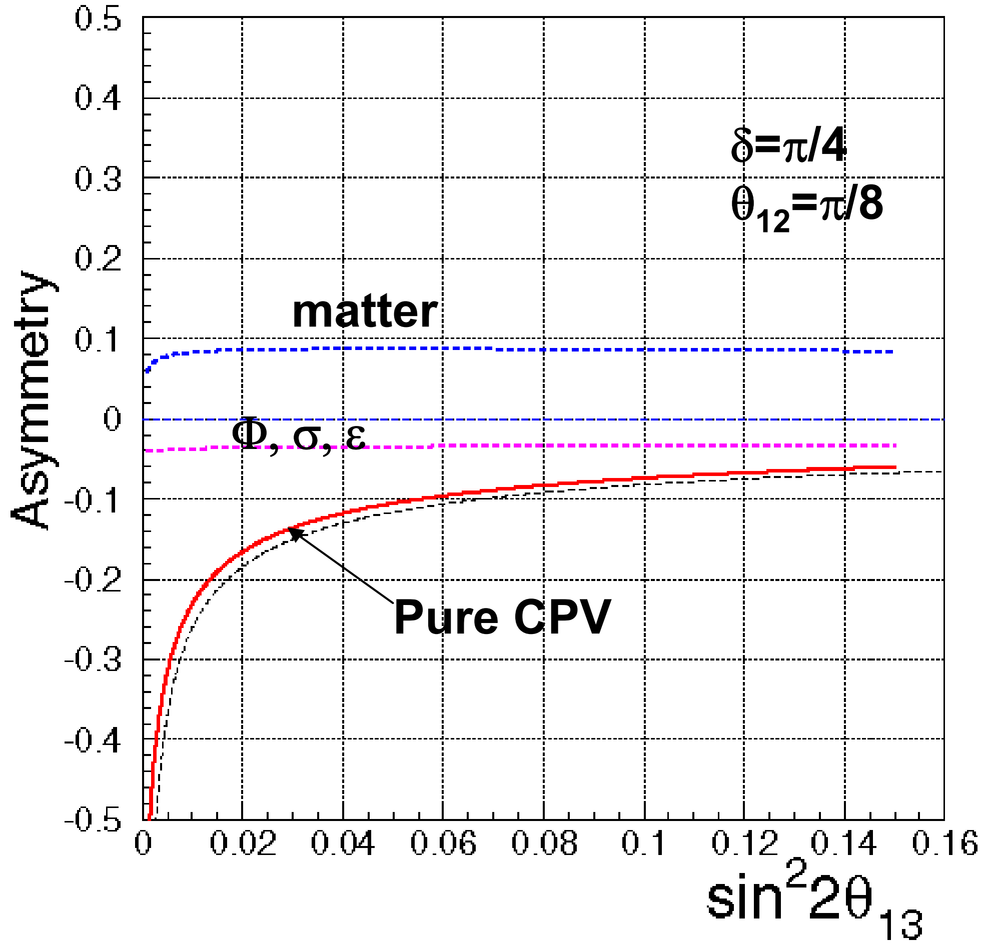
$$\Rightarrow A = 2\left(a / \Delta m_{31}\right)\cos 2\theta_{13}$$

$$\approx 0.1(1 - 2\theta_{13}^2)$$

mild function on osc.param.

- 10% level correction
- Effect from θ_{12}: 2nd order

CP asymmetry



Both correction need to be estimated at ~10% level
→ΔA<0.01

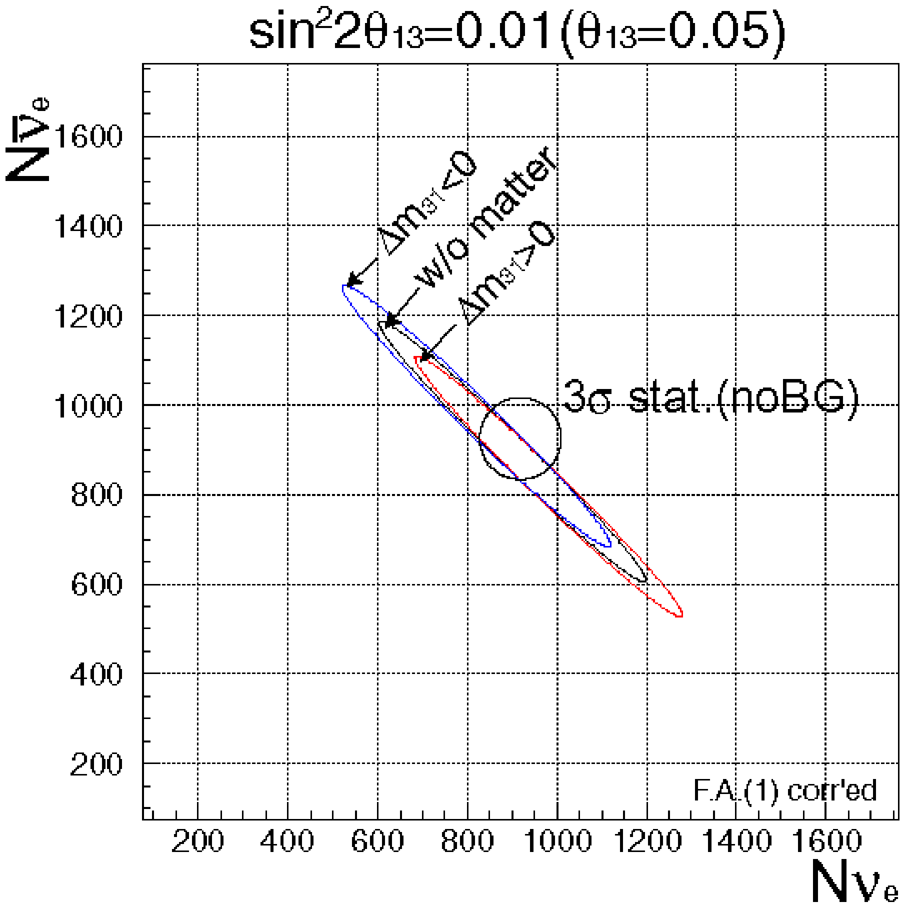
Φ,σ,ε **cor.**

$$A_{CP} \sim A_{obs} - 0.04 + 0.1$$

matter corr.

Asymmetry correction is not the "real" enemy

CP measurement

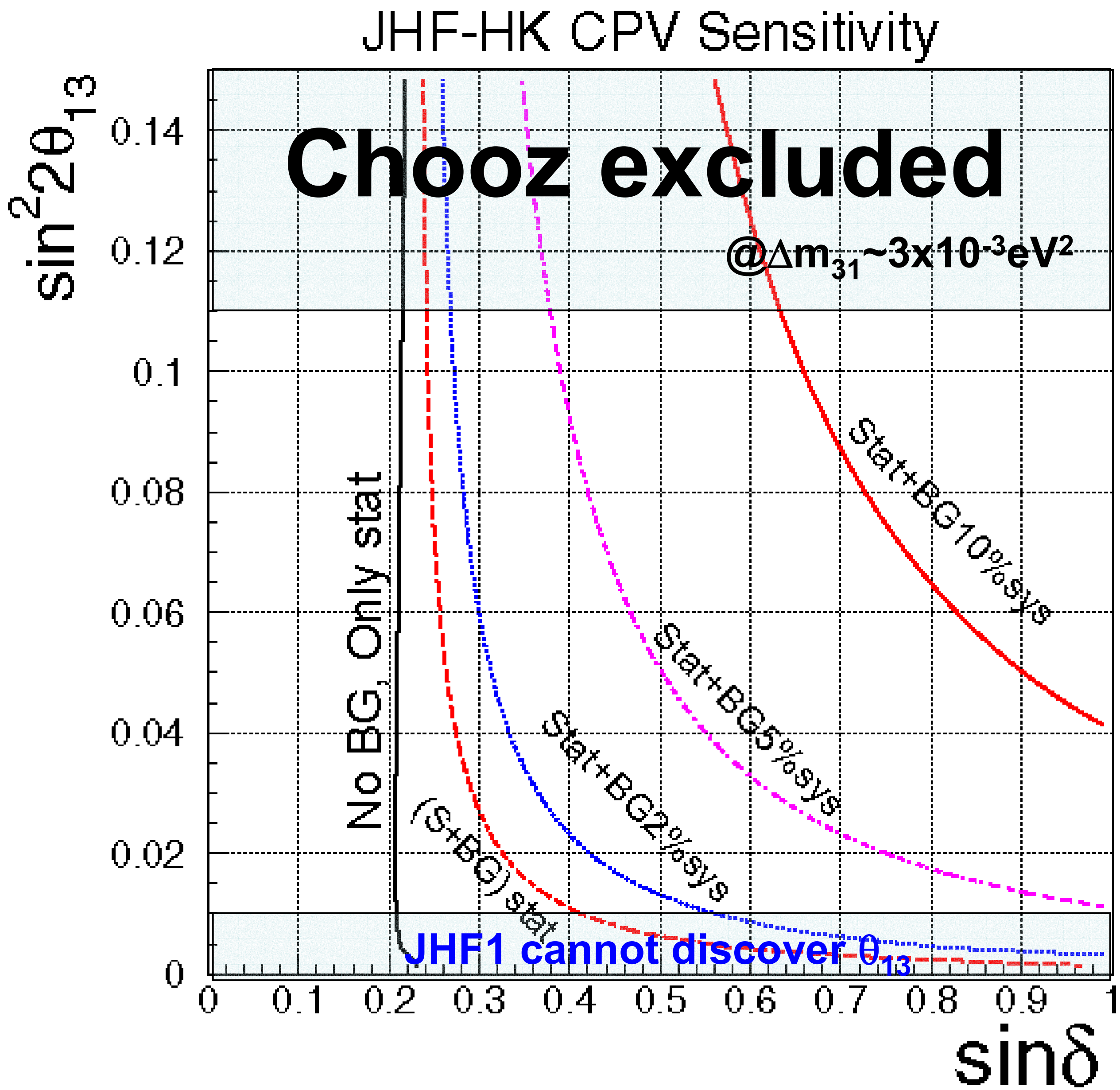


Matter effect is small.

CPV could be established w/o precise knowledge on matter effect.

4MW
1Mt
ν2yr
ν̄6.8yr

Sensitivity(3σ)



BG sys 2%のとき

$\sin^2 2\theta_{13}=0.01$
→$\sin\delta>0.55$
(33deg)

large $\sin^2 2\theta_{13}$
→$\sin\delta>0.25$
(14deg)

BG reduction/estimation is essential.

Summary

- Potential of CPV search in 2nd phase JHF-Kamioka Project is studied
- 4MW, 1Mt FV ν_μ 2yr, $\nu_\mu$bar 6.8yr
  - → ~850k int.(w/o osc)
- 3σ discovery reach
  - $\sin^2 2\theta_{13}=0.01$ → $\sin\delta>0.55$ (33deg)
  - large $\sin^2 2\theta_{13}$ → $\sin\delta>0.25$ (14deg)
  - Assuming 2% BG syst. at current BG level
- BG rejection/estimation is essential
  - Especially wrong sign component

    → Charge separation for low E muon in front detector